PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA
Ministry of Higher Education and Scientific Research
Mohamed Khider University – BISKRA
Faculty of Exact Sciences, Natural Sciences and Life
Department of Computer Science

Order n° : …./M2/2022

Memory

Presented for the Academic Master's degree in

Computer Science

Option : **Information and Communication Networks and Technologies (RTIC)**

Optimization of energy management in smart grids

By :

HADID WALA

Defended on 26 / 06 / 2022, in front of the jury composed of :

Chami Djazia	Dr	President
Mouaki Benani Nawel	Dr	Supervisor
Hamida Ammar	MAA	Examiner

Academic year 2021-2022

Dedication

This work is dedicated to my mother Djoudi Lamia, who has raised me to woman I am today, to my father Hadid Lazhari who is the source of my happiness, to my two brothers (Mohamed and Rami) and my only sister Racha, to my best friends (Maria, Zineb, Ibtissem, Naila, Dalila, Roufaida, Meriem, Noussaiba, Mouna and Tourkiya), to my dear cousins (Wissem, Sawsen, Sara, Hala, Imane), to my big family, to the soul of my grandFather Djoudi Hachani(RIP) and specially madam Mouaki Benani Nawel for helping me to develop my knowledge and skills, thank you all for everything.

Acknowledgements

First, I want to thank almighty ALLAH for giving me the will, patience and health to develop this work.

I would like to express my profound gratitude to my supervisors Dr. Mouaki Benani Nawel, for her involvement in this research work and for the support they have given me, their patience, their availability and the relevance of their advice that have been of invaluable assistance throughout this work.

I would like to thank Dr. Ilyes Naidji for his advices and support in my project.

I extend my sincere thanks to the members of the jury, for having accepted to judge this work.

Finally, I thank my big family and my friends for encouraging me during this year, and to have always been available when I needed it.

Abstract

With the advent of networked microgrids, the architecture of smart power distribution systems has become increasingly complex. Maintaining the energy balance between supply and demand in a cost-effective way becomes a very challenging task. Due to the intermittent nature of renewable energy and the distributed architecture of microgrids (MGs), power management in interconnected microgrids requires intelligent coordinated control.The main problem is how to manage energy sources to have an efficient and economic energy supply. In this context,an optimal energy management system (EMS) for networked microgrids in a smart distribution system is proposed in this work. The network of MGs is autonomously self-organized into multiple stable coalitions for efficient and economical energy exchange.Multiple MGs form coalitions to exchange energy at competitive costs in order to optimize their usefulness. A coalition formation game between MGs is used to formulate the problem of energy management in networked MGs. To assure the stability of formed coalitions and maximize MG profitability, we develop a merge-and-split based coalition formation (MSCF) algorithm. Then, in order to reduce power loss, we devise an intra coalition energy transfer (ICET) algorithm for transferring energy between MGs within the same coalition. Due to the proposed cooperative energy management software, the results show satisfactory performance in minimizing power losses and reducing costs.

Key-words : Microgrids, Energy, Energy management, Coalition formation, Energy transfer.

Résumé

Avec l'avènement des microréseaux en réseau, l'architecture des systèmes intelligents de distribution d'électricité est devenue de plus en plus complexe. Maintenir l'équilibre énergétique entre l'offre et la demande d'une manière rentable devient une tâche très difficile. En raison de la nature intermittente des énergies renouvelables et de l'architecture distribuée des microréseaux (MGs), la gestion de l'énergie dans les microréseaux interconnectés nécessite un contrôle coordonné intelligent. Le principal problème est de savoir comment gérer les sources d'énergie pour avoir un approvisionnement énergétique efficace et économique. Dans ce contexte, un système optimal de gestion de l'énergie (EMS) pour les microréseaux en réseau dans un système de distribution intelligent est proposé dans ce travail. Le réseau de MGs est auto-organisé de manière autonome en plusieurs coalitions stables pour un échange d'énergie efficace et économique. De multiples MGs forment des coalitions pour échanger de l'énergie à des coûts concurrentiels afin d'optimiser leur utilité. Un jeu de formation de coalition entre MGs est utilisé pour formuler le problème de la gestion de l'énergie dans les MGs en réseau. Pour assurer la stabilité des coalitions formées et maximiser la rentabilité des MG, nous développons un algorithme de formation de coalition (MSCF) basé sur la fusion et le fractionnement. Ensuite, afin de réduire la perte de puissance, nous concevons un algorithme de transfert d'énergie intra-coalition (ICET) pour le transfert d'énergie entre MGs au sein d'une même coalition. En raison du logiciel de gestion de l'énergie coopérative proposé, les résultats montrent une performance satisfaisante en minimisant les pertes de puissance et en réduisant les coûts.

Mots-clés : Microréseau, Energie, Gestion de l'énergie, Formation de coalition, Transfert d'énergie.

ملخص

مع ظهور الشبكات الكهربائية الصغيرة، أصبحت بنية أنظمة توزيع الطاقة الذكية معقدة بشكل متزايد. و اصبح الحفاظ على توازن الطاقة بين العرض والطلب بطريقة فعالة من حيث التكلفة مهمة صعبة للغاية. نظرًا للطبيعة المتقطعة للطاقة المتجددة والهندسة المعمارية الموزعة للشبكات الصغيرة، تتطلب إدارة الطاقة في الشبكات الكهربائية الصغيرة المترابطة تحكمًا منسقًا ذكيًا. المشكلة الرئيسية هي كيفية إدارة مصادر الطاقة للحصول على إمدادات طاقة فعالة واقتصادية. وفي هذا السياق، يقترح في هذا العمل نظام أمثل لإدارة الطاقة للشبكات الكهربائية الصغيرة المترابطة في نظام توزيع ذكي. شبكة الشبكات الكهربائية الصغيرة منظمة ذاتيًا بشكل مستقل في تحالفات متعددة مستقرة لتبادل الطاقة الفعال والاقتصادي. تتكون التحالفات من العديد من الشبكات الكهربائية الصغيرة التي تتبادل الطاقة بأسعار طاقة تنافسية لتعظيم فائدتها. نقوم بصياغة مشكلة إدارة الطاقة في الشبكات الكهربائية الصغيرة من خلال لعبة تشكيل التحالف بين الشبكات الصغيرة. نقوم بتطوير خوارزمية تشكيل تحالف قائمة على الدمج والانقسام لضمان استقرار التحالفات المشكلة وتعظيم أرباح الشبكات الصغيرة. بعد ذلك، نصمم خوارزمية نقل الطاقة داخل التحالف لنقل الطاقة بين الشبكات الكهربائية الصغيرة داخل نفس التحالف لتقليل فقدان الطاقة. تظهر النتائج أداءً مرضياً في تقليل فقدان الطاقة وخفض التكاليف بسبب برنامج إدارة الطاقة التعاوني المقترح.

الكلمات المفتاحية : الشبكات الكهربائية الصغيرة، الطاقة، إدارة الطاقة، تشكيل التحالف، نقل الطاقة.

Contents

List of Figures

List of Tables

List of Algorithms

List of Equations

Introduction

An electrical grid, electric grid, or power grid is a structured network for supplying electricity from producers to consumers. The traditional power grid has been installed since more than 100 years without much changes in its basic infrastructure although electricity demand has increased drastically during the last few decades, which mandates efficient management of electricity production and consumption on a large scale.

Due to an increase in electricity demand and consumption, the associated problems in power grid have also amplified multiple fold, these include frequent power outages, load-shedding, and weather and climate vulnerabilities, etc. The electrical power system which has served humanity efficiently for a century must now evolve to meet changing requirements: increasing renewable energy sources, decreasing fossil fuel use, managing greater total demand, using electricity to fuel transportation, enabling more customer control of both demand and supply, dealing with security threats, and adapting to disruptive technologies. This evolution electrical power grid called smart grid[1].

From the perspective of the smart grid, the improvement of the power system performance is one of the main objectives behind the development of the traditional power grid. After the appearance of microgrids that consists of renewable energy sources, the operation and control of the power system is significantly evolved.

This evolution is due to the deregulation of the system caused by the intermittent nature of renewable energy. These changes impose challenges to smart grid development in both research and operational levels. The smart power distribution networks are composed of multiple microgrids, which include distributed energy resources (DERs) such as renewable energy sources (e.g., photovoltaics panels, wind turbines...etc), end users, and the control components for the microgrid operation.

The microgrid should provide stable and sufficient power supply for the end users either by cooperating with the main power grid, i.e., “on-line” mode or by autonomously supplying the users disconnected from the main power grid, i.e., “off-line” mode. The limitation of the interaction to only the distribution system can reduce the gain of MGs due to the unprofitable energy transfers between microgrids (MGs) and distribution system operator(DSO) [2]. In addition, the energy transfer between MGs and DSO increases the power loss due to the long transferring distances.

In this respect, the main contribution of this work is the proposal of a new cooperative energy management software in networked MGs using coalitional game theory to self-organize into multiple stable coalitions for maximizing the profits of MGs. We develop a merge-and-split-based coalition formation (MSCF) algorithm based on coalitional game theory and merge and split rules and take in account the distance between the microgrids , where we can control the surroundings of the formed coalitions.

Then, we develop an intra coalition energy transfer (ICET) algorithm to transfer energy between MGs that are in the same coalition.The ICET algorithm [3] aims to minimize power loss resulting from transferring energy in long distances. Significant gains are obtained with the proposed energy management software in terms of profit maximization, thanks to the designed coalition formation algorithm, and in terms of energy saving, thanks to the energy transfer algorithm

The remaining work is organized as follows: Section I General introduction. Section II presents an overview of the smart grid. Section III explains energy management and optimization methods for smart Grid. Section IV addresses the problem formulation and describes the proposed cooperative energy management software in networked microgrids using coalition game theory. Section V discusses the implementation of our system and the programming tools to achieve our system. Finally, this work is concluded in the section VI

Chapter 1

Smart Grid

1.1 Introduction

Electrical energy is one of the most important factors in a country's development and sustainability[4]. It has a direct impact on the economy and connections to improve the standard of living of the people of the country. As the world's population grows day by day, we need more energy to meet our energy needs[5].

Technology has converted our manner of life, however our electric powered grid — which we agree with to hold energy flowing to our homes, schools, workplaces, and hospitals — hasn‘t been modernized to match. Now it can be, with a new investment in our nation's energy infrastructure called smart grid (SG)[6].

Traditionally, economic dispatch and demand response (DR) are considered separately, or implemented sequentially, which may degrade the energy efficiency of the power grids.

The term ”smart grid” is a term used to name an electrical energy delivering system merging both digital technologies and long transmission networks to optimize energy consumption, as well as to open up new processes for energy production and distribution.

The main driving factors to enhance current power distribution grids can be classified into different categories [7]:

1. Improving the distribution grid's reliability (by reducing the risk of blackouts or brownouts), efficiency, and safety by reducing peak demand.

2. Increasing power consumption flexibility.
3. Allow houses to act as either electricity consumers (if consumed) or electricity suppliers (if produced). As for the first driving factor, the overall load connected to the grid can change significantly over time.

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”[8].

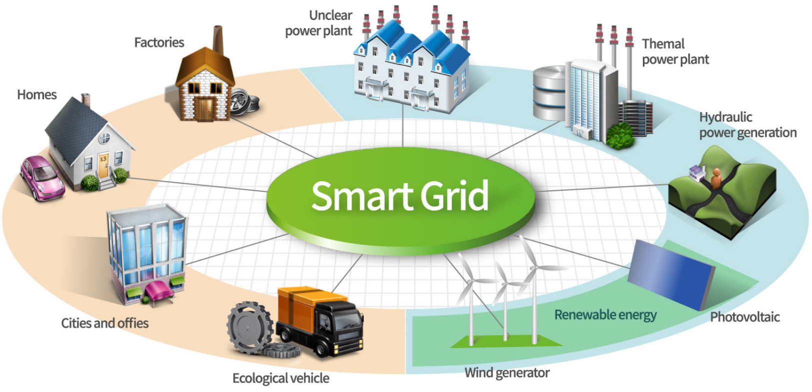


Figure 1.1 – Smart Grid

1.3 SG components

A wide range of appliances must be developed and implemented in order to attain a modernized smart grid. These appliances work in a predefined manner, and they are intelligent enough to understand and use the incoming power supply. They are grouped into following key technology areas as listed below.

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[9].

1.3.2 Smart meters

The smart meters provide two-way communication between power providers and the end user consumers to automate billing data collections, detect device failures and dispatch repair crews to the exact location much faster[10].

Figure 1.2 – Smart meter[10].

1.3.3 Smart substations

Substations are included monitoring and control non-critical and critical operational data such as power status, power factor performance, breaker, security, transformer status, etc. substations are used to transform voltage at several times in many locations, that providing safe and reliable delivery of energy.
Smart substations are also necessary for splitting the path of electricity flow into many directions. Substations require large and very expensive equipment to operate, including transformers, switches, capacitor banks, circuit breakers, a network protected relays and several others[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[9].

1.3.5 Super Conducting Cables

These are used to provide long distance power transmission, and automated monitoring and analysis tools capable of detecting faults itself or even predicting cable and failures based on real-time data weather, and the outage history[10].

1.4 Applications of a 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 become 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. Basic applications of smart grids are [11]:

- They improve the adeptness of transmission lines.
- Quick recovery after any sudden breakage/disturbance in lines and feeders.
- Cost Reduction.
- Reduction of peak demand.
- They possess the ability to be integrated with renewable energy sources on a large level which leads to sharing of load and reduction of load on large scale.

1.5 Different between Traditional Power grid and Smart Grid

The traditional grid and smart grids are characterized by great differences, they are summarized in the following table (tab1.1):

Conventional Power Grid	**Smart Grid**
Electromechanical	Digital
One-way communication	Two-way communication
Centralized generation	Distributed generation
Few sensors	Sensors throughout
Manual monitoring	Self-monitoring
Manual restoration	Self-healing
Failures and blackouts	Adaptive and islanding
Limited control	Pervasive control
Few customer choices	Many customer choices

Table 1.1 – Comparison between conventional grid and smart grid[12].

1.6 Architecture of Smart Grid

1.6.1 Conceptual model of SG

Various efforts have been made regarding the standardization of smart grid communication. A number of organizations that are working on this: IEEE, International Electrotechnical Commission (IEC), and the National Institute of Standards and Technology (NIST) [13]. NIST has published standards include NIST 1108 (describes, among others, smart grid inter-operability and requirement of communication networks); and NIST 7628 (describes smart grid information security issues).

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. This does not represent the final architecture of the Smart Grid; rather it is a tool for describing, discussing, and developing that architecture[14]. The conceptual model is shown in fig 1.3.

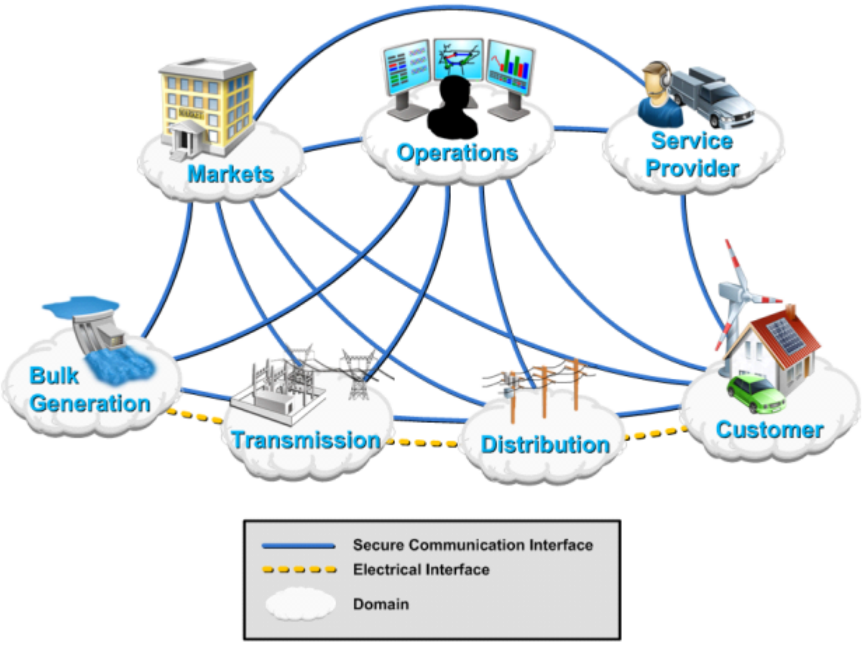


Figure 1.3 – Smart Grid Conceptual Model [14].

The conceptual model consists of several domains, each of which contains many applications and actors that are connected by associations, which have interfaces at each end [14]:

- **Actors** may be devices, computer systems or software programs and/or the organizations that own them. Actors have the capability to make decisions and exchange information with other actors through interfaces.
- **Applications** are the tasks performed by the actors within the domains. Some applications are performed by a single actor, others by several actors working together.
- **Domains** group actors to discover the commonalities that will define the interfaces. In general, actors in the same domain have similar objectives. Communications within the same domain may have similar characteristics and requirements. Domains may contain other domains.
- **Associations** are logical connections between actors that establish bilateral relationships. At each end of an association is an interface to an actor.
- **Interfaces** show either electrical connections or communications connections.

In Figure 1.3, the electrical interfaces are shown as yellow lines and the communications interfaces are shown in blue. Each of these interfaces may be bi-directional. Communications interfaces represent an information exchange between two domains and the actors within; they do not represent physical connections. They represent logical connections in the smart grid information network interconnecting various domains.

The Smart Grid domains summarizes in tab 1.2 as shown below:

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.

Table 1.2 – Smart Grid domains [14].

1.6.2 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 as a holistic view of an overall architecture in the Smart Grid domain [15].

The SGAM is a three-dimensional visualisation, presented in fig 1.4, that helps to identify components and their relations.

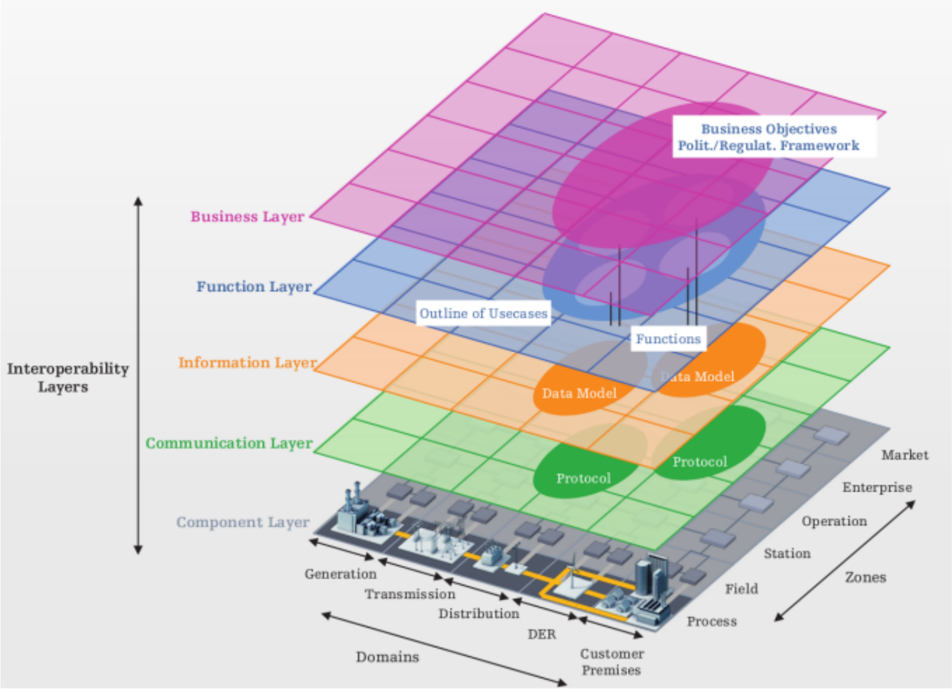


Figure 1.4 – Overview of the Smart Grid Architecture Model[16].

1. **First dimension :** From the top to the bottom, five layers are used to consider different interoperability aspects (viewpoints). It starts with the *Business Layer*, where regulatory and economic structures, business models and processes are positioned. On the next layer, the *functional view*, the functionalities are located. The required functionalities result from analysing different Use Cases.

   On the *Information Layer*, the used and exchanged information is considered; i.e., the Use Case specific semantic for functions and services to enable an interoperable information exchange. Therefore, information objects and canonical data models are positioned here. On the *Communication Layer*, protocols and mechanisms for the information exchange between actors are positioned; i.e., the data channel specification. The *Component Layer* is the lowest level and covers the individual entities that contribute to the Smart Grid. It includes autonomous systems, connected components, atomic applications, and any kind of smart devices.

   Each layer spans all domains along the energy conversion chain, from generation to consumption, as well as the control and management zones, from process until market control and management, respectively.

2. **Second dimension :** The energy conversion chain starts with the *generation* of electric energy that is typically connected to the transmission system. The *transmission* is the infrastructure and organisation that distributes the electricity over long distances to major industry and cities.
   The *distribution* represents the infrastructure and organisation that distributes the electricity to customers within a specific region. *Distributed Energy Resources* (DER) are comparably small power plants feeding electricity into the distribution grid. At the end of the chain, *customer premises* refers to the industrial, commercial, and residential facilities of energy consumers. The aggregation, separation and utilisation of the information used to manage the power system is governed by organisational and legal rules on participating in the energy sector.

3. **Third dimension :** In the *market* zone, possible market operations along the energy conversion chain are considered; e.g., energy and capacity trading. The *enterprise* zone covers commercial and organisational processes and services; e.g., customer contracting and billing. The *operational* zone refers to power system control operations for the generation, the transmission and the distribution systems. The *station* zone aggregates data and functions from the *field* zone, which describes the equipment to protect, control, and monitor physical processes and power flows. In the *process* zone, physical, chemical, and spatial transformation of energy, the applied physical/mechanical/electrical equipment, is represented [16].

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) [17]. The schematic diagram of the smart grid communication infrastructure based on these networks is shown in fig 1.5.

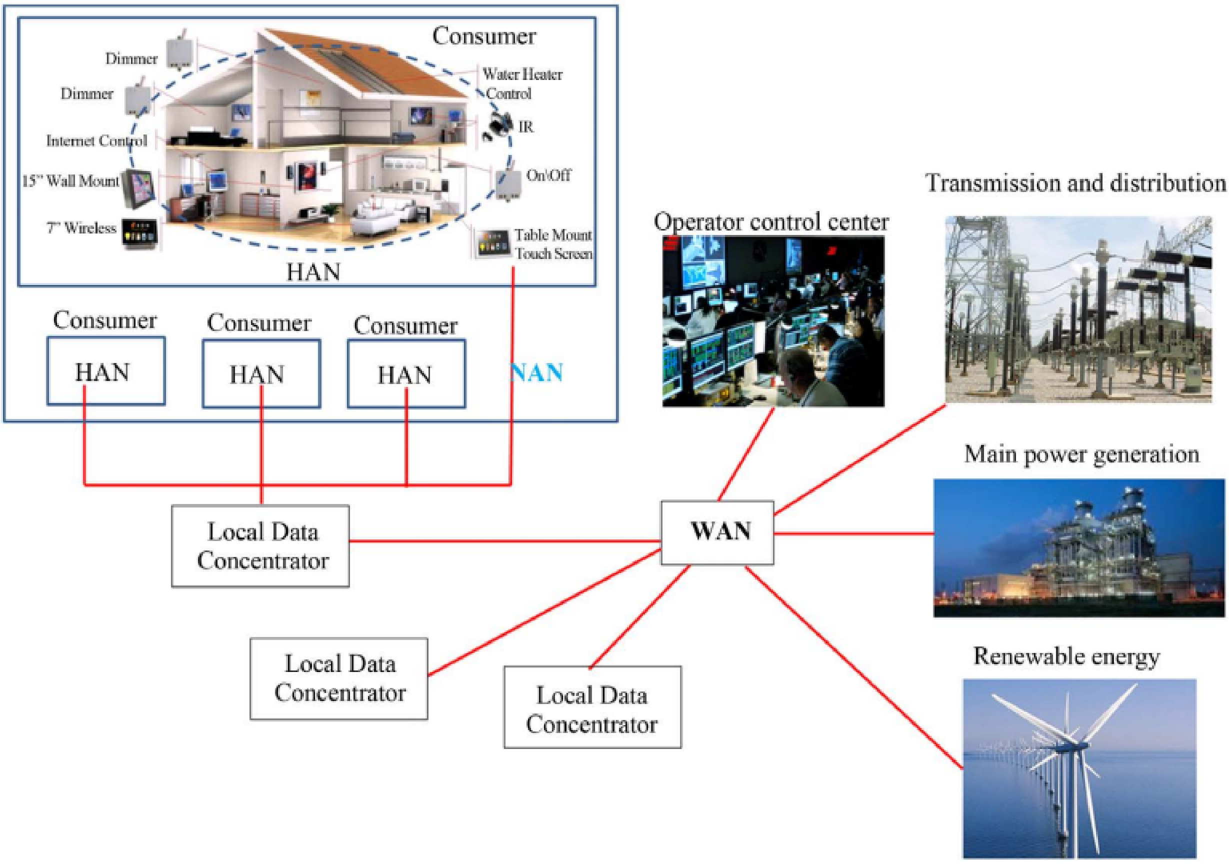


Figure 1.5 – Smart grid communication infrastructure [17].

— **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 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. HAN allows more efficient home energy management. HAN can be implemented by ZigBee or Ethernet technologies .

- **NAN** is deployed and operated within area of hundreds meters which is actually 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 vast area of tens of kilometers and it consists of several NANs and LDCs. Moreover, the communication of all smart grid's components including operator control center, main and renewable energy generation, transmission and distribution, is based on WAN. The WAN has very high transmission data rate up to few Gbps.
  The WAN can be implemented by Ethernet networks, WiMAX, 3G/LTE and micro-wave transmission [17].

1.8 Overview of Communication Technologies That Can Be Used in Smart Grid

There are several technologies that can be applied to the smart grid [17]:

1.8.1 ZigBee

ZigBee is based on an IEEE 802.15 standard. ZigBee is used in applications that require a low data rate, long battery life, low cost and secure networking. The technology defined by the ZigBee specification is intended to be simpler and less expensive than other wireless personal area networks (WPANs), such as Bluetooth or Wi-Fi. ZigBee networks are secured by 128 bit symmetric encryption keys.

There is a "ZigBee Smart Energy" application that allows integration of smart meters into the ZigBee network together with other devices. By using this application, smart meters can collect information from the integrated devices and control them. Moreover, the consumers can view their energy consumption in real-time. It also allows better energy consumption and real-time dynamic pricing.

The advantages of ZigBee application in smart grid are low price, small size and it uses relatively small bandwidth.

The disadvantages of the ZigBee are small battery that limits its lifetime, small memory, limited data rate and low processing capability.

1.8.2 WLAN

A wireless local area network (WLAN) links two or more devices using spread-spectrum or Orthogonal Frequency Division Multiplexing OFDM and usually providing a connection through an access point to the wider Internet.

This gives users the ability to move around within a local coverage area and still be connected to the network. Most modern WLANs are based on IEEE 802.11 standards, marketed under the Wi-Fi brand name. WLANs have become popular in the home due to ease of installation, and in commercial complexes offering wireless access to their customers. WLAN could be easily integrated into smart grid due to its vast deployment around the world.

The advantages of WLAN are low cost, vast deployment around the world, plug and play devices.

The major disadvantage of WLAN is high potential for interference with other devices that communicate on the same frequencies.

1.8.3 Cellular Networks

Cellular networks are largely deployed in most countries and have well established infrastructure. Moreover, they allow high data rate communications up to 100 Mbps. Therefore, the cellular networks can be used for communication between different components and devices in smart grid. There are several existing technologies for cellular communication such as GSM, GPRS, 2G, 3G, 4G and WiMAX.

The WiMAX technology is the most interesting for smart grid implementation.

The WiMAX chips are integrated inside the smart meters that are deployed through the smart grid.

The advantages of the cellular networks are already existing infrastructure with wide area of deployment, high rates of data transfer, available security algorithms that are already implemented in the cellular communication.

The major disadvantage is that cellular networks are shared with other users and are not fully dedicated to the smart grid communications. This can be serious problem in case of emergency state of the grid.

1.8.4 Power Line Communication (PLC)

Power line communication allows data exchange between devices through electrical power lines. PLC is implemented by adding a modulated carrier signal to the power cables. The data rate of OFDM based communication can be up to several Mbs.

In smart grid applications, the PLC is used in Neighborhood Area Network communication for connecting between smart meters and Local Data Concentrator (LDC). However, the Wide Area Network communication, from LDC to other smart grid components such as operator control center, generation, transmission and distribution, is performed through cellular networks.

The advantage of the PLC is already established, wide-spread infrastructure that reduces installation costs.

The disadvantages are presence of higher harmonics in the power lines that interfere with communication signals and limited frequency of communication.

1.8.5 Benefits of Smart Grid

The benefits expected from the Smart Grid can be grouped into three basic categories: electric utilities, end users and society[18].

- **Electric utilities :**
  - Optimized Transmission and distribution network operation.
  - Enhanced power generation and storage.

- **End users :**
    - Dynamic power consumption.
    - Lower cost of power backup.
    - Lower frequency and duration of interruptions and outlages.
    - Extra Revenues from on site power generation.
- **Society :**
    - Enhanced security and resilience of the electricity infrastructure.
    - Effective and highly reliable power delivery.
    - Reduced CO2 emissions.

1.9 The Challenges of Smart Grid Technology

This section presents the possible challenges on the smart grid :

Technology	Challenges	Obligations
Self-Healing Action	Security	Exposed to internet attacks (Spasm, Worms, virus etc.), question of National security
	Reliability	Failure during natural calamities, system outages and total blackout
Renewable Energy Integration	Wind/Solar Generation	Long-term and un-predictable intermittent sources of energy, unscheduled power flow and dispatch
	Power Flow Optimization	Transmission line congestions and huge investments
	Power System Stability	Decoupling causes system stability issues causes reduced inertia due to high level of wind penetration
Energy Storage Systems	Cost	expensive energy storage systems like Ultracapacitors, SMES, CAES etc.
	Complexity	Complex customary design module and networks
	Non Flexibility	Unique designs for all individual networks not ease adaptation.
Consumers Motivation	Security	Malware, data intercepting, data corruption, Illegal power handling and Smuggling
	Privacy	Sharing of data cause privacy invasion, etc.,
	Consumer awareness	Corruption and system threats like security and privacy issues
Reliability	Grid Automation	Need of strong data routing system, with secure and private network for reliable protection, control and communication
	Grid Reconfiguration	Generation demand equilibrium and power system stability with grid complexity
Power Quality	Disturbance Identification	Grid disturbances due to local faults in grids, load centres or sources
	Harmonics Suppression	System instability during sags, dips or voltage variation such as over-voltages, under-voltages, voltage flickers, etc.

Table 1.3 – Smart Grid Technology challenge[19].

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 components, Application of SG, different between Traditional Power grid and Smart Grid , architecture, infrastructure and technologies that can be applied to the smart grid, finally with benefits and challenges. In the next chapter, we introduce the energy management in smart grid.

Chapter 2

Energy management

2.1 Introduction

The integration of highly fluctuated distributed generations threatens the stability of the power and distribution systems. The main cause is that the power ratio between the supply and demand may not be balanced. An excess/shortage in the generation or consumption of power may perturb the network and create severe problems such as voltage drop/rise and in severe conditions, blackouts. To increase the balance between the supply and the demand in an efficient way, and to reduce the peak load during unexpected periods, energy management systems are utilized.

One important goal of optimal energy management (OEM) is to maximize the social welfare through the coordination of the suppliers' generations and customers' demands. Thus, it is desirable to consider the interactive operation of economic dispatch and DR, and solve them in an integrated way[6]. Energy management has many barriers and limitations. However, it has a prominent future in which most of the current research is focused on developing sophisticated algorithms and models to better manage the energy on the grid [20].
This chapter we will present a review of energy management, We define a set of requirements for do it and some optimisation methods that can use and we will describe the networked microgrids system architecture and the pricing scheme that allows to apply the coalition formation .After we will formulate the problem of energy management in networked MGs .

2.2 Definition of energy management

The energy management can be defined as a set of strategies and functions that can adjust and optimize the energy use. These set of functions increase the energy efficiency and coordinate the energy resources. It is the process of observing, controlling and conserving electricity usage in a building, a neighborhood, etc. Energy management should be able to optimize costs and to minimize the risk of loss of production excess[21].

2.3 Two side management

There is two side for power management: Demand side management (DSM) and Demand Response (DR).

2.3.1 Demand side power 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 [22]. Therefore, the main goal of DSM implementation is to reduce electricity costs by controlling energy consumption, environmental and social development, improving reliability and reducing grid problems.

2.3.2 Demand response power management

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 [23]: “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 elec-

tricity 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 [24]. In a traditional grid, consumers have no concept of the energy efficiency of their loads and no incentive to change their consumption behavior. In this case, utilities maintain a balance between production and demand by monitoring production resources.

2.4 Renewable energy

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[25].

- **Solar:** The Sun’s radiation can also be used as a power source. Solar energy can be converted into electricity using photovoltaic cells. These cells provide only enough energy to operate a calculator when used alone, but when joined to form solar panels or even larger arrays, they produce a lot more electricity.
- **Wind energy :** Wind turbines are used to generate electricity. The blades of the turbine are pushed by the wind, and this mechanical energy is converted into electricity by a generator. This electricity can be used to power homes and other structures, as well as being stored in the power grid.
- **Biomass :** refers to organic material from plants or animals. This includes wood, sewage, and ethanol, among other things (which comes from corn

or other plants). Because this biological material has absorbed energy from the Sun, it can be used as a source of energy. When this energy is burned, it is converted to heat energy.

- **Hydropower :** has been used for thousands of years and is one of the oldest renewable resources. Hydroelectricity is now used in every state in the United States. The mechanical energy of flowing water is used to generate electricity in hydropower. Hydroelectric power plants generate energy by turning a turbine that is powered by the flow of rivers and streams.
- **Geothermal energy** comes from the heat generated deep within the Earth's core. Geothermal reservoirs can be located along tectonic plate borders or deep underground, near volcanic activity. Drilling wells to pump hot water or steam to a power plant can be used to harvest geothermal energy. After that, the energy is used for heating and power.

2.5 Energy storage

Renewable energy resources, such as solar or wind, offer a greener solution compared to traditional energy resources such as fossil fuels. However, their intermittent nature makes it difficult to balance demand and supply, which is essential in a power grid. Both electricity generation from the renewable energy resources and electricity demand are stochastic processes. The Energy Storage Devices (ESD) should be a solution for random energy problem as they can smooth out variations in generation and demand [26].

The energy storage has long been identified as an important technology to leverage supply and demand. In an operational context, the energy storage can be used to store energy excess when supply exceeds demand and then dispatch it when it is needed which improves the energy efficiency. The energy storage can alleviate the need to generate power exactly at the time it is needed. Furthermore, it can smooth out the variations of energy utility due to random power demand and uncertain energy supply[27].

2.6 Microgrid

A microgrid is a local electrical network that (1) comprises power generation units, power consumption units, and a means of delivering power from the generation units to the consumption units, (2) may be connected to a larger utility power system, and (3) 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). Microgrids can therefore include all the functions previously presented (DR, EVs, etc.). They are connected to the network but can also be used in an isolated way in case of failure of the transport network. Once the problem is solved, the microgrid can be resynchronized. A microgrid is controlled by a supervisory controller that decides which microgrid energy resources to use at what times in order to balance load and generation [25].

Fig 2.1 shows a microgrid model integrating numerous generation resources, battery storage system, EVs and the main electric utility.

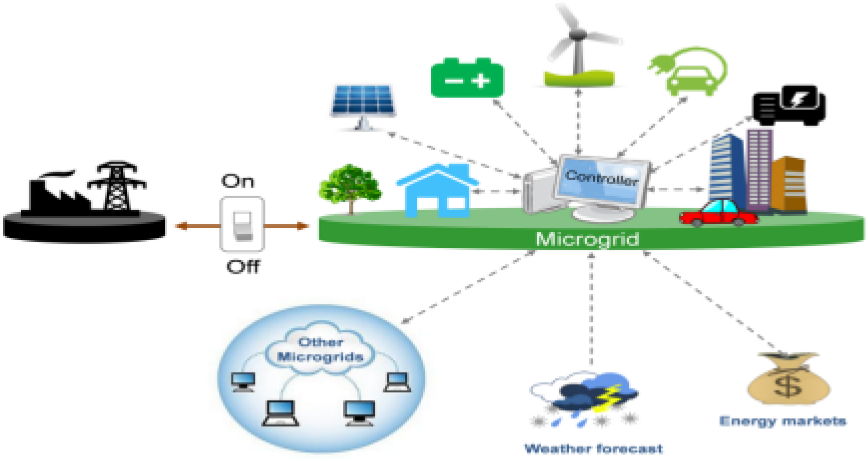


Figure 2.1 – Microgrid model[25].

2.7 Energy management in smart grid

2.7.1 Definition of EM in smart grud

Energy management in the Smart Grid (SG) ensures that the stability between supply and demand is maintained, while respecting all system constraints for economical, reliable and safe operation of the electrical system. It also includes optimization, which ensures a reduction in the cost of power generation[28].

2.7.2 Application of Energy Management

Energy management can be divided into two major categories. The first one is from the electricity supplier's viewpoint, while the second one is from the electricity consumer's viewpoint.

The electricity supplier (such as electric utility, power plant operators and production units) can use the energy management to control its generation units in an efficient way. For example, to meet a certain power demand of the consumers, using energy management, the electric utility can turn on some generators, which may have the least operation cost, while the generators with high operation cost are left to supply extra load demand in specific peak periods. In this way, the electric utility is trying to minimize the operation cost of its generation units.

The system operator (such as transmission and distribution systems) can use energy management to regulate the power flow in a way to minimize the energy losses on the network and increase the penetration level of renewable energy sources (such as PV and wind farms) in an efficient way.

The end-users (such as householders, residential and commercial buildings, industries, faculties, etc.) use energy management to minimize their electricity bill and schedule their load demand in an efficient way[20].

2.7.3 Why is Energy management important?

In a world where the energy demand is on the rise, the power generation should also increase to satisfy the user needs and improve their daily life. However, because the number of consumers is raising, and also because of the unpredictability nature of the electric load, power demand may cause challenges to the electric utilities and system operators. High peak demands have a great probability to occur in many periods and may be a threat to the system functionality. To resolve this issue, the electric utility and system operators have two choices available[20]:

- Increase the size and dimension of the network which is costly and requires time to implement
- Utilize energy management in order to reduce the possibility of high peak demand during peak hours

The second solution sounds more reasonable; however, it requires sophisticated algorithms and methods to be capable of managing energy. Energy management is considered a must for a smarter grid for many reasons[20]:

1. It is automated and does not require direct intervention from human beings.
2. It gives accurate results and predictions.
3. It helps the electric utility to better optimize the. functionality of its generation units and reduce the generation cost.
4. It helps the system operator in reducing the energy losses on the network and lines, which may reduce drastically the indirect distribution electricity cost.
5. It helps the end-users to better manage their load demand and reduce their electricity bill.
6. It increases the load factor, in which the power profile becomes smoother and less fluctuating.
7. It increases energy efficiency.
8. It conserves the resources.
9. It reduces pollution and protects the climate.

2.7.4 Methods uses for energy management in SG

Several solution approaches have been used in EMS to ensure efficient and optimal operation of the emerging network.

Fig 2.2 presents a summary of these optimization approaches. Many of the methods are based on classical approaches, such as linear and non-linear mixed integer programming. Linear programming can be qualified as a good approach depending on the objective and constraints, while artificial intelligence methods focus on approaching situations where other methods lead to unsatisfactory results, such as forecasting renewable energy production and optimal operation of energy storage taking into account the aging of batteries, among others[28].

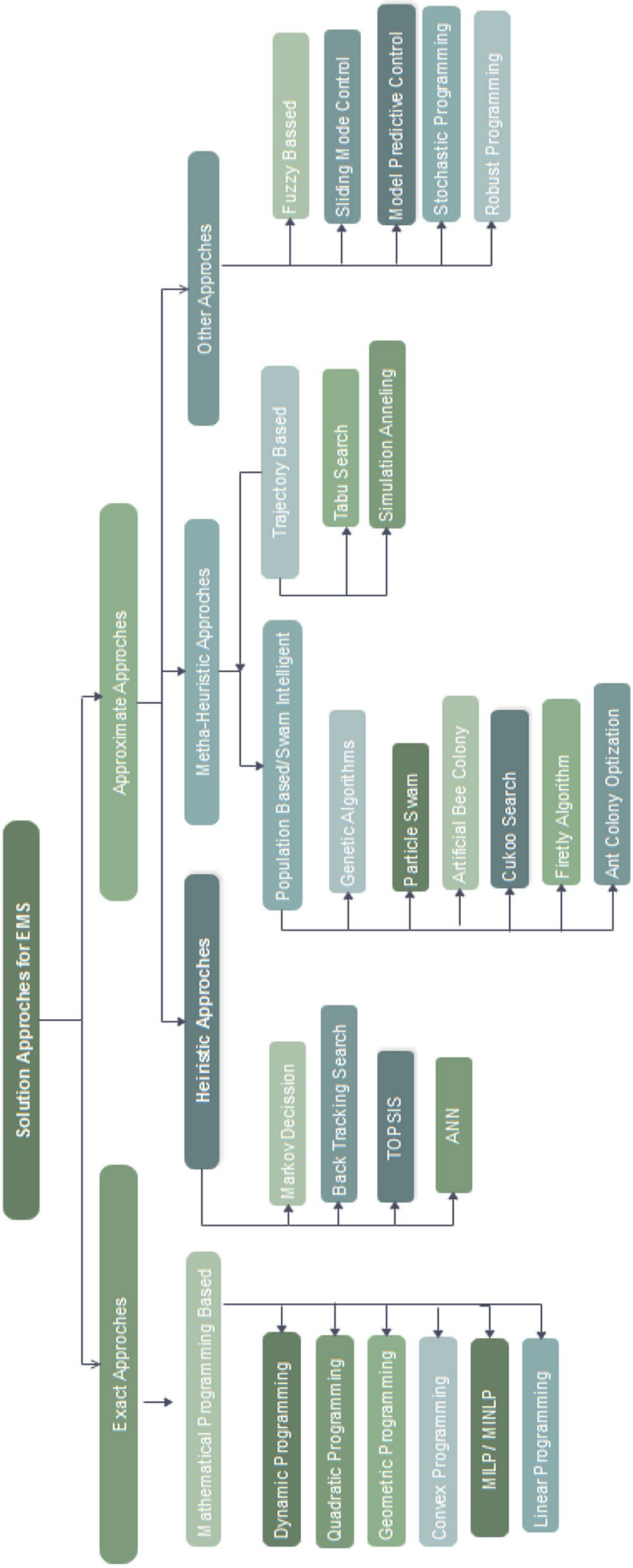


Figure 2.2 – Optimization/programming approaches applied to EMS [28].

In fig 2.2, solution approaches for EMS are grouped into four categories, i.e. mathematical programming based, heuristic, meta-heuristic, and another solution approach. The mathematical programming based optimization methods belong to the exact solution approach methods. As the name suggests, exact optimization methods guarantee an optimal solution.

However, the complexity of the calculations increases in this case. For this reason, they are not preferable for a real-time application, especially if it takes longer to find a solution. Whereas approximate optimization methods do not guarantee an optimal solution but provide a solution within a reasonable time with the optimal or closest result. Heuristic or meta-heuristic optimization techniques belong to the approximate algorithms that provide the result at the best price within a reasonable time and can be applied to online or real-time problems [28].

2.7.4.1 Mathematical programming-based EMS (equationbased)

The EMS problems solved by these optimization techniques share common properties, such as the possibility of being expressed in mathematical terms, the possibility of having continuous or discrete variables, the proven difficulty (NP-complete or worse) and the possibility of including dynamic aspects. Mathematical optimization requires careful consideration when modeling, and the model must be operated with a view to reliability and efficiency. Composite problems suffer from the complexity of the calculations and the curse of dimensionality[28].

2.7.4.2 Heuristic-based solution approaches for EMS

The heuristic approach is the most knowledge based and elementary method of providing approximate solutions to a given problem according to predefined rules. For EMS, heuristic approaches are well designed to decrease the complexity of calculating the assigned task for an efficient solution. To obtain the best solution, heuristic techniques are combined using biological evolution, genetic algorithms, and statistical mechanisms to achieve optimal energy operation and control[28].

2.7.4.3 Meta-heuristic-based solution approaches for EMS

Meta-heuristic methods, and decentralized management is frequently implemented in methods based on multi-agents. Most meta-heuristic methods, such as genetic algorithms (GAs), ant colony optimization, PSO, bee colony optimization, simulated annealing (SA), and many other methods, are stochastic and are motivated by nature, physical, or biological principle and try to resemble them making a balance between exploration (diversification) and exploitation (intensification). Most meta-heuristic methods are population-based and are a non-random algorithm. For EMS, some methods were used by the researchers, namely GA, PSO, SA, fuzzy, Tabu Search (TS), firefly and ABC.

In particular, SA and PSO have become popular as search and optimization tools because of their versatility and their ability to search and optimize in complex multimodal search spaces, non-differentiable cost functions, changing environments, and so forth. These meta-heuristic techniques are computationally robust, but do not require the lens to be convex. Meta-heuristic approaches are well known for their ability to deal computationally efficiently with complex search and optimization problems[28].

2.7.4.4 Other solution approaches for EMS

Apart from heuristics, meta-heuristics, and mathematical programming, few other solution methods have been used in EMS to achieve computational advantages, to improve problem modeling, and precision in results.

Such methods as stochastic, MPC, sliding mode control, and fuzzy programming have been developed by various authors. Among these approaches mentioned above, stochastic and robust methods are the most appropriate for dealing with uncertainties; at the first approach, uncertainties are characterized with parameter distributions, while at the second one, we assume that they belong to certain sets, without making any assumptions about the distribution[28].

2.7.5 Discussion

Mathematical programming requires more time than heuristic and meta-heuristic programming. Most meta-heuristic problems are population-based, and a near optimal or optimal solution can be found from the search space with less computational load. On the other hand, heuristic approaches are knowledge-based, which makes it possible to find a rough solution to the problem.

In the case of heuristic approaches, it is necessary to have prior knowledge of energy management with certain assumptions and flexibility to obtain a solution closer to the optimum with less computational time. Stochastic, robust, MPC, SMC, and so forth, approaches are difficult to implement, but their computer traceability and the accuracy of the results are guaranteed[28].

In table below show a comparative of mathematical programming, heuristic approach and metaheuristic.

Methods Caracteristic	Mathematical programming	Heuristic approach	Meta-heuristic approach
Less time Demand	X	√	√
Optimal solution	√	X	X
Knowledge based	√	√	X
Easy implementation	X	X	√
Complex	√	X	X

Table 2.1 – Comparison of optimization methods.

Different techniques were used by the researchers. Energy management and control optimization in a MG may involve one or more objective functions.

These may vary depending on the optimization problem posed. The result may be a single-objective or multi-objective problem, which may include minimizing costs (fuel cost, operating and maintenance cost, and the cost of degrading storage elements such as batteries or capacitors), reducing emissions, and minimizing unmet load. Different researchers propose meta-heuristic techniques to solve the problem of optimization due to multiple constraints, multiple dimensions and highly non-linear combinatorial problems[28].
Wasilewski[29] presented a meta-heuristic optimization method for optimizing a microgrid. The methods include evolutionary and swarm particle algorithms. These methods take into account the fact that the deterministic conditions assumed in the problem impose an important limitation on the methodology employed. However, it also recognizes the uncertainty associated with the use of renewable energy.

Radosavljevic´ et al[30]. suggested MG power and operation management using PSO for minimizing their total cost by optimally setting the energy management and operation control variables.

In the other hand, Sousa et al [31] proposed an SA approach for energy control in a VPP (virtual power plant). This approach is based on a case study of a 33-bus distribution network with 1000 grid-connected vehicles, 66 generators, 32 loads, and the SA results are compared with the MINLP(Mixed-Integer Nonlinear Programming) approach. It has proven that SA approach has been more efficient for the management of energy resources in the VPP, providing the best solution in a short time, which is an important aspect in a SG environment, especially when many distributed resources are involved [28].

Table below (tab 2.2) shows a comparative analysis of different meta-heuristic based solution approach in an EMS.

Meta-heuristic methods	**Objective**	**Advantage**	**Drawbacks**	**Architecture /uncertainties**
Genetic algorithm	The operation, the cost of emissions have minimized and increased commercial profit	Scalable population-based algorithms including operations such as crossing, mutation and selection at find the optimal solution. Convergence at the right speed. Widely used in many fields.	It is necessary to define crossing and mutation parameters, as well as population parameters and stopping criteria.	Centralized/ forecasted
Particle swarm algorithm	Reduces the MG operating cost	Derivative-free, simple in implementation, required limited inputs	High computational time, difficult real-time implementation	Decentralized/ forecasted
Tabu search	VPP operating cost reduced	Require less computational time	Verification of the optimality of the result requires other methods such as branching and binding	Centralized / Scenario based
Artificial bee colony	Operating cost of MG reduced	Robust population -based algorithm, easy to implement.Adequate convergence speed	Complex process.	Centralized/ forecasted
Firefly	Operating cost of MG reduced	Ability to handle non-linear multimodal optimization	Risk of trapping in local zones.	Centralized / scenario based

Table 2.2 – Comparative analysis of different metaheuristic-based solution approach in an EMS[28].

2.8 Networked Microgrids Architecture

The system consists of N networked MGs with distributed energy resources (DERs) that are composed of: Distributed generation (DG) units which can be conventional or renewable generators, and energy storage systems(ESSs). The distributed energy resources are responsible for the power supply of the microgrid. We assume that each microgrid has loads to serve. We also assume that each microgrid has an energy management software (EMS) that is responsible for the optimization of power consumption and usage of DERs[3].

We organize MGs into groups (also called coalitions). Let Θ_i^j denotes the i^{th} MG belonging to the j^{th} group (i.e., coalition). Let $D(\Theta_i^j)$ be the total demand of Θ_i^j and $S(\Theta_i^j)$ its total supply. The energy status $E(\Theta_i^j)$ of Θ_i^j is given by the difference of total supply and demand, i.e.,

$$E(\Theta_i^j) = S(\Theta_i^j) - D(\Theta_i^j) \tag{2.8.1}$$

A positive value of energy status denotes that Θ_i^j can sell $E(\Theta_i^j)$ amount of energy while a negative value denotes that Θ_i^j needs to purchase $E(\Theta_i^j)$ amount of energy from the distribution system. Therefore, the set of all MGs can be grouped into three subsets that are balanced MGs $\Lambda = \{\Lambda_1, ..., \Lambda_{|\Lambda|}\}$, MGs with energy surplus $\Pi = \{\pi_1, ..., \pi_{|\pi|}\}$ and MGs with energy shortage $\Psi = \{\psi_1, ..., \psi_{|\psi|}\}$.

The formation of coalitions between MGs is an attractive suggestion for achieving cost-effective energy management and minimizing power loss. The MGs in a coalition can exchange energy at a competitive price and, as a last resort, interact with the distribution system operator to minimize power loss and reduction of cost.

The networked MGs system is described in fig3.1 each microgrid consists of distributed energy resources (DERs) such as distributed generation (DG) units and energy storage systems (ESSs). Furthermore, each microgrid is connected with the distribution system through a voltage transformer while it is connected with the other MGs via a low voltage power line. With this architecture, a microgrid can exchange power with another microgrid if there is a transmission line between them, i.e., a low voltage power line. This energy exchange brings more profit to both MGs since it is cheaper and more efficient than exchanging with the distribution system[3].

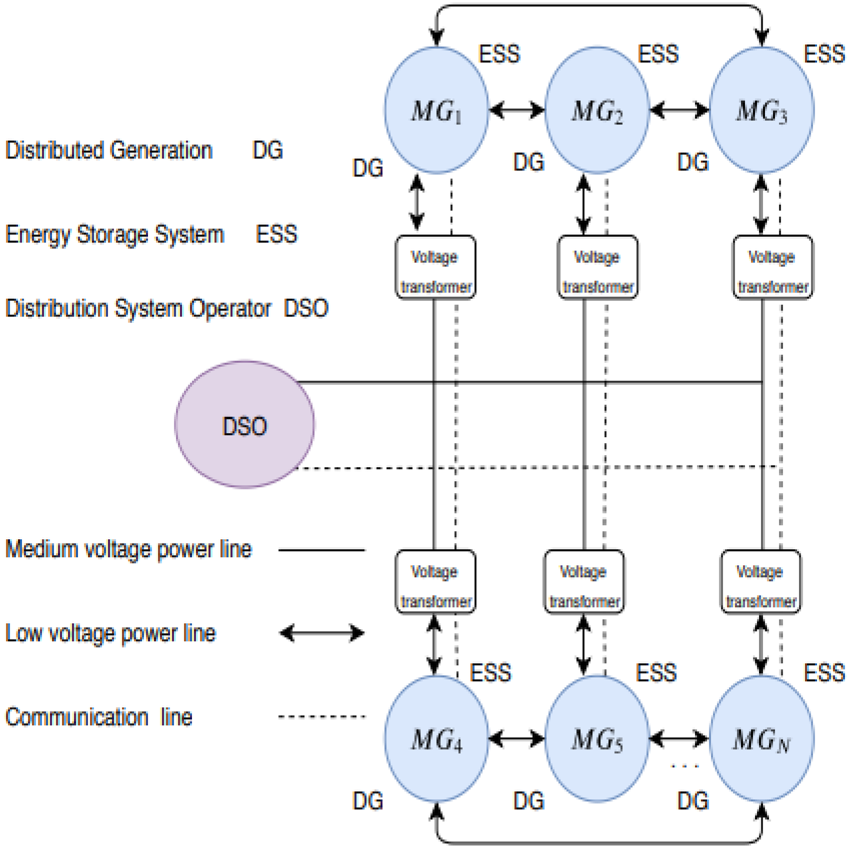


Figure 2.3 – Networked MGs system architecture [3]

2.9 Pricing Scheme for Coalition Formation

The pricing scheme is influential factor to perform cooperation between MGs. Particularly, the coalition formation process should justify the preference of MGs over the DSO in energy exchange. The design of inappropriate pricing scheme will result in disadvantageous outcome. The designed pricing scheme must motivate a MG to cooperate with the other MGs by exchanging the energy surplus. In this respect, we have designed a motivating pricing scheme that ensures that forming coalition between MGs is always prioritized than DSO[3].

For instance, let $\alpha = 0.2\$/kwh$ denotes the price of selling energy to the DSO, $\beta = 0.7\$/kwh$ denotes the price for purchasing energy from the DSO and $\gamma = 0.3\$/kwh$ is the price of selling/purchasing between MGs. Such that, a MG always prefers to exchange energy with the other MGs since it can save

0.1\$/kwh in selling and 0.4\$/kwh in purchasing by exchanging energy to MGs instead of DSO. Such that, the pricing scheme is designed as follows:

$$\beta \gg \gamma > \alpha \tag{2.9.1}$$

where $(\gamma - \alpha) \gg \sigma$ is a predefined threeshold.

2.10 Problem formulation

This section gives the formulation of the energy management problem in networked MGs. Because the networked MGs system is a cyber-physical system, efficient software is required to solve the problem of energy management.

The main problem here consists of two sub-problems that are coalition formation and energy transfer.

The first sub-problem consists of forming several stable coalitions between MGs to optimize the power supply availability economically and efficiently. A coalition formation game is formulated for the cooperation between MGs to optimally exchange the power surplus.

The second sub-problem consists of transferring energy in each formed coalition. The energy transfer problem is formulated as a power loss minimization problem to optimally transfer energy in each coalition[3].

2.10.1 Coalition Formation Game

2.10.1.1 Challenge

Instead of sharing the power surplus with the DSO, MGs can cooperate with others to exchange their power surplus by forming several coalitions with taking into account the distance between MG. Unbalanced power of each microgrid is purchased or sold within coalition. After performing the energy transfer within coalition, the rest of energy surplus or shortage can be balanced by the DSO as a last resort [2].

2.10.1.2 Formalization

Coalition formation is a process to form the best coalitions structure in order to have an optimal energy management between networked microgrids.
The coalitional game can be defined with the following pair (N, v) that consists of a finite set of players N (MGs in our case) and a characteristic function or value v. The carachteristic function $v : 2N \rightarrow R$ associates a payeoff $v(\Xi_j^k)$ for each coalition (Ξ_j^k), i.e.

$$v(\Xi_j^k) = min\ |S(\Xi_j^k) - D(\Xi_j^k)| \tag{2.10.1}$$

The characteristic function v of a coalition Ξ_j^k is defined by the aggregated energy status in this coalition. Thus, v(Ξ_j^k) has its best value when the difference between the total power demand and supply is minimized. The members of the coalition Ξ_j^k can distribute this payoff among themselves. Here, as less as a microgrid exchanges energy with the distribution system operator (DSO), it receives more payoff. A distributed coalition formation game is given by specifying a value for each coalition. The set of the formed coalitions form the coalition structure CS, .i.e,[3]

$$CS = \bigcup_{j=1}^{|\Omega k|} \Xi_j^k \tag{2.10.2}$$

The coalition structure payoff $\rho(CS)$ is the sum of the local coalition payoffs, i.e.,[3]

$$\rho(CS) = \sum_{j}^{|\Omega k|} v(\Xi_j^k) \tag{2.10.3}$$

2.10.2 Energy transfer

The energy transfer (ET) among MGs in a coalition should have a minimum power loss $P_L^{\Xi_j^k}$. The overall power loss $P_L^{\Xi_j^k}$ of a coalition Ξ_j^k while transferring power among MGs is given by

$$P_L^{\Xi_j^k} = \sum_{i,e \in \Xi_j^k} P_L(i,e) \tag{2.10.4}$$

where $P_L(i,e)$ is the power loss resulting from transferring energy over transmission lines between Θ_i^j and Θ_e^j. Note that, the power loss is defined as a characteristic function of a coalition Ξ_j^k instead of microgrid Θ_i^j , this is because loss occurs during power transfer between MGs in the same coalition. Technically, the power loss function is given by[2]

$$P_L(i,e) = I^2R = [\frac{P(E)}{\Psi}]^2 \; . \; \alpha \; . \; d(i,e) \tag{2.10.5}$$

where P(E) is the power required for energy transfer, Ψ is the carrying voltage on the transmission line, α is the line resistance and d(i, e) is the distance between Θ_i^j and Θ_e^j.

The characteristic function of the coalition formation game is designed to consider a tradeoff between power supply and loss. In the coalition formation process, the aggregated energy status is the characteristic function and in the energy transfer process, the power loss is the characteristic function.[2]

Overall, the energy management problem of networked MGs can be formulated with the following equations:

$$CS = arg\ max\ \rho(CS) \tag{2.10.6}$$

$$ET = arg\ min \sum_{\Xi_j^k \in CS} P_L^{\Xi_j^k} \tag{2.10.7}$$

2.11 Conclusion:

In order to improve the efficiency and reliability of power and distribution systems, energy management is critical. Many optimization techniques are used to maximize energy production from each particular source, minimize electricity costs, or maximize storage systems. Meta-heuristic methods are preferred over other methods of achieving this goal due to their versatility and ability to search and optimize in complex multi-modal search spaces, non-differentiable cost functions, and changing environments.

Chapter 3

Design of Energy management system for smart grids

3.1 Introduction

Energy management in the smart grid is critical and is of great importance to the efficiency of the smart grid. Conventionally, the energy transfer is carried out between MGs and DSO. Consequently, this transfer results in more power loss due to the existence of transformers and the transmission loss due to the Joule effect if the DSO is located within long distances to the microgrids. Furthermore, the energy transfer between MGs and DSO is unprofitable to MGs due to operator policy that imposes disadvantageous energy prices (e.g., the operator buy in low prices and sell in high prices)[3].

In this chapter, we will present an architecture of our system to acheive the optimal solution for energy management in, the system ensures the cooperation between MGs by forming several stable coalitions which lead to a significant technical and economical gains.

3.2 Global architecture of system

In this section, we presented a general view of our system

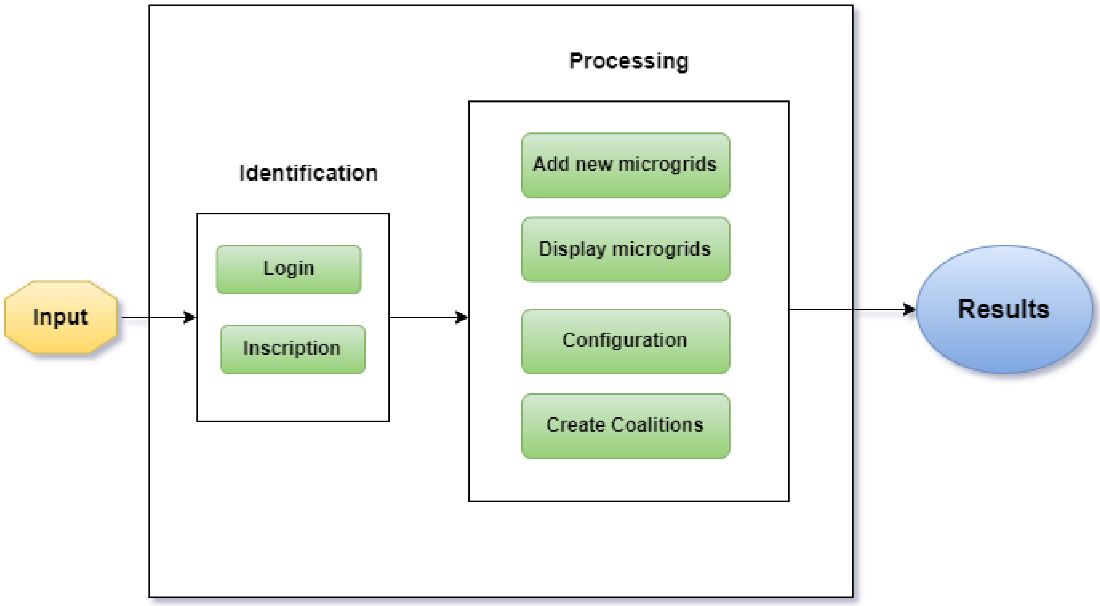


Figure 3.1 – Architecture global of Energy management System.

In our system, the administrator is the only one who can access to our system and to do it, must first log in if they have an account, otherwise if they don't have an account they must create an account after logging in. When accessing the system, it can add new microgrids, display existing microgrids, configure the network of MGs or create coalitions and see results. And we can also describe the architecture of our system with diagram below:

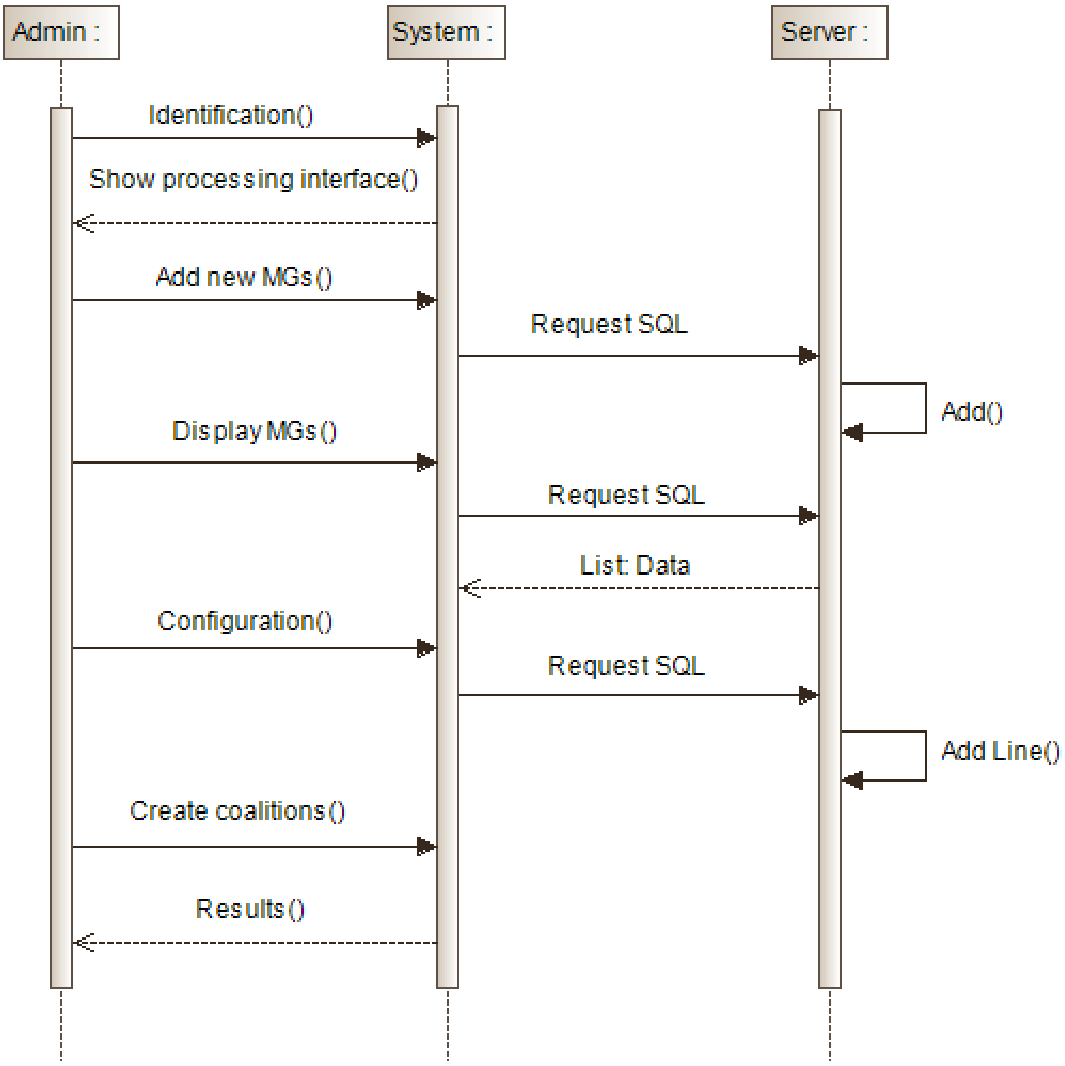


Figure 3.2 – Diagram sequence of system.

3.3 Detailed architecture

To get a clear view of our system, we used the sequence diagram UML. In this section we will provide a detailed architecture for each operation in our system.To get a clear view of our system, we used the sequence diagram UML.

3.3.1 Identification

The identification process is the first thing to do in our system. To access the system, you must log in or create an account and then log in.

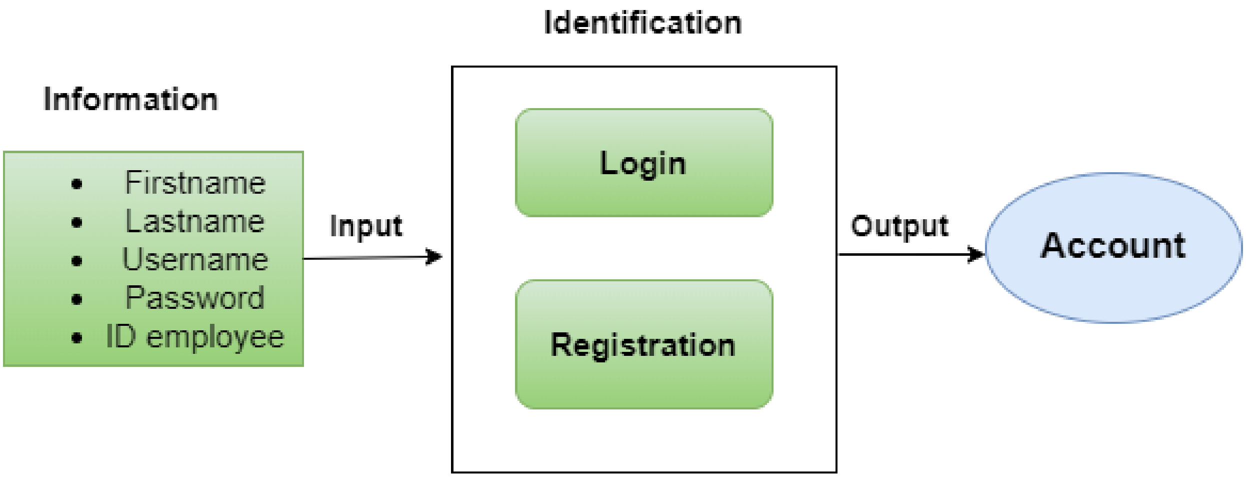


Figure 3.3 – Overview of architecture for identification.

3.3.1.1 Login

The administrator is the only one who can access to the system. A form containing the username and password must be completed. Then the system sends a request to verify the existence of the account in the database. If the account is exists, he will get an access to system, otherwise he will get an error message.

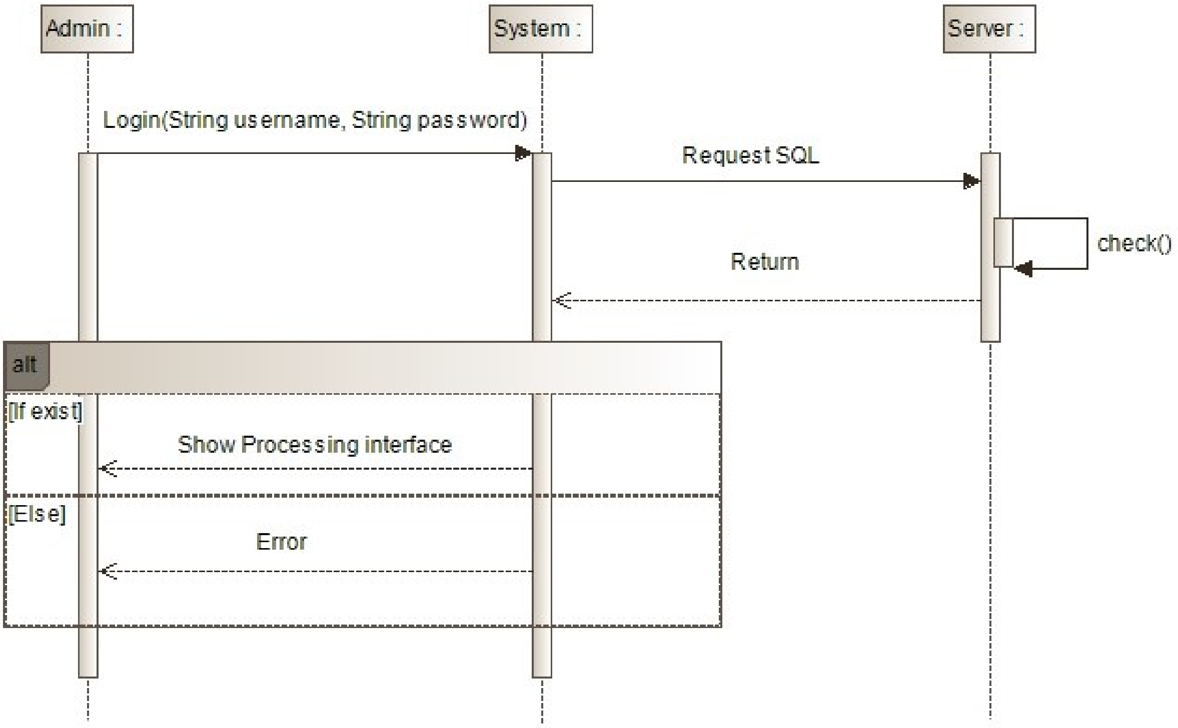


Figure 3.4 – Diagram sequence of login.

3.3.1.2 Inscription

If the administrator does not have an account, they can create a new account. A registration form contain first name, last name, username, password and employee ID must be filled. After input the information, the system make a set of verification (admin input).

First, the system checks if all the fields are filled if this is the case, then it checks if this account already exists .If is not exists, a successful message is received . Finally it saves these data in the database.

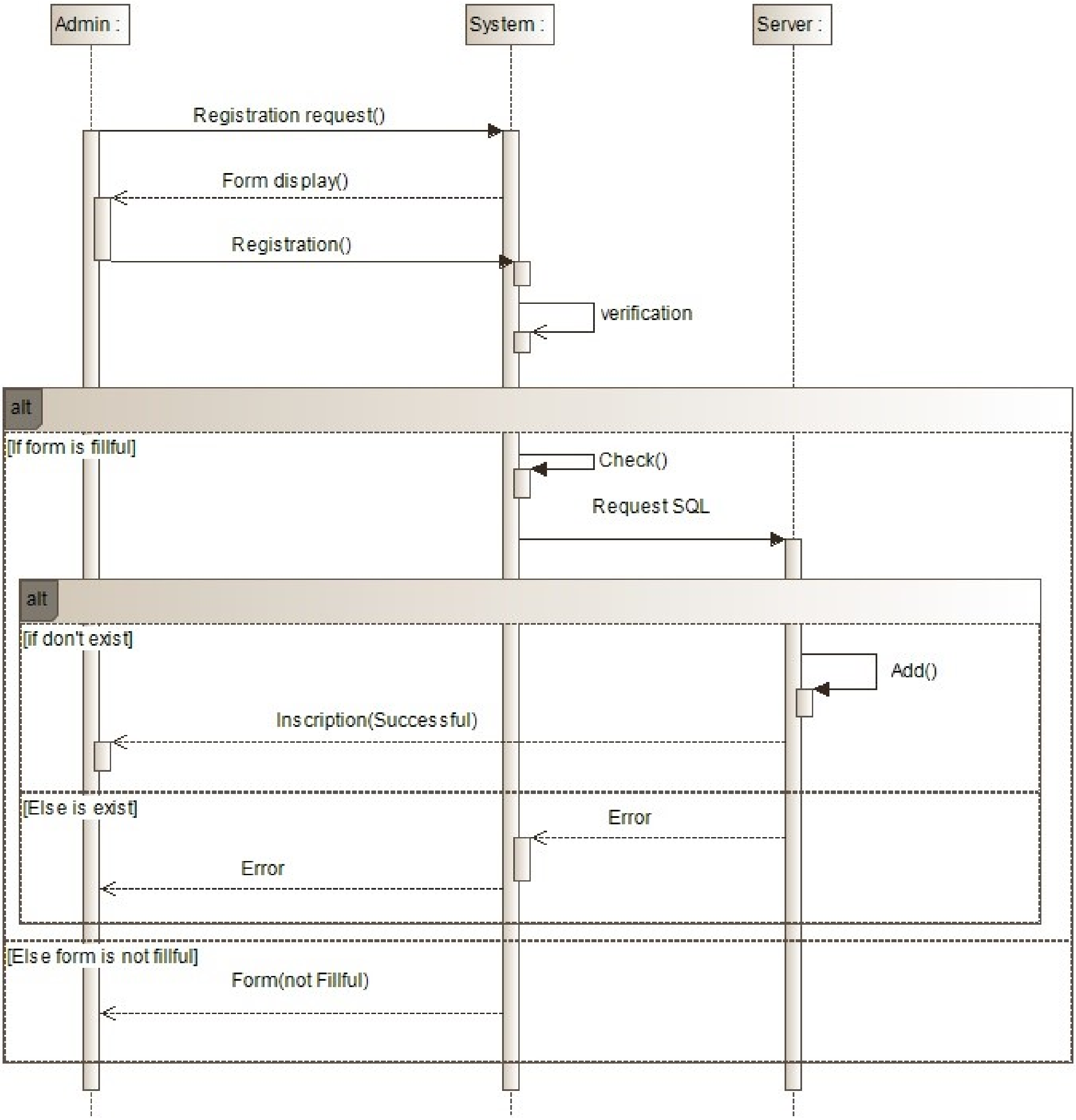


Figure 3.5 – Diagram sequence of Inscription.

3.3.2 Processing

In this section, we will explain every process the administrator can do in our system after the login process.

3.3.2.1 Add new microgrid

In our system, we can add new microgrids in the database and to do it, an form must be filled that contain 4 field :

- **ID :** each microgrids has an unique ID.
- **Power Demand :** (PD) is the energy needed for each microgrids.
- **Power Supply :** (PG) is energy generator in each microgrids.
- **Position :** Coordinates of microgrid location.

and Other properties that implement in database automatically and don't display in the form:

- Energy Status: is given by the difference of total supply and total demand.

$$Energy\ status = PG - PD \tag{3.3.1}$$

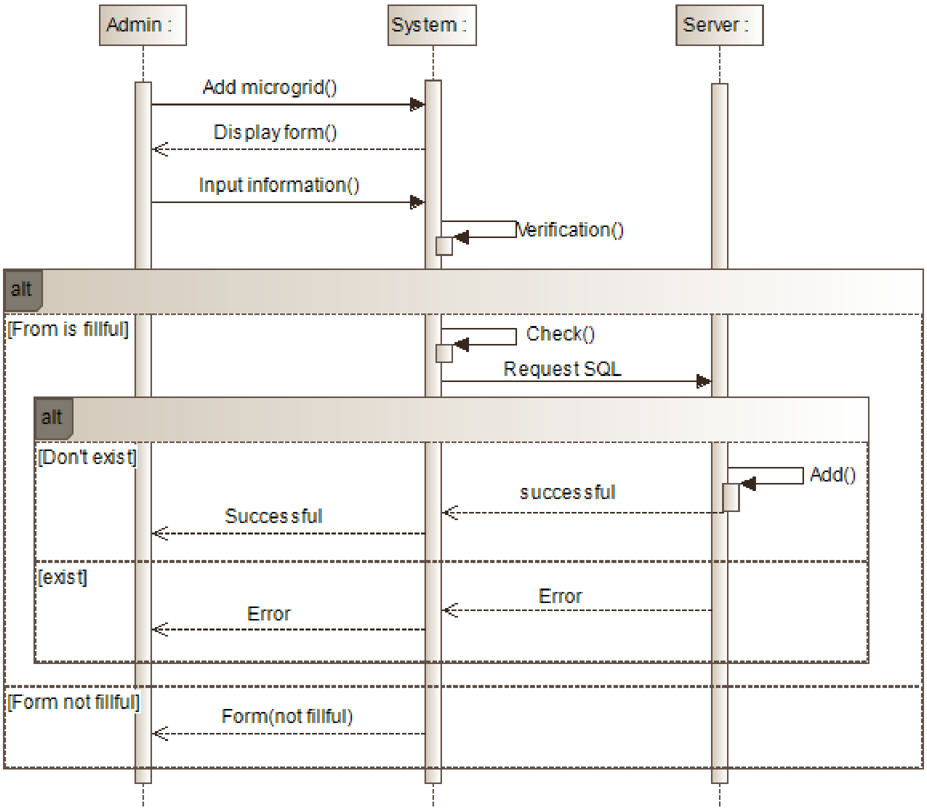


Figure 3.6 – Diagram sequence of add new microgrids.

3.3.2.2 Display microgrids

A graph is displayed that contain the location of each microgrid in our system. A request is sent to the server for recover the data from the database and display it.

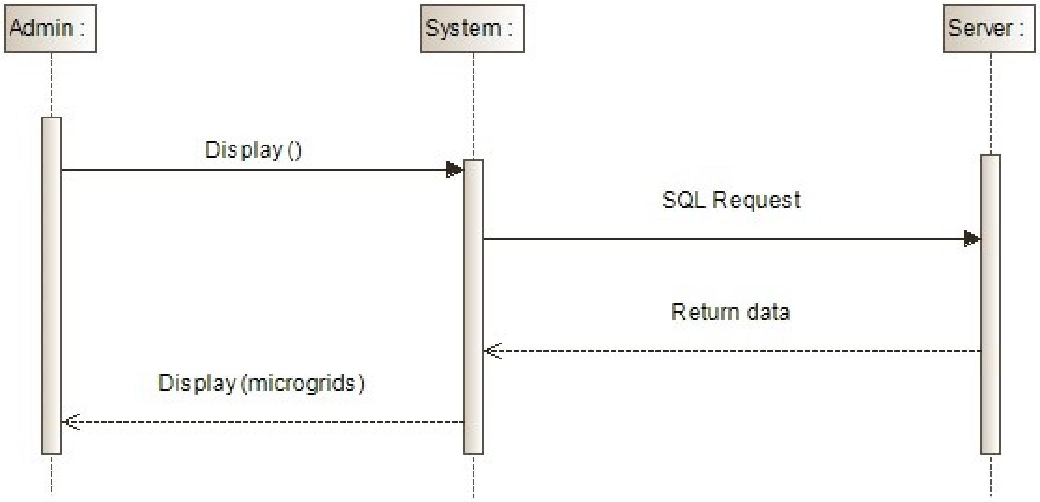


Figure 3.7 – Diagram sequence of display microgrids.

3.3.2.3 Configuration

The administrator can add a new transmission line by input its properities, the system will check if this line is already exist or no before add it in database.

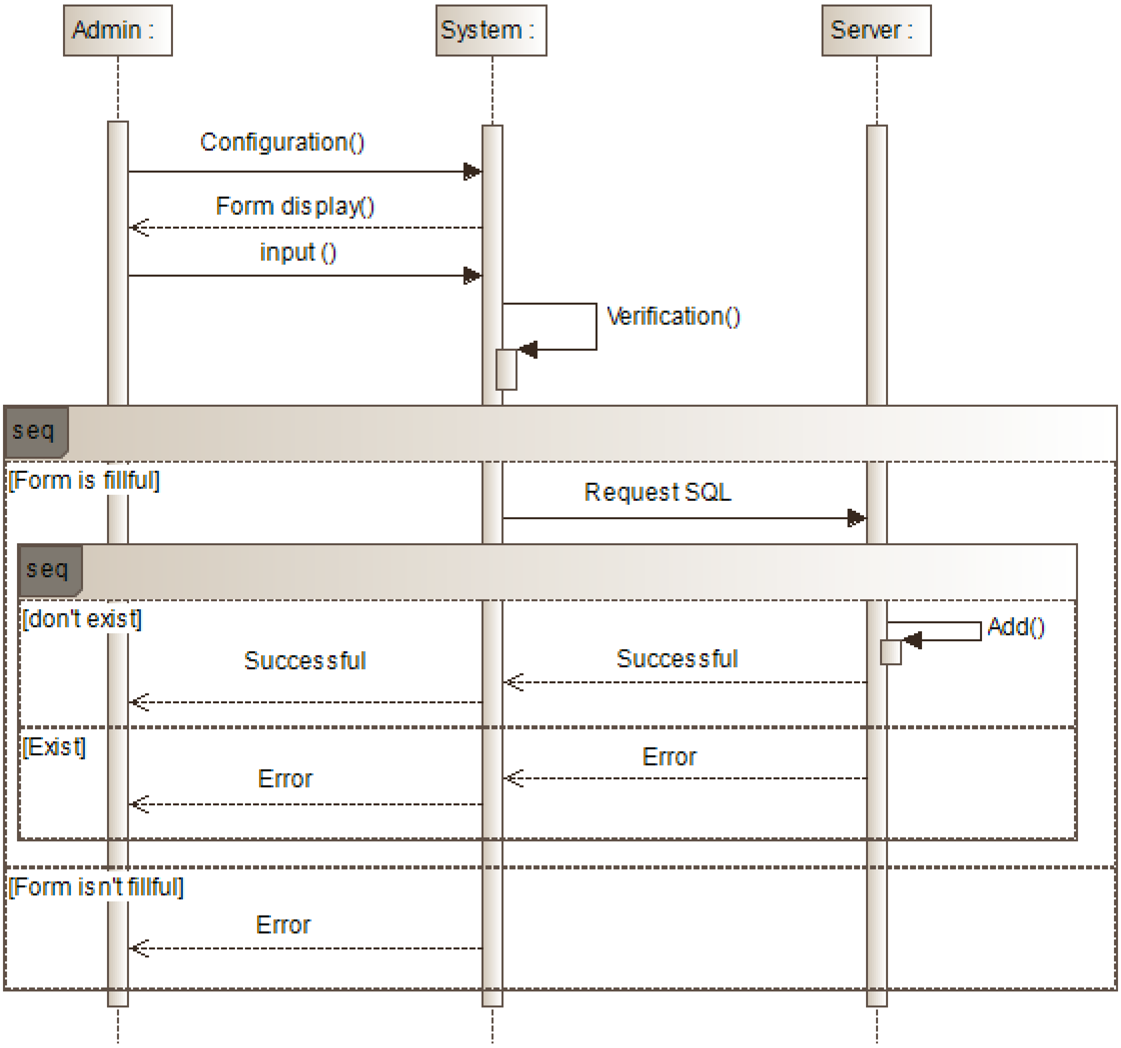


Figure 3.8 – Diagram sequence of configuration.

3.3.2.4 Create coalitions

Create coalition is a process to form the best coalitions structure in order to have an optimal energy management between networked microgrids.

The proposal solution in our energy management software is based on two consecutive steps that are coalition formation and then energy transfer. A coalition formation game is designed to form a stable coalition structure in order to maximize the profits of MGs.

After that, the energy transfer process is executed to exchange energy in each coalition with the objective to minimize power loss.[3]

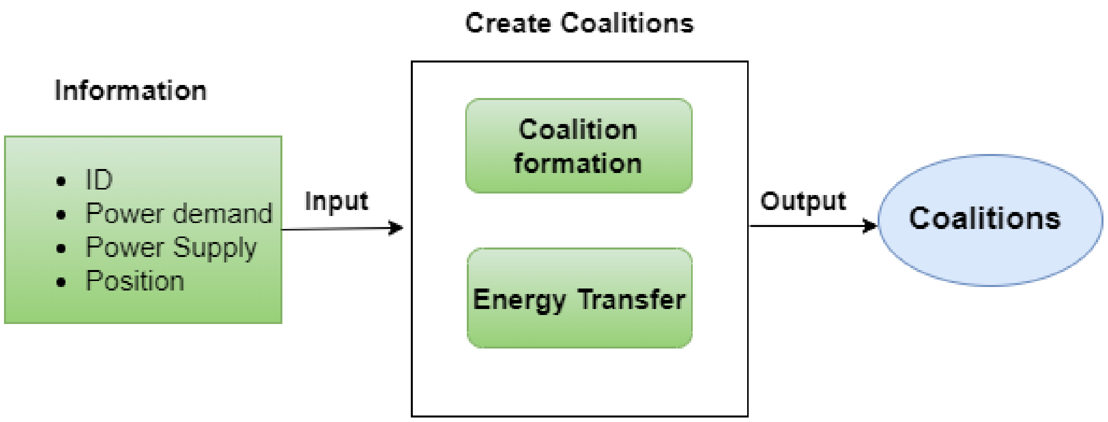


Figure 3.9 – Overview of architecture for create coalition.

— **Coalition formation**

The network is self-organized into coalitions that are formed with merge and split rules as show in diagram below (fig 3.10).

First the merge process starts forming several coalitions until no merge occurs. Then a split process start to search any split occurs in every coalitions, if one or more coalition is splitting, the process of merge and split is repeated until no merge or split occurs. As a result, the final coalition structure is done .

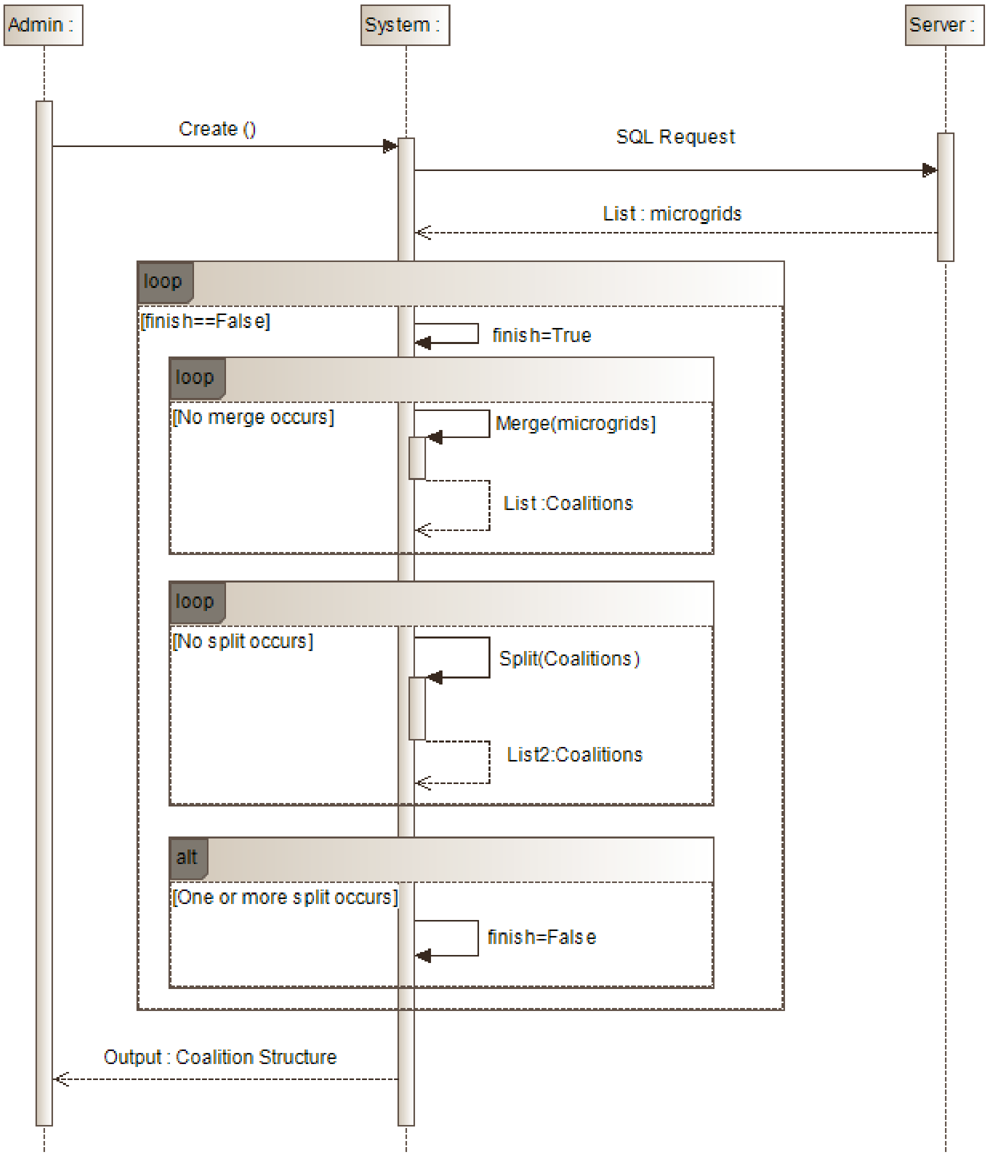


Figure 3.10 – Diagram sequence of Coalition formation.

- **Energy transfer**

  After the coalition formation process, the energy transfer among coalitions members is executed to exchange energy in each coalition with the objective to minimize power loss.

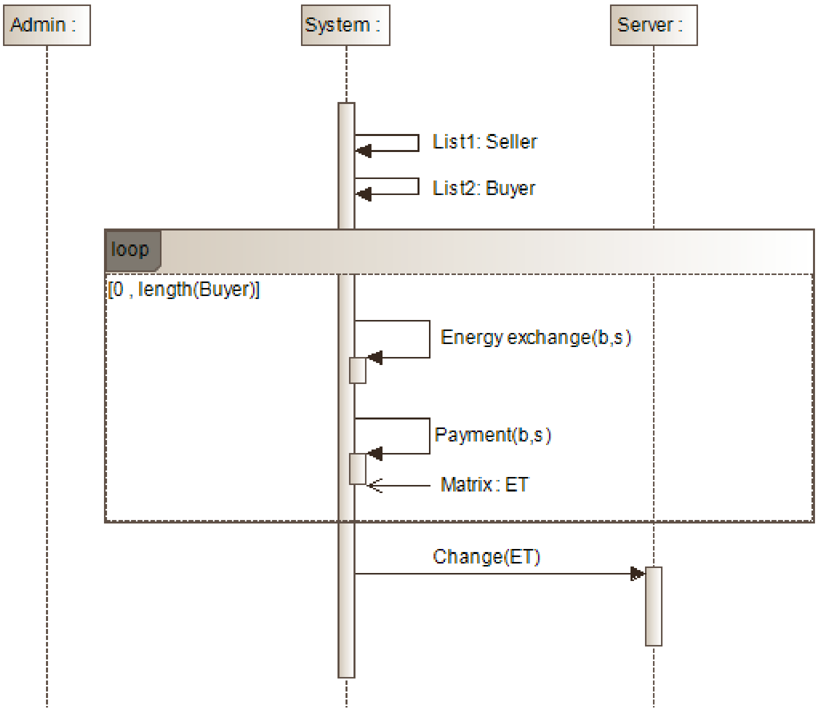


Figure 3.11 – Diagram sequence of Energy .

3.4 Conclusion

In this chapter, a design of our system for energy management in smart grids was presented. Started with a global system architecture and then a detailed architecture for each process with sequence diagrams. In the next chapter,we will see the implementation of our solution and the results obtained.

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 tools

4.2.1 Working environment

All the program are performed on laptop Dell i7-7500U CPU @2.70GHz 2.90GHz Intel(R) Core(TM), RAM: 8.00 Go, Hard disk: 1 To, Operaten System: Windows10 64bit.

4.2.2 PyCharm

is an integrated development environment (IDE) used in computer programming, specifically for the Python programming language. It is developed by the Czech company JetBrains (formerly known as IntelliJ). It provides code analysis, a graphical debugger, an integrated unit tester, integration with version control systems (VCSes), and supports web development with Django as well as data science with Anaconda[32].

Figure 4.1 – PyCharm logo .

4.2.3 WampServer

is a Windows web development environment. It allows you to create web applications with Apache2, PHP and a MySQL database. Alongside, PhpMyAdmin allows you to manage easily your databases[33].

Figure 4.2 – WampServer logo.

4.3 Programming language

4.3.1 Python

Python is an interpreted, object-oriented, high-level programming language with dynamic semantics. Its high-level built in data structures, combined with dynamic typing and dynamic binding, make it very attractive for Rapid Application Development, as well as for use as a scripting or glue language to connect existing components together[34].

Figure 4.3 – Python logo.

4.3.2 MySQL

MySQL is a full-featured relational database management system (RDBMS) that competes with the likes of Oracle DB and Microsoft's SQL Server. MySQL is sponsored by the Swedish company MySQL AB, which is owned by Oracle Corp. However, the MySQL source code is freely available because it was originally developed as freeware. MySQL is written in C and C++ and is compatible with all major operating systems[35].

Figure 4.4 – MySQL logo.

4.4 System interfaces overview

4.4.1 Login interface

The admin login to application using an username and a password. An interface login offers the ability to admin , view main page to fig 4.5 presents is the login page where the admin shall directly login if he already has an account.

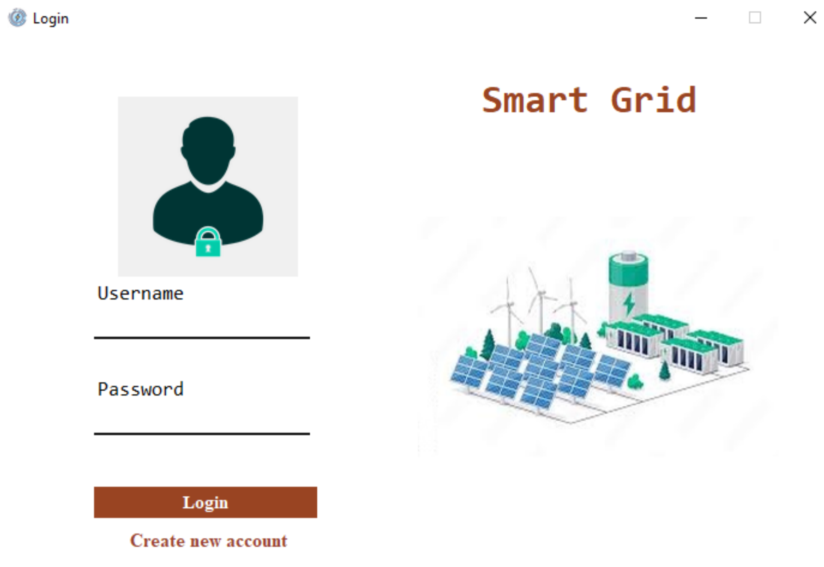


Figure 4.5 – Login interface

4.4.2 Inscription Interface

In this interface (fig 4.6), the admin can sign-up for new account and full his own information then the data send with query information by SQL into the DB by Wamp Server.

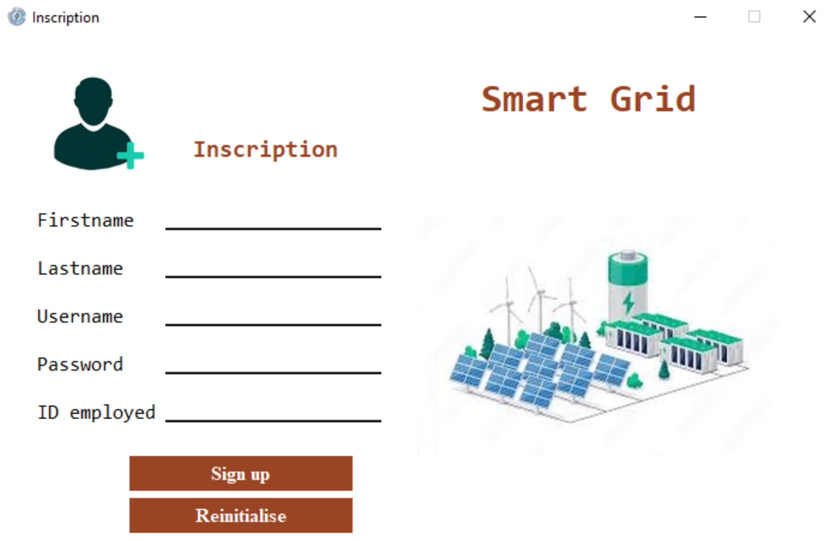


Figure 4.6 – Inscription interface.

4.4.3 Processing interface

Through this interface, the admin selects the task he or she want to do: add new microgrids to system , display microgrids, configure power loss in transmission lines or create coalitions and see the results.

Figure 4.7 – Processing interface.

4.4.3.1 Add new Grid

Through this interface (fig 4.8), admin add new grids to the system by entering their own information.

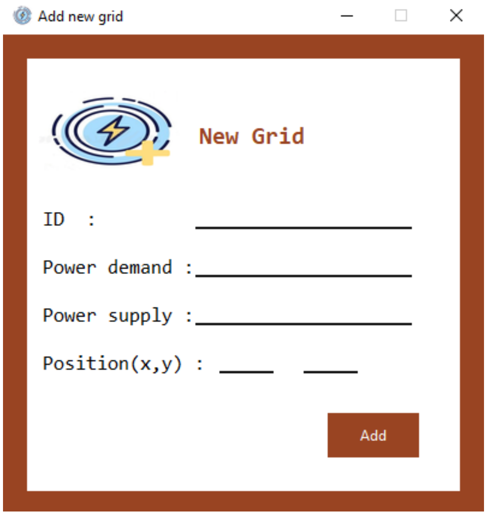


Figure 4.8 – Add new grid interface.

4.4.3.2 Display microgrids

This window (fig 4.9) shows the distribution of microgrids around the distribution system operator (DSO).

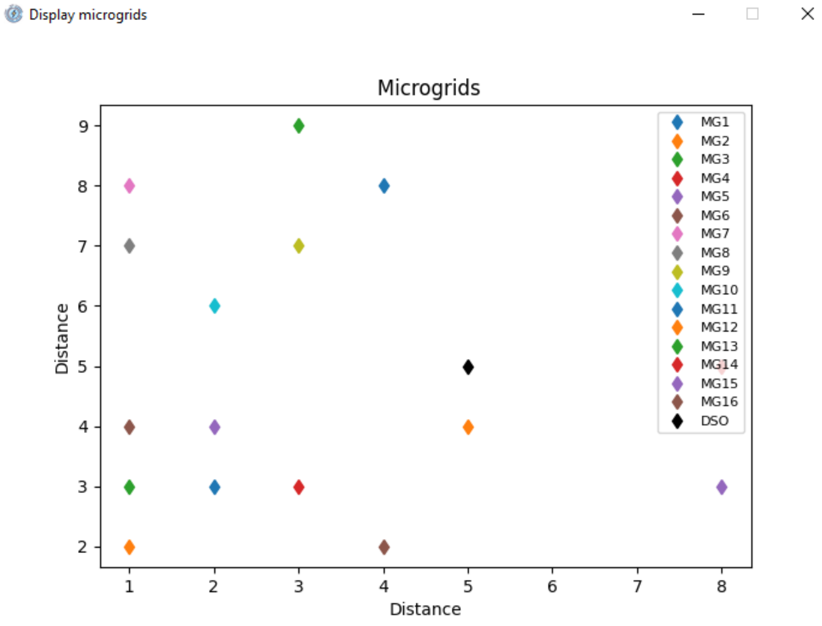
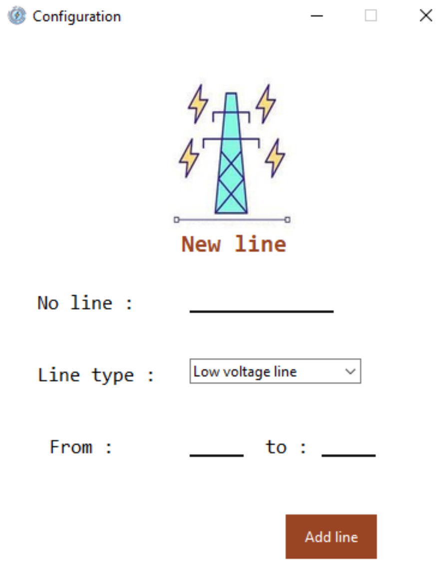


Figure 4.9 – Display microgrids interface.

4.4.3.3 Configuration

Through this interface(fig 4.10), The administrator can add a new transmission line by identifying its type and the two microgrids he links. The types exist in this system is two : low voltage line and medium voltage line.



No line : ____

Line type : Low voltage line

From : ____ to : ____

Figure 4.10 – Configuration interface.

4.4.3.4 Create coalitions

We assume that the microgrids are randomly located around the distribution system operator (DSO) which is located in the center of the network. We have randomly scatter 16 microgrids which is a reasonable number of MGs in real smart grids.

Fig 4.11 shows the coalition structure of the proposed MSCF algorithm which is applied on our case study.

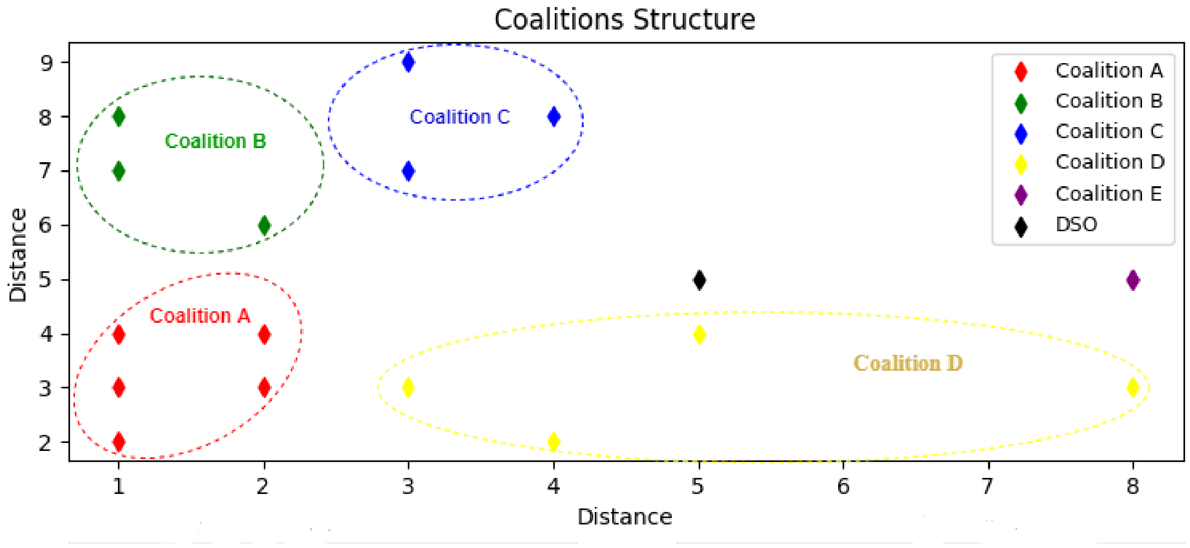


Figure 4.11 – Create coalitions interface.

The proposal solution in our energy management software is based on two algorithm:

- **Algorithm 1**

  Algorithm below presents the proposed merge-and-split coalition formation algorithm (MSCF) [3]

  The first collection Ω_k is initialized with every singleton microgrid Θ_i^j as a coalition $\Xi_j^k \in \Omega_k$. A matrix called visited is used to memorize all pairs of the visited coalitions for merge process. The matrix has the structure of an adjacency matrix. Initially, the visited matrix is set to false for all coalitions, after that, the merge process starts. The collection Ω_k is submitted for merging, i.e., a random pair of coalitions (Ξ_j^k, Ξ_l^k) is chosen from Ω_k to check if $\{\Xi_j^k\} \bigcup \{\Xi_l^k\} \triangleright \{\{\Xi_j^k, \}, \{\Xi_l^k\}\}$ and if the distance between MGs within these two coalitions is less than the specified distance'd' (this means that the merger of these two coalitions should lead to a new coalition where the microgrids in , is in the specific surroundings) $distance(\Xi_j^k, \Xi_l^k) \leq d$, then coalitions Ξ_j^k and Ξ_l^k decide to merge.$\Xi_j^k \bigcup \Xi_l^k$ is saved in Ξ_j^k, and Ξ_l^k is removed from Ωk, then Ξ_j^k enters in the next merge step. So, the visited matrix is updated. Ω_k continues for merging by searching non-visited coalitions. After the test

Algorithm 1 Coalition formation algorithm

```
    Input $\Theta_1^0, \Theta_2^0, ..., \Theta_N^0$
    Output CS $\{coalitionStructure\}$
for $j \leftarrow 1$ to $N$ do
    $\Xi_j^k = \Theta_j^j$ ;
initialization $\Omega_k = \{\Xi_1^k, \Xi_2^k, ..., \Xi_N^j\}$
repeat
    finish=true ;
    forall $\Xi_j^k, \Xi_l^k \in \Omega_k, j \neq l$ do
        visited $[\Xi_j^k][\Xi_l^k] \leftarrow False$
    $\{Mergeprocess\}$
    repeat
        $\Omega_k = Merge(\Omega_k)$ with distance
        update visited matrix
    until (no merge occurs);
    $\{Splitprocess\}$
    repeat
        $\Omega_k = Split(\Omega_k)$
    until (no split occurs);
    if (One or more split occurs) then
        finish=false;
until (finish==true);
CS= $\Omega_k$;
```

of all the combinations, if there is no merge, the merge process ends. The resulted Ωk is then passed to split process. Every coalition $\Xi_j^k \in \Omega_k$ having more than one member, i.e., microgrid, is subject to splitting. The algorithm tries to split Ξ_j^k into two disjoint coalitions Ξ_l^k and Ξ_m^k where $\Xi_l^k \triangleright \Xi_m^k = \Xi_j^k$.

The splitting occurs only if one of the MGs belonging to the coalition can improve its individual payoff, without hurting the payoff of the other MGs. If one or more split occurs, then merge process starts again. Multiple successive merge-and-split processes are repeated until the coalition formation game terminates. The termination criteria is that there are no merge or split to execute for all existing coalitions in Ω_k.[3]

- **Algorithm 2 :**

  Algorithm below was used to find the optimal energy transfer between MGs in the same coalition by transferring energy between the closest MGs in order to minimize the power loss[2]

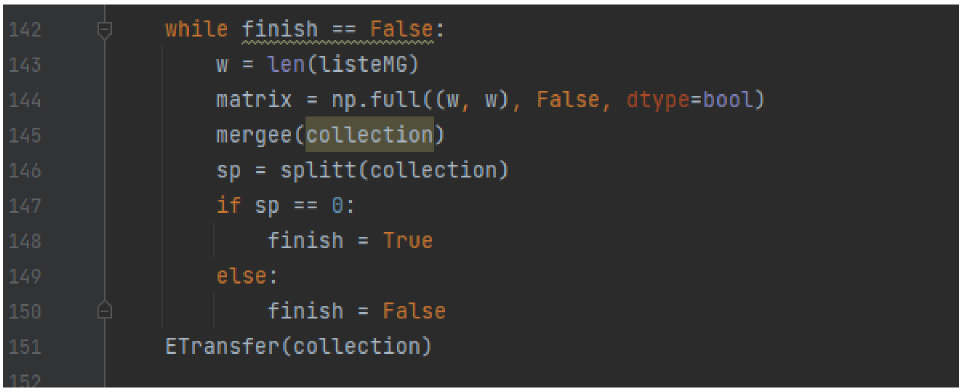
  Initially, for each MG buyer, we search for the nearest MG seller. After

Algorithm 2 Energy Transfer algorithm

```
    Input : Coalition $\Xi_j^k$ , distance matrix dist
    Output : Energy transfer matrix ET
$\Pi$ = set of energy seller within $\Xi_j^k$
$\Psi$ = set of energy buyer within $\Xi_j^k$ in decreasing order;
foreach $\psi \in \Psi$ do
    $\pi = argmin\ dist(\psi, \pi)$
    if $\psi$ is None then
        $ET(0, \psi) = \psi.energy$
        break;
    dif= $\pi.energy- \mid \psi.energy \mid$;
    $\psi.energy- = dif$;
    $\pi.energy- = dif$;
    $ET(\pi, \psi) = dif$;
foreach $\pi \in \Pi$ do
    if $\pi.energy > 0$ then
        $ET(\pi, 0) = \pi.energy$;
```

that, we subtract the given amount of energy from the energy buyer and seller and the energy transfer matrix ET is filled with the energy sellers in rows and with energy buyers in columns and so on until we supply all the MGs that have energy shortage. Finally, if an amount of energy rests, it is saved in ET indexed with energy sellers in rows and zero in columns.[2]

Instruction code :



```
while finish == False:
    w = len(listeMG)
    matrix = np.full((w, w), False, dtype=bool)
    mergee(collection)
    sp = splitt(collection)
    if sp == 0:
        finish = True
    else:
        finish = False
ETransfer(collection)
```

Figure 4.12 – Source code for create coalitions.

4.4.4 The result

For the results, we have two goals to achieve : reduce the energy cost and minimize the power loss.

4.4.4.1 Energy cost

In this situation, we have two cases, number one with coalition formation and number two without them (Fig 4.9).

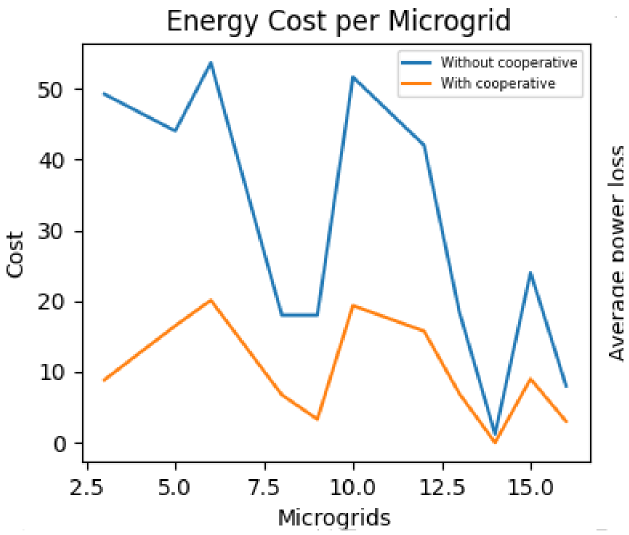


Figure 4.13 – Overall power cost comparison with and without coalitions.

- **Case 1** : When we use cooperative approach to oragnize micro grids, there is a lower cost due to low sale/power purchase price between MGs.
- **Case 2** : When we didn't use cooperative approach, we find a high cost because the energy transfer between MGs and DSO is unprofitable to MGs due to operator policy that imposes disadvantageous energy prices(sell in high prices)

4.4.4.2 Power loss

The most important thing in smart grid energy is power loss. because when you get less power loss it means less energy need and it means less cost.

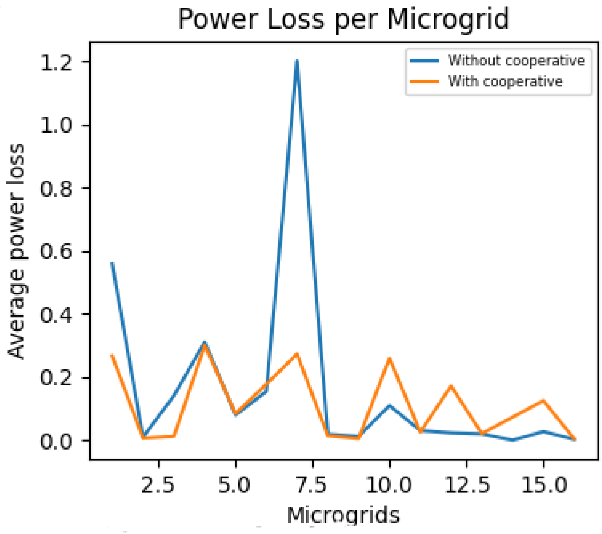


Figure 4.14 – Overall power loss comparison with and without coalitions..

Fig 4.14 shows the average power loss for individual MGs with non cooperative approach as in , and with a cooperative approach.

- **Case 1** : In the non-cooperative approach (with DSO), a high level of power loss is observed due to the long distances between MGs and DSO .
- **Case 2** : A significant decrease in power loss is observed with the cooperative approach . The proposed MSCF algorithm forms many small size coalitions resulting in short distances of power transfer which reduce the power loss compared with traditional approach.

4.5 Conclusion

In this chapter, we discussed the implementation of our solution for optimization of energy management in smart grid and we saw the result obtained .

Conclusion

In order to improve the efficiency and reliability of supply and distribution systems, energy management is necessary. This is accomplished through the use of intelligent algorithms and modern control systems to effectively optimize and schedule load demand.

In this work an efficient cooperative energy management system for networked MGs was designed and developed. This system is beneficial from the economic and technic point of view.

We develop a scalable merge and split based coalition formation (MSCF) algorithm that guarantees network stability with having control over the coalition's environment. Finally, to transfer energy within each coalition, we propose an intra coalition energy transfer (ICET) algorithm. Due to the stability of the coalitions formed by the MSCF algorithm, the ICET algorithm produces the best results in terms of reducing power loss.

The importance of the proposed MSCF algorithm can be seen in the decrease of energy load on the distribution system as well as the reduction of technical loss while maximizing MG gains from energy exchange.

In this work, we have several difficulties passed, because the smart grid is not implemented in our country and this research is one of the latest research in the field of efficient energy management in smart grids.

The SGEM system would help to build a smart grid for the smart nations by providing optimization energy management for networked microgrids and as a perspective, we will develop this work by increasing the number of microgrids in our system and trying to apply it in the real world.

Bibliography

[1] Chun-Hao Lo and Nirwan Ansari. “The progressive smart grid system from both power and communications aspects”. In: *IEEE Communications Surveys & Tutorials* 14.3 (2011), pp. 799–821.

[2] Ilyes Naidji et al. “Two-Stage Game Theoretic Approach for Energy Management in Networked Microgrids”. In: *International Conference on Software Technologies*. Springer. 2019, pp. 205–228.

[3] Ilyes Naidji et al. “Cooperative Energy Management Software for Networked Microgrids.” In: *ICSOFT*. 2019, pp. 428–438.

[4] Astitva Kumar, Mohammad Rizwan, and Uma Nangia. “A hybrid optimization technique for proficient energy management in smart grid environment”. In: *International Journal of Hydrogen Energy* 47.8 (2022), pp. 5564–5576. ISSN: 0360-3199. DOI: `https://doi.org/10.1016/j.ijhydene.2021.11.188`. URL: `https://www.sciencedirect.com/science/article/pii/S0360319921045754`.

[5] Muhammad Haseeb et al. “Multi objective based framework for energy management of smart micro-grid”. In: *IEEE Access* 8 (2020), pp. 220302–220319.

[6] KM Ravi Eswar. “Smart grid-future for electrical systems”. In: *Int. J. Electr. Electron. Res* 3.2 (2015), pp. 603–612.

[7] Rosario Miceli. “Energy Management and Smart Grids”. In: *Energies* 6.4 (2013), pp. 2262–2290. ISSN: 1996-1073.

[8] Muktadir Ahmed et al. “Minimization of power shortage by using renewable (solar) energy through smart grid, perspective: Bangladesh”. In: *2015 3rd International Conference on Green Energy and Technology (ICGET)*. 2015, pp. 1–5.

[9] *SG Technology and Applications, visited at 12/06/2022*. URL: `https://electricalacademia.com/electric-power/smart-grid-technology-applications-smart-grid-components/`.

[10] *Overview of Smart Grid Technology And Its Operation and Application, visited at 12/06/2022*. URL: `https://www.elprocus.com/overview-smart-grid-technology-operation-application-existing-power-system/`.

[11] *Smart Grid Their Application in the Grid System, visited at 12/06/2022*. URL: https://www.electricaltechnology.org/2015/05/what-is-a-smart-grid.html.

[12] Nur Mulyono. “User Behavior Assessment of Household Electric Usage”. In: *The Asian Journal of Technology Management (AJTM)* 6 (Jan. 2013). DOI: 10.12695/ajtm.2013.6.2.1.

[13] Aziz Naamane and NK Msirdi. “Towards a smart grid communication”. In: *Energy Procedia* 83 (2015), pp. 428–433.

[14] *Report to NIST on the Smart Grid Interoperability Standards Roadmap, visited at 12/06/2022*. URL: http://www.nist.gov/smartgrid/upload/Report_to_NIST_August10_2.pdf.

[15] Christian Dänekas et al. “Towards a Model-Driven-Architecture Process for Smart Grid Projects”. In: *Digital Enterprise Design & Management DED&M 2014*. Springer International Publishing, Feb. 2014, pp. 47–58. DOI: 10.1007/978-3-319-04313-5_5. URL: http://link.springer.com/chapter/10.1007/978-3-319-04313-5_5.

[16] Marion Gottschalk et al. “From Integration Profiles to Interoperability Testing for Smart Energy Systems at Connectathon Energy”. In: *Energies* 11.12 (2018). ISSN: 1996-1073. DOI: 10.3390/en11123375. URL: https://www.mdpi.com/1996-1073/11/12/3375.

[17] Dmitry Baimel, Saad Tapuchi, Nina Baimel, et al. “Smart grid communication technologies”. In: *Journal of Power and Energy Engineering* 4.08 (2016), p. 1.

[18] Spiros Livieratos, Vasiliki-Emmanouela Vogiatzaki, and Panayotis G Cottis. “A generic framework for the evaluation of the benefits expected from the smart grid”. In: *Energies* 6.2 (2013), pp. 988–1008.

[19] V Jayalakshmi. “Course Number and Name”. In: *IEEE Transactions On Industrial Informatics* 7.4 (2011).

[20] *Energy Management in Smart Grid, visited at 06/06/2022*. URL: https://smartgrid.ieee.org/bulletins/august-2019/energy-management-in-smart-grid.

[21] Joelle Klaimi et al. “Energy management algorithms in smart grids: state of the art and emerging trends”. In: *International Journal of Artificial Intelligence and Applications (IJAIA)* 7.4 (2016), pp. 25–45.

[22] Gilbert M Masters. *Renewable and efficient electric power systems*. John Wiley & Sons, 2013.

[23] BS Hartono, Sri Paryanto Mursid, and Sapto Prajogo. “Review: Home energy management system in a Smart Grid scheme to improve reliability of power systems”. In: *IOP Conference Series: Earth and Environmental Science* 105 (Jan. 2018), p. 012081. DOI: 10.1088/1755-1315/105/1/012081.

[24] David Kathan et al. "National action plan on demand response". In: *The Federal Energy Regulatory Commission Staff, Federal Energy Regulatory Commission, Washington, DC, Tech. Rep. AD09-10* (2010).

[25] Fady Y Melhem. "Optimization methods and energy management in" smart grids"". PhD thesis. Université Bourgogne Franche-Comté, 2018.

[26] Yashar Ghiassi-Farrokhfal, Srinivasan Keshav, and Catherine Rosenberg. "Toward a realistic performance analysis of storage systems in smart grids". In: *IEEE Transactions on Smart Grid* 6.1 (2014), pp. 402–410.

[27] Yuanxiong Guo, Miao Pan, and Yuguang Fang. "Optimal Power Management of Residential Customers in the Smart Grid". In: *IEEE Transactions on Parallel and Distributed Systems* 23.9 (2012), pp. 1593–1606. DOI: `10.1109/TPDS.2012.25`.

[28] Meryem Meliani et al. "Energy management in the smart grid: State-of-the-art and future trends". In: *International Journal of Engineering Business Management* 13 (2021), p. 18479790211032920.

[29] J Wasilewski. "Optimisation of multicarrier microgrid layout using selected metaheuristics". In: *International Journal of Electrical Power & Energy Systems* 99 (2018), pp. 246–260.

[30] Jordan Radosavljević, Miroljub Jevtić, and Dardan Klimenta. "Energy and operation management of a microgrid using particle swarm optimization". In: *Engineering Optimization* 48.5 (2016), pp. 811–830.

[31] Tiago Sousa et al. "Intelligent energy resource management considering vehicle-to-grid: A simulated annealing approach". In: *IEEE Transactions on Smart Grid* 3.1 (2011), pp. 535–542.

[32] *PyCharm, visited at 06/06/2022*. URL: `https://en.wikipedia.org/wiki/PyCharm`.

[33] *WampServer, visited at 06/06/2022*. URL: `https://www.wampserver.com/en/`.

[34] *Python, visited at 06/06/2022*. URL: `https://www.python.org/doc/essays/blurb/`.

[35] *MySQL, visited at 06/06/2022*. URL: `https://www.techopedia.com/definition/3498/mysql`.