INSTITUTO POLITÉCNICO DE BRAGANÇA
Escola Superior de Tecnologia e Gestão

Design and Development of an Electronic Card for Hybrid Systems

Ali Berrachedi

Thesis presented in the School of Technology and Management of the Polytechnic Institute of Bragança to fulfill the requirements of a Master in Renewable Energies and Energy Efficiency.

Supervised by
Prof. Dr. José Luis de Sousa Magalhães Lima

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May they find here all my gratitude and love.

Abstract

The development of multi sources systems for the production of energy is more and more considered and the interest in it increases day after day. These systems may ensure the production of energy needed and reduce the cost of energy production while taking into account the environment and reducing emissions.

The aim of this thesis is the study of multi sources systems with the design and development of a multi-source cell selection system to control various sources of renewable and non-renewable energy, Due to the different characteristics of each energy source, the best solution remains to rely on all these sources at the same time.

We proposed to use an Arduino mega board with an electronic card, which we will show the stages of its development, that manages the power transfer to the load according to the required energy.

Keywords: hybrid system, multi-source system, power management, supervision system

Resumo

O desenvolvimento de sistemas de fontes múltiplas para a produção de energia é cada vez mais considerado e o seu interesse aumenta dia após dia. Estes sistemas podem garantir a produção de energia necessária e reduzir o seu custo, levando em consideração o meio ambiente e reduzindo as emissões.

O objetivo desta tese consiste no estudo de sistemas de fontes múltiplas com a concepção e desenvolvimento de um sistema de seleção e controlo de várias fontes de energia renováveis e não renováveis. Devido às diferentes características de cada fonte de energia, a melhor solução será selecionada de todas essas fontes simultâneamente.

É proposto usar um Arduino mega e uma placa de circuito impresso, onde serão mostradas as etapas de seu desenvolvimento, que gere a transferência de potência para a carga de acordo com a energia necessária.

Palavras-chave: sistema híbrido, sistema de múltiplas fontes, gerenciamento de energia, sistema de supervisão.

ملخص :

يتم النظر أكثر فأكثر في تطوير أنظمة متعددة المصادر لإنتاج الطاقة ويزداد الاهتمام بها يومًا بعد يوم. قد تضمن هذه الأنظمة إنتاج الطاقة اللازمة وتقليل تكلفة إنتاج الطاقة مع مراعاة البيئة وتقليل الانبعاثات.

هذه الأطروحة مخصصة لدراسة نظام لإنتاج الطاقة الكهربائية يعتمد على مزيج من أنواع مختلفة من مصادر الطاقة المتجددة والتقليدية (نظام متعدد المصادر/ الانضمة الهجينة).

كما قدمنا مكونات نظام متعددالمصادر وكذلك طرق مراقبة وإدارة الطاقة.

أيضا قمنا بتقديم نماذج و تكوين أنظمة متعددة المصادر (الطاقة الضوئية ، توربينات الرياح ، الديزل...) وأنواع التهجين المختلفة.

أخيرًا يتم تقديم بطاقة تحكم منخفضة الطاقة مع شرح مبدأ التشغيل والغرض.

الكلمات المفتاحية :

أنظمة متعددة المصادر ، أنظمة الطاقة الهجينة ، إدارة الطاقة ، أنظمة الإشراف

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Abbreviations

- MPPT: Maximum Power Point Tracking
- HS: Hybrid system
- AC: Alternating current
- FPGA: Field Programmable Gate Array
- DC: Direct current
- PV: Photovoltaic system
- WSN: Wireless Sensor Network
- P2G: Power to gas
- ED: Economic Dispatch
- LFC: Load-Frequency Control
- AGC: Automatic Generation Control
- PID: Proportional Integral Derived
- MPC: Model Predictive Control
- GPS: Global Postionning System
- PCB: Printed Circuit Board
- VCC: Voltage at the Common Collector.
- GND: Ground

Chapter 1

Introduction

The arrival of the various technologies of electrical generation is in the process of favoring a profound change of the current electrical networks in the next years[1]. The figure 1.1 presents the integration of new modes of electricity production in electricity grids. Several types of actors have to interact within an electrical network. Indeed, the producers ensure the production of the electric power thanks to power stations of electricity production. When these plants are thermal or nuclear using fossil fuels (coal, fuel, gas), they are non-renewable sources of power in the sense that the consumption of these energies is faster than their natural renewal. However, when these plants are hydroelectric, solar, wind, these sources are considered renewable [2].

Figure 1.1: Integration of new electricity generation methods in electricity grids (source: Institute for Energy and Transport).

The major problem facing electricity producers is storage [3]. It is necessary to ensure at each moment of network balancing, in other words to ensure that the production is equal to the consumption. If the gap between production and consumption increases too much, the network suffers from frequency and voltage disturbances [4]. The consequences can go as far as disconnecting certain branches of the network. Developments in electricity supply and demand have made their adjustment much more complex. The figure 1.2 illustrates this mismatch of wind supply (in blue) and demand (in pink) measured at a source station.

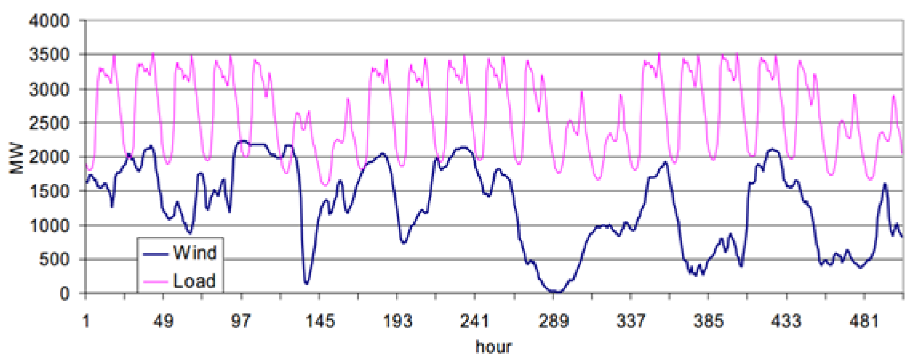


Figure 1.2: Comparison between wind supply and demand : Institute for Energy and Transport (RTE)

The massive insertion of renewable energies in electricity grids is not easy. In order to facilitate their integration, it is essential to have flexible sources capable of reducing the gap between supply and demand. Thus, the interconnection of small, independent productions and very different technologies presents a vast field of research: control / command, power electronics, optimal point tracking (MPPT), fault tolerance, frequency adjustment , etc. The problem of power management is one of those research and development themes that can be decisive in order to technically and economically favor these new modes of generating power. Among these different sources of energy, we can mention wind energy, photovoltaic solar energy [5]. Because of the variability of these resources, or even their unavailability, it is interesting, to improve the continuity of the power supply, to associate them with storage sources and / or conventional sources (diesel, etc ...) or emerging (micro-gas turbine, etc...). The establishment of a supervisor who coordinates all these sources is necessary to ensure the proper functioning of the multi-source system. In order to study the behavior of these production systems, models based on the fundamental laws of physics must be developed. It is interesting to use these models as a basis for optimizing power management. In addition, one of the issues hindering the massive integration of renewable resources in networks is their randomness and limited predictability [6].

Innovative management methodologies that consider all these aspects are necessary. Many operators still consider renewable resources as negative charges, explicitly the renewable power is considered a disturbance that will add to the load, which is quite acceptable in the case of low penetration of these renewable resources[7].

1.1 Motivation and Objectives

In the twentieth century, the world population was multiplied by four: there were 1.6 billion people on Earth in 1900 and 6 billion in the year 2000. During that time, energy consumption was multiplied by twenty. Today, however, the energy needs of humanity are largely covered by fossil fuels (80%), which are polluting in nature. Around the world, the unstable situation of fossil fuel markets and the need to protect the environment and reduce greenhouse gas emissions call for a review of energy strategies. To this end, renewable energies (energies that are renewed at a proportion (rate) greater than that to which humans consume) have essential assets to take first place in the energy packages of countries. Thus, they reduce the dependence on fossil fuels and thus minimize the harmful effects of global warming. They are therefore an answer that is particularly adapted to the considerable energy needs of emerging countries, which today provide the bulk of global growth, enabling them to develop their natural resources, hydraulic power, sunshine, wind, biomass, etc. , to bring production sites closer to consumption centers and to reduce the dependence of these countries on fossil fuels. However, renewable energies also have their disadvantages. They are known to be less competitive than traditional production systems, mainly because of their relatively high costs. In addition, the random and discontinuous nature of renewable energies makes them difficult to control and it is necessary to characterize as precisely as possible the variations of these resources. The variable and unsecured power produced by these sources of energy can be solved by coupling supply sources and forming a so-called hybrid system (HS) or multi-source system [8]. This end-of-study project brief is precisely part of this vision by dealing with a simple case of combining several sources of renewable energy (solar panels and wind) and other non-renewable sources . Technically speaking, the present work has been crowned the development of a selection system of a multi-source low power cell and how we can ensure the continues feed of the load.

I started researching multi-source and hybrid systems almost two years ago when I was in the Higher School in Applied Sciences of Tlemcen, Algeria. I graduated in 2019, and it was the same field of research that I continue to work on to this day[9]. During my study in Portugal, I developed my research, and I reached solutions and came up with results for several points that I did not address before. As represented in the following :

1. Expanded research and access to recently published study on multi-source systems
2. Improved Knowledge and get a clear idea about supervising and managing multi-source systems
3. Development of an algorithm and a program on Arduino based on multi-source systems management rules
4. Development of the electronic circuit and making adjustments
5. Changing the operating system from the AC mode to the DC mode due to the obstacles encountered with the principle of operating with AC mode and the failure to reach the correct results
6. Wrote research in English, which was previously in French.
7. After several attempts, I reached the right results and values through the simulation.

1.2 Plan of thesis

This thesis is organized as follows:

- Chapter 1: Introduction
  - Considered as an introduction to multi-source systems, motivations and the objective of this work.
- Chapter 2: State of the art
  - Is devoted to the state of the art of multi-source systems.
- Chapter 3: Power Management and supervision in Hybrid Systems
  - In this chapter we presented the different methods of supervision and power management.
- Chapter 4: Design and Development
  - Aims to present the operating principle and assembly objectives of our multi-source cell selection system.
  - Presentation of the results obtained through simulation with the observation and discussion of the main important results obtained.
- Chapter 5: Conclusion and future work
  - Presents the conclusions and the recommendations for future works.

Chapter 2

State of the art

This work aims to study the management and combining of energy sources with their different characteristics to reach a system that combines these sources so that we can insure the energy availability all the time with the lowest cost while taking into account the preservation of the environment.

It started with a paper on the same topic that was a thesis presented in the Higher School in Applied Sciences of Tlemcen, Algeria. The idea of designing a multi-source cell selection system was initiated, and this paper adopted the AC mode as the operating system [9].

Also, many kinds of research are done in this field. Starting with a paper published in July 2017, which is an application of a hybrid power generation system using three different sources of energies from photovoltaic panels, batteries and generators with storage management and distribution of energy to the receivers to optimize the power of the battery and the operating time of the generator. To reach this optimization, they proposed using an FPGA card that controls and manages the power produced to transfer it to the receivers according to the need for energy, with maximum use of photovoltaic energy and minimizing the amount of fuel source relief and the air pollution emissions.

Another research are made in this field where they proposed,in urban areas, a semi-isolated and safety system for self-feeding of buildings equipped with renewable electricity, using a multi-source system (photovoltaic panels, storage, and public grid) [11]. The

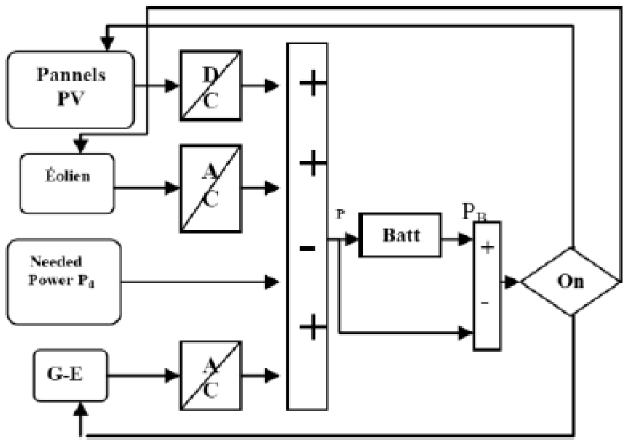


Figure 2.1: Management of battery power to a multi-source system[10].

results focus on the redefinition of the electrical network for buildings equipped with renewable sources, with the proposal of a semi-isolated grid with taking in consideration the available storage level and taking into account the public grid connection, as illustrated on the Fig.2.2 and 2.3. The results achieved confirm the relevance of such network in urban areas with integration and optimization of energy management of the building.

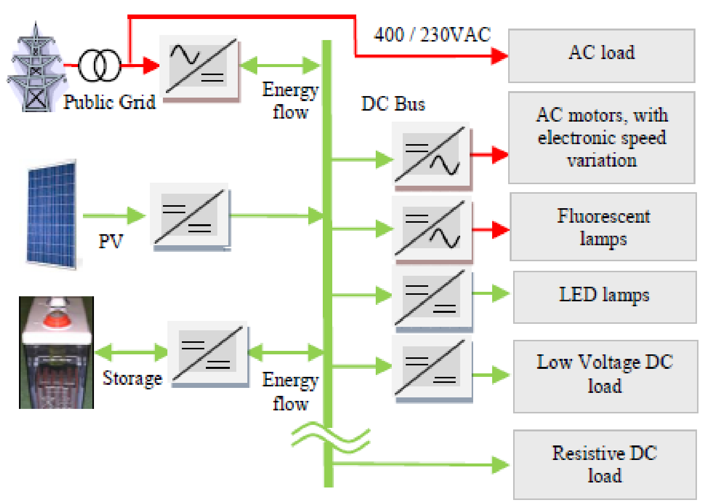


Figure 2.2: DC semi-isolated and safety electrical network [11]

Also another article published in this topic concerns the modeling and control of an

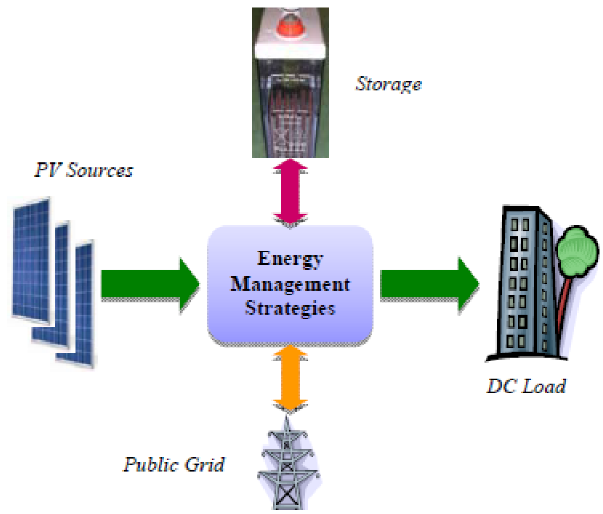


Figure 2.3: Multi-source power generation system [11]

hybrid system consisting of one renewable energy source, photovoltaic which is fed an isolated load.The system supplies a telecommunications relay, almost constant consumption a voltage of 48v and consists in Study dimensioning and optimization of an hybrid system photovoltaic/generator: application to a telecommunications site and other related equipment with the whole of the elements of the necessary conversion to this system [12].

Another article published on February 2019 Multisource Energy Harvesting System for a Wireless Sensor Network (WSN) Node in the Field Environment, they presented the design, implementation, and characterization of a hardware platform applicable to self-powered WSN nodes. According to the application environment, they designed a multisource energy harvesting system, including wind, solar, and thermal energy harvesters, which could make full use of the energy from the surrounding environment. Using appropriate WSN hardware infrastructure interfaces, the platform could continuously supply power to the node over a long period of time with an average daily power output far more than the daily power consumption of the node when it operates normally [13]

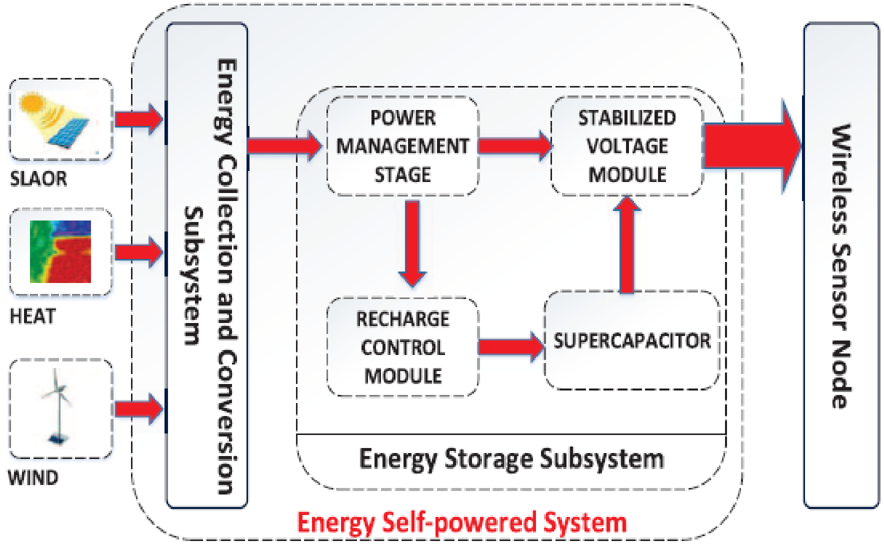


Figure 2.4: Block architecture of the self-powered WSN node system. [13]

2.1 State of the art of supervision techniques for multi-source systems

In recent years, energy management has been the subject of numerous publications, particularly in the field of multi-source systems [14]. Its purpose is to generate the references of the various control loops so as to respect the objectives of the specifications and to check all the constraints. In order to find an optimal solution, prior knowledge of the profile of the load and possibly renewable resources is required. The constraints imposed by the sizing of the system elements must be respected and additional attention must be paid to the state of charge and the solicitation of the storage elements, if they are part of the hybrid system. The major challenge of this objective is notably that the power demanded by the load on renewable resources cannot be known in advance. So the supervisor must respond to an instantaneous request for power without prior knowledge of the future profile of the demand for power.

2.2 Composition of a multi-source power station

Transmission and distribution networks are starting to open up to independent producers, which are cheaper and more efficient. An hybrid system includes all the power supplies provided by the coupling of two (or more) sources of different natures. Hybridization of sources can reduce the use of the power source, or provide additional power. The storage elements facilitate the development of this hybridization and their design. Hybridization thus allows [15]:

1. to minimize disturbances and smooth the power
2. to increase reliability
3. reduce storage size
4. to reduce production costs.

These are the reasons why electrical systems are more and more often supplied by a main source of energy (photovoltaic panels, wind turbines, generators, etc.) hybridized by one or more auxiliary sources [16][17][18][19]. This is particularly the case for systems that are partly or totally autonomous with respect to the distribution network. We are talking about a multi-source system. On the other hand, the main drawbacks of such a system is the complexity, the difficult choice of its subsystems and the difficulty in managing the level of power. In order to mitigate the randomness of a given renewable energy field (wind, solar), an hybrid combination of two or more different technologies with a storage system or conventional generation units can improve the performance of the system. For example, photovoltaic panels and wind turbines are complementary for a given area (site windy in winter, and sunny in summer). In general, multi-source systems transform all primary sources (fuel, wind, solar radiation) into a single form of energy (electrical) and / or store this energy in another form (chemical, compressed air, inertia, etc...). In order to increase the reliability of multi-source systems, the choice of technology and sizing are two essential factors that improve the overall performance [20]. Thus, their sizing must improve performance, while limiting the number of elements. Also, their management must have a control of their internal operating state as the state of charge to ensure not to degrade their life and avoid any accident. We then find ourselves in a specific case where the management of the power and the dimensioning are closely related and must be treated jointly. As mentioned in the introduction, the need to protect the environment and reduce dependence on fossil fuels has led many countries to change their policies regarding electricity generation. The maturation of several new technologies will promote this change. These technologies include the production of electricity from renewable energies, such as wind, photovoltaics, biomass, geothermal energy, ocean waves and tides, as well as clean sources, that is to say which has less impact on the environment compared to conventional sources of energy production. Examples include gas micro-turbines and fuel cells. They can be considered renewable if the fuel itself is renewable (case of the micro-turbine) where hydrogen is produced from a renewable source (case of the fuel cell). Although polluting, diesel units are still widely used, even for relatively high-power ranges, particularly in remote areas and autonomous systems. Diesel units are cheap and have a relatively good performance and can have a less harmful impact on the environment if they are fueled by a bio-fuel. From an economic point of view, the hybridization of the sources makes it possible to satisfy a local load without being constrained to construct new lines of electricity transmission [21]. The elements of the hybrid system can be installed in a very short time, in any place. However, some renewable sources that may be part of the hybrid system such as solar panels and wind turbines may require certain conditions (well-ventilated site, sunshine, etc...). In isolated autonomous systems, hybrid systems can be more economical. Hybridizing the sources can have a positive impact on the life of the elements that constitute it and reduce the consumption of fuel or any other fuel. From an operational point of view, several studies have shown the beneficial effects of multi-source systems on the voltage profile and the power quality problems [22] [23].

2.3 Different elements of a multi-source power plant

Multi-source energy systems depend on combining several sources of energy of different nature, traditional and renewable, to achieve continuous energy supply to feed the load and meet the needs of the consumer. Multi-source energy systems contain of several elements.

In the followings, we will list the most common elements component of multi-source systems.

- **Traditional Combustion Generators (Micro-Turbine)**

  Micro-turbines can run on natural gas, propane or fuel. They consist of a compressor, a combustion chamber, a turbine and a generator. micro-turbines operate at lower temperatures and pressures and run at very high speeds (typically between 40,000 rev/min and 120,000 rev/min). They can be installed easily, have a good overall yield (85%), and very low pollutant emissions, especially nitrogen oxide. In addition, the micro-turbines are known for their fast dynamics and have very good performance regarding the continuation of the charge. The heat produced can be used to meet the heating needs. Gas micro-turbines produce gases of very high temperature and pressure. This gas is used to rotate the axis of the micro-turbine that drives the compressor and the alternator[24].

- **Storage elements**

  Stationary energy storage technologies are divided into many categories [25]:

  1. Mechanical energy (potential or kinetic): gravity storage by pumping,
  2. Compressed air storage, flywheels;
  3. Electrochemical and electrostatic energies: batteries, capacitors, superconductors;

4. Electromagnetic (Supercapacitors, Superconductors)
5. hermal and thermochemical energy: sensible or heat, absorption energy;
6. Chemical energy: hydrogen, methanation, P2G etc.

- **Renewable generators**

The unavoidable depletion of fossil resources, combined with a desire to reduce the rate of global warming, naturally leads to the introduction of a diversification of electricity production based on renewable energy generators, alongside diesel generators up to present only used in micro networks. Compared to the centralized production units (nuclear power plant, ...), the renewable energy generators are of very small powers because of the sizing of the primary conversion system (surface of the photovoltaic panels (PV), length of the blades, ...). On the other hand, this dimensioning favors the installations on a distribution network at the private individuals and thus in very large numbers. The growth of these renewable sectors should remain very strong and thus continue to increase their share of global electricity production. In the first place, these technologies have made tremendous progress, whether in terms of reliability, or in terms of their ability to reduce their production costs. This progress has attracted new investors interested in development prospects. These have made it possible to increase the size of renewable energy projects and thus to increase very quickly the producible of these sectors. The most popular renewable energy sources currently are [26]:

1. Solar energy,
2. Wind energy,
3. Hydro energy,
4. Tidal energy,
5. Geothermal energy,
6. Biomass energy,

Chapter 3

Power Management and supervision in Hybrid systems

Renewable energies pose management problems for power system operators because of their random and intermittent nature. The problem worsens even more when the level of penetration of renewable energies is important on the electricity grid. Renewable energy production units must meet a certain number of technical constraints related to the operation of electrical systems to be connected to the grid. Some constraints will be redefined taking into account the specificities related to renewable energy. For this, one solution is to use at the same time other means of energy production (excluding renewable energies) with a major problem of optimal energy management.Currently, the network operator has tools to forecast the demand for electrical energy, and other tools are being developed to forecast the production of renewable energy and tools for predicting wind and photovoltaic productions[27][28]. In the long term, the forecast of electricity production could be a decision-making tool for producers and the grid operator, whether in the case of island systems or in the general case of wholesale electricity markets. For small island networks, intermittent generation prediction will be coupled with storage systems. In addition, a reduction in intermittency and variability of production can be ensured by a multiplication of distant sources, a process called geographical expansion. Thus, the storage, the proliferation and the prediction of intermittent energies should allow a better integration of renewable energies in the electrical networks. Their forecast will predict the energy reserves that will take over to preserve the security of the system[15].

3.1 Multi-level supervision of multi-source power plants

The subdivision of supervision into several levels is mainly due to three elements[28]:

1. the existence of strong uncertainties,
2. the characteristics of the means of production,
3. the constraints of the operation of the network,

Closest to real-time control is needed as forecasts are less uncertain. In addition, the technical constraints of production plants do not allow to respond quickly to demand, hence the need to predict variables, with a longer or shorter horizon, depending on the dynamics of the power plant. These characteristics of the means of production (nuclear power plant, thermal ...) oblige the actors of the network to solve optimization calculations, over a long enough period in order to take into account the necessary dynamics. Finally, the constraints imposed by the network manager must be respected in real time. The major problem for all players in the electricity system and more particularly the operator is to maintain the balance between supply and demand. To meet this objective, four types of actions are carried out at different horizons: Level 3 (years), Level 2 (1 day to several days), Level 1 (10 to 15 minutes), Level 0 (very close to real time)[15][28]. Although these levels are interdependent, their separation is mainly done in order to reduce the computation efforts of the problem. It should be noted that the problem of optimally coordinating the means for adjusting a network to ensure a steady state quality criterion is often referred to as optimal power flow distribution [29]. It is an optimization process, centered around an objective function to minimize. The optimal power flow is based on a load distribution calculation, to know the electrical state of the network, by the balance between production and consumption at near losses and at a lower cost. Figure 3.1

shows the operations taking place according to the prediction horizon. The details of the operations performed in each level are described below.

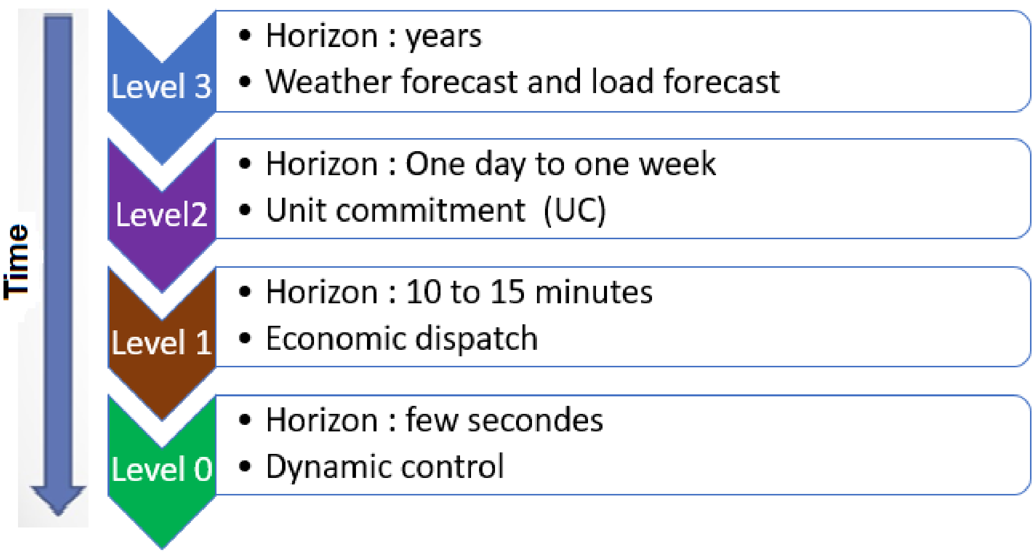


Figure 3.1: Energy management of a hybrid system, on several levels according to the scale of time.

3.2 Level 3: Long-term supervision (horizon: one year to several years)

This level concerns long-term or even very long-term horizons. The very long-term forecasts make it possible to know the investments to be made in the means of production and transport. It is therefore a question of planning in order to highlight the investment needs of the electricity production-transport system. In the case of a multi-source cell, multi-year supervision foresees the production of each element according to annual demand cycles and maintenance programs [30] .

3.3 level 2: Mid-term supervision (horizon: 1 day to a week)

For a close horizon, from the day before, for example, it is necessary to provide first of all the dates of commissioning of the structures, then the fuel requirements, the consignments of the maintenance work and the load plan. for groups. All these operations are based on forecasts of consumption and possibly of renewable production, refined as we get closer to the given day. The control system, aimed at optimizing the operation of the micro-network from the technical, economic or ecological point of view, is exercised at the higher level, on the basis of the information available (state of the network, availability of the generators, consumption forecasts, tariffs in force, etc.) and determines the program of generation of the next hours[30].

3.4 level 1: Short-term supervision (Horizon: 10 to 15 minutes)

When approaching real time, forecasts of loads and resources are updated and medium-term supervision (level 2) will provide the reference powers to the constituent elements of the multi-source system, while maximizing and decreasing the fluctuation of the power supplied to the network. At this level, the fast dynamic production means (examples: battery, flywheel, etc.) are used because they are very quickly exploitable. The name usually given to this problem is: Economic Dispatch Problem (ED Problem) or economic dispatching problem. The basic objective of an economic dispatching (ED) is the generation and operation at minimum cost of electrical energy in a network by satisfying all the demand with the constraints of equality and inequality of the system. One of the limitations of economic dispatching is the static aspect of the problem. Indeed, when we solve an economic dispatching, we do it for a request at a specific time. When the problem takes a dynamic dimension, that is to say when the demand evolves in a given time interval (a day for example), it is then necessary to take into account the states of the power stations as well as the changes of state which cause additional costs [30] [31].

3.5 Level 0: very close to real time

The lower level control (level 0) is the local control of voltage and current of each generator (via a power converter, or not). These controllers realize at any time the regulation, in order to generate the active and reactive powers desired. These local controllers provide the power of reference with some dynamics. There is another problem of power management in power grids which concerns the deviation of the frequency. In other words, the multi-source cell is connected to a network powerful enough to impose its frequency (50 Hz). The network can thus compensate for the off sets between the requested power and the power produced in the case where the cell is not able to fully satisfy the load.

The deviation of the frequency indicates that there is an imbalance between the power generated and the power demanded by the load. In order to keep the frequency within an acceptable range of variation, the generation must be adjusted in real time to meet the discrepancies between the current values and the predicted values. Under normal operating conditions, the frequency is closely maintained in a narrow band around the nominal frequency. In the case of a loss of line for example following a fault, the frequency must be maintained above a predetermined frequency threshold. If this threshold value is exceeded, the protection system will disconnect a large part of the generation and the consumer is affected. There are two types of frequency regulation in power grids: an individual primary control of each unit of production and a secondary control which consists of controlling the production areas [32]. A primary control of the frequency is very fast and it is intended to compensate the imbalances between the generation and the load. It is implemented using speed regulators in conventional production plants (thermal, hydraulic, etc.). These controllers make it possible to adjust the output power of the generators, in response to a deviation of the frequency. The delay for a primary frequency check is between a few seconds to a minute. The secondary control (LFC:

load-frequency control or AGC: automatic generation control) is realized by a centralized regulator located at the control center of the control zone and whose role is to modify automatically the production program of the power stations up to cancel the adjustment gap of the zone.

3.6 Dynamic supervision of a multi-source power plant

It is recalled that a multi-source power plant consists of several controllable or non-controllable elements (in particular not completely controllable for a certain number of renewable energy sources), and often very different dynamic characteristics, and that these sources must contribute to a specified power level, for example in levels 1 and 2. The previous parts show that there is a gap between level 1, which distributes the powers statically (Economic Dispatch) without taking into account the uncontrollable variations of the level. The power of some sources, the respective dynamics of these sources, and the local controls of each of the controllable elements (Level 0). Dynamic supervision is a reference trajectory generation for each of the local controllers, taking into account, on the one hand, the orders given at levels 2 or 1, and on the other hand, the closed-loop dynamics of each of the elements of the power plant. Our supervision stage can be inserted between the level 1 and 0. This is justified by the fact that the predictions of 10 to 15 minutes are not precise, in particular as regards the production of the solar power whose dynamics of variation are very fast during the days marked by very frequent passage of clouds. As such, the problem of optimal control of multi-source system would approach a classic problem of calculating optimal production plan of the power plants of a network (Unit Commitment), brought to a very small scale. One can indeed neglect the influence of the network, the losses being brought back in yield of production of the generators, and the supervisor having to decide plans of stop and starting over the period of the controllable generators. However, following this approach as a Unit Commitment problem would require a mass of exhaustive information in terms of cost curves, power demand, availability rates, and so on. In addition, 24-hour forecasts of charges and renewable resources are generally very crude. Existing driving algorithms such as Unit Commitment and Economic Dispatch are therefore not adaptable to our problematic and do not allow to integrate the dynamics of the elements of the multi-source cell and to effectively account for predictions. Note that a frequency control (Load Follow) is not necessary in the case of a multi-source system connected to the network. In other words, the network can exchange power with the hybrid system and compensate for any off sets. Each element of the multi-source cell has its own controller (MPPT controller, PI regulator, $\cdots$) and the sources are perfectly controlled (Level 0) [15].In what follows we will draw up a non-exhaustive list of methods of supervision classified according to two criteria [15]:

1. supervisory methods, requiring or not a model of the system,
2. method of supervision according to the approach used (optimization, sequential, etc.),

3.7 Supervision methods with or without model

The control functions of an hybrid system can be divided into two categories, namely the local controllers and the supervision system, as shown in the figure 3.2.

Local controllers allow the overall system to operate properly according to the instructions. They can be subdivided into two sub-categories:

1. sequential control types on /off (example: connect or disconnect an element),
2. PID regulator or other, which will ensure the control of the controlled variables,

which can be, for example, the optimization of the extracted power of the device (MPPT device: Maximum Power Point Tracking), the control of the electrical quantities (instructions power active-reactive or frequency-voltage, for example), mechanical quantities, etc. The supervision system is primarily aimed at satisfying the load, taking into account several parameters of the hybrid system. Unlike local control, the supervisory system should only be designed after an understanding of the characteristics of the overall

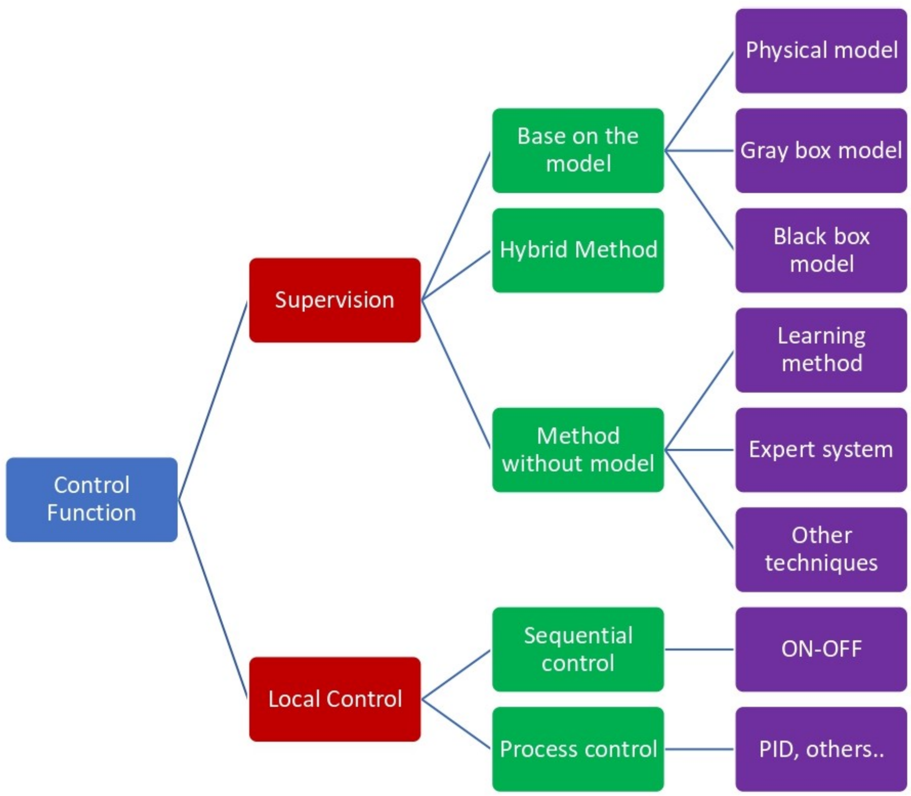


Figure 3.2: Classification scheme of control functions in hybrid systems.

system, the possible interactions between the subsystems and their associated variables. Knowledge of these features can be used to minimize an "objective" function, which will lead to improved system performance. As shown in Figure 3.2, supervision strategies can be divided into three groups: model-based methods, without model methods, and hybrid methods.

Method without model

This type of method does not require knowledge of the model of the targeted system. Expert systems and learning methods can be used to design this type of supervisor. An expert system can mimic human reasoning to make decisions for a given operating point based on a knowledge base. It also has the ability to deduce reasonable solutions even when the data is incomplete. An expert system can be easily implemented; however, it is affected by the richness of its database and outside its area of expertise, it can induce significant errors. Learning methods do not require knowledge of the mathematical model of the system either. They describe a learning paradigm in which the system attempts to improve its behavior in relation to previous actions. These methods can find an optimal or near-optimal solution. However, they take a considerable amount of time to "learn" from the controller. These methods are very sensitive to learning parameters; this is why it is difficult to implement them in practice.

Model-based methods

The knowledge of the model makes it possible to predict the response of the system in order to adapt the parameters of the control. The main role of optimization is to minimize the energy at the input of the system while having acceptable performance. At each sampling step, an optimization technique is applied to the system to minimize a cost function and to evaluate the control variables. Controls respond quickly to changing conditions outside the system. Depending on the model used, the model-based supervision method can be divided into three subcategories: supervision method based on a physical model, gray box model and black box model.

Physical models

They are built from a physical, chemical,...analysis by applying the general principles-based laws (mechanics, electromagnetism, fluxes) that govern the dynamics within the processes studied. These models do not generally include adjustable parameters, or parameters that can be adjusted in very small numbers. In practice, it is always desirable to establish a knowledge model of the processes under study. Nevertheless, it often happens that the process is too complex, or that the phenomena that govern it are very poorly known, so that it is possible to establish a model of knowledge sufficiently precise for the considered application. It is then necessary to conceive purely empirical models, based exclusively on the results of measurements made on the process. In general, these detailed or simplified models have relatively high performance regarding predictions of their future behaviors. Nevertheless, a very detailed model can hinder its application in real time.

Model "gray box"

When knowledge expressible in the form of equations is available but insufficient to design a satisfactory knowledge model, we can use a "gray box" (or semi-physical modeling) model that takes into account both knowledge and measurement. Such a model can reconcile the advantages of intelligibility of a knowledge model with the flexibility of a model with adjustable parameters.

Black box model

The "black box" models are built essentially on the basis of measurements made on the inputs and outputs of the process to be modeled. The modeling then consists in using, to represent the relations between the inputs and the outputs, parametric (algebraic, differential) equations, and to estimate the parameters starting from the available measurements, in order to obtain the best possible precision with the smallest number of adjustable parameters. They are developed on the basis of the empirical behaviors of the system. Model parameters do not usually have a physical meaning. In general, these models do not require detailed knowledge of the system, however they are only accurate over a well-defined interval. Outside this range, extrapolations can lead to significant errors.

Hybrid method

Different types of methods can be used simultaneously to design a supervisor. For example, some hybrid methods may use the model-based approach, and the modeless approach. The supervisor thus formulated can have high performance.

3.8 Rules-based supervision strategies

The most common way to implement a supervisor for multi-source systems is to introduce a set of rules, which takes into account some significant parameters and decides the distribution of power between the different elements of the cell. Unlike techniques based on optimization methods, rule-based supervision does not use a formal description of the problem [33] [34] [35]. These rules come from the intuition of the engineer: the qualitative objective is to extract the maximum power of renewable origin and to ensure that the elements operate at their maximum efficiency. The parameters of the rule-based controller (for example, the threshold values that decide when to switch from one mode to another) are generally obtained by calibration based on the modeling and simulation of the power chain, possibly using optimization techniques. The main benefit of rule-based control is its simplicity and ease of implementation on hybrid systems. For example, if the state of charge of a battery falls below a certain value, the main source must provide additional power to recharge it. The rules can be complex and detailed depending on the desired performance. The main drawbacks are the absence of evidence of optimality, and the fact that there is no standard method for the synthesis of rules (for example, the rules are decided on a case-by-case basis, but it does not it is not possible to determine a priory that a given set of rules is appropriate for a specific application). In addition, the presence of thresholds and parameters makes the calibration (which may allow to have a wide range of driving), quite difficult. Nevertheless, this strategy is widely used in hybrid systems and possibly in conjunction with other optimization- based algorithms. Another way to design a supervisor is the fuzzy logic [36]. It allows to extend the notion of classical logic, associated with Boolean variables taking only two values 0 and 1. It is then possible to associate with variables of membership coefficients to fuzzy subsets taking values in the interval [0,1] and quantifying a possibility. For example, the fuzzy control method of a photovoltaic/wind hybrid system with limited power batteries. The energy management system controls the output power of the hybrid wind /photovoltaic generator and the state of charge of the batteries, which are compared to the power demanded to apply the fuzzy inference rules. Each wind turbine can then be disconnected if the output is exceeded in relation to the load, without the possibility of storage, and likewise for each PV module, which ensures a coarse load monitoring.

3.9 Global optimization techniques

Global optimization techniques as discussed in the literature, are generally placed in the perspective of dimensioning an installation taking into account a long-term scenario, a given supervision strategy (based on rules, optimizations,...), investment costs, a load profile and possibly a production profile from a renewable source. Solving such a problem can determine the ideal distribution of source types (wind turbines, solar panels, bat...), which minimizes the return on investment. Given the lack of knowledge and uncertainties of several parameters, such as the evolution of fuel prices, the pricing conditions of energy, and this over several years. This approach can only lead to trivial results, since it is assumed that all the parameters are known. The supervision of hybrid systems is a fertile field of research and one of the major challenges in the field of hybrid systems and micro-networks. Although there are many effective strategies for the supervision of multi-source systems, the depletion of fossil resources, have pushed the actors of the power grid to pay more attention to optimal control and robust supervision. As evidenced by the evolution of the production of scientific papers over the past 20 years Figure 3.3, efforts have been made to develop optimal supervision strategies for multi-source systems.

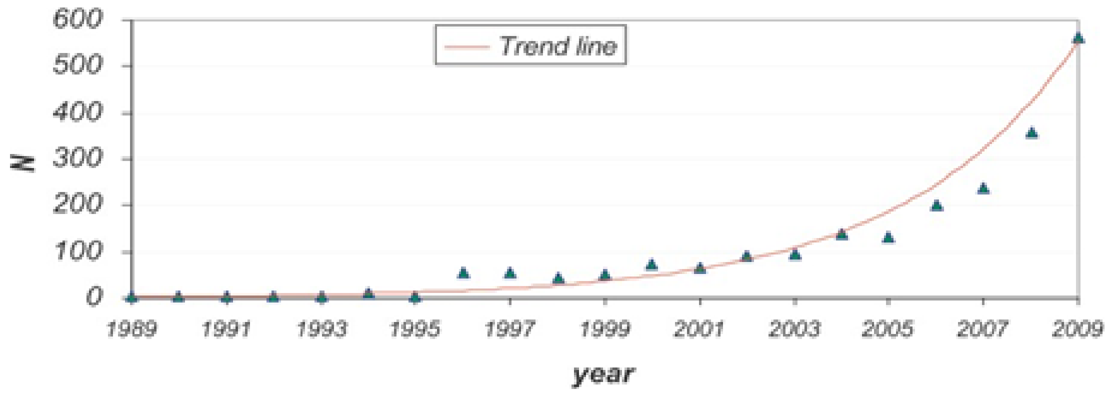


Figure 3.3: Number of published articles using optimization techniques applied to renewable energies [14].

The optimization algorithms based on global optimization, to which an objective function and constraints can be submitted can be totally different. The choice of the algorithm integrates the knowledge of the quantity to be optimized and control quantities which influence the quantities to be optimized. The objective function and the command quantities can be continuous or discrete [29]. They can have degrees of non linearity more or less high (linear, quadratic...) and the system can be constrained or not constrained. In the case where we already know the power profile of the load and renewable resources, a global optimization approach can be undertaken based on the general theory of optimal control [37]. While the proportion of renewable energy penetration is large, uncertainties about the level of uncontrolled power can be significant, but can be unacceptable for the application of this type of method. These approaches are incomplete and do not allow to propose an applicable response as it is in real time. This stage is thus often used as a reference to evaluate the performance of the strategy actually used, which must necessarily cover all aspects: anticipatory and optimized. Thus, the exploitation of the short-term predictions should make it possible to have an appreciable gain compared to a technique in which the exogenous parameters are perfectly known, because the short-term predictions are more precise. In what follows we will detail the contributions of such an approach.

3.10 Predictive control

Predictive control is part of the class of optimal controls. The modern theory of optimal control began in the second half of the twentieth century [38]. Predictive control is widely used in the industrial field to control the behavior of complex processes. This type of method relies on the model of the process to determine in anticipation, using the knowledge of the future evolution of the setpoint, the optimal value of the command entries to be applied, in the sense of a previously defined performance criterion. which characterizes the goal that one wishes to achieve (regulation, pursuit, or any other criterion of quality). One of the advantages of predictive control is the consideration of constraints imposed on the system from the design stage. In addition, the system may take into account future changes in the setpoint and disturbances, if these are measured or predicted. This type of control is therefore particularly suitable for multi-source systems who's future setpoint can be programmed or predicted (load evolution, solar radiation in the case of photovoltaic panels, etc. ...)

The Model Predictive Control (MPC) command is applied in power systems [39], but also in renewable energy systems. This method was invented by the French J. Richalet in 1978 and generalized by D. W. Clarke in 1987 in agreement with major industrial groups in the United States of America and in Europe (Shell and Adersa). For example, the authors of the articles [40] and [41] proposed an MPC command to dynamically control a wind turbine, a control strategy of a dual power asynchronous wind turbine based on the predictive control was studied. The goal is to reduce the fatigue of the transmission system while maximizing the power extracted. The results obtained are better compared to the case of a conventional regulator. The predictive command [42] can be used as a local controller but also as a supervisor. It is applied in several types of energy management system as a control driving closed-loop systems.

3.11 Optimal control of heating systems in the building sectors

In the article [43], the authors propose a predictive command to supervise the energy management in a residential building. The system can simultaneously produce power and heat. The cost function has been designed to minimize the cost of energy. It takes into account the consumption of fuel oil, the purchase price and the sale of energy to the grid. The main objective of the control of thermal systems in the building is expressed in the form of an optimization problem: to minimize the consumption (or the cost) while guaranteeing the desired level of comfort (thermal). This objective seems the sufficient argument for the use of the predictive command in this case. However, the high cost of the technology required for implementation and especially the difficulty of obtaining a satisfactory mathematical model have long penalized the use of optimal (predictive) controls in the energy management of buildings. Note that these systems are characterized by slow dynamics.

3.12 Power management in hybrid vehicles

The authors of [44] examine the possibility of applying the predictive control to a hybrid parallel electric vehicle. It is assumed that the vehicle speed is constant and a GPS is used to estimate the slope of the road during the prediction horizon. Thus, the required wheel torque during the prediction horizon is estimated and the optimal control result is obtained by minimizing the cost function, which introduces the fuel consumption during the prediction horizon. The demand for future power is supposed to be perfectly well known on a long horizon, which is not realistic. The authors present a predictive control supervision application to control a hybrid vehicle [45]. The algorithm uses the fuel cell model to predict its dynamic response and thus send the necessary power reference to the battery to satisfy the demand with satisfactory dynamics. The objectives shown are the minimization of the use of hydrogen and the maintenance of the state of charge of the battery around a nominal value. The cost function is the sum of three terms: The difference between the state of charge and the reference, the cost of using hydrogen, and the difference between the power supplied and the reference power.

3.13 Multi-source electricity generation systems based on renewable energies

The constraints of using the MPC command in multi-source systems are very different, compared to the case of energy management in buildings or in the hybrid vehicle. For example, the management of heating in the tertiary sector is characterized by very slow dynamics because of the inertia of the building, and the constants of time reaching several tens of minutes. In the case of hybrid vehicles, the load must be satisfied at every moment (no error range possible) and the structure is not very complicated (at most three different sources). This is the main feature of hybrid systems dedicated to portable applications. A common feature is the significant influence and variability of outdoor conditions (temperature, vehicle travel, or sunshine...) [6]. In the case of multi-source systems dedicated to electricity generation, environmental and economic constraints are forcing producers to integrate more and more renewable energies into their generating facilities. However, to facilitate their integration, it is essential to have flexible facilities capable of adjusting production to demand from the network. This requires process optimization as well as control. Preferred technologies include photovoltaic panels and wind turbines. Given their random and intermittent characters, the steering constraints of a cell are more important. Currently, the control of a cell containing such sources only takes into account the instantaneous power supply. Today, several operators are still modeling photovoltaic panels and wind power as negative loads, which they therefore include as disturbances in the hybrid cell control algorithm. In order to improve the availability and maneuverability of an installation comprising several renewable sources, it is interesting to associate storage systems and /or sources of production using fossil sources. On the other hand, the insertion of storage elements and fuel-based production sources (gas) complicates flow management in multi-source systems (state of charge management, aging,... yield). Innovative multi-source systems management methodologies that consider all of these factors are needed. However, the environment of multi-source power plants being very variable (sunshine, wind, production needs,...) it is important to take into account an estimate of these variations. A predictive control type approach makes it possible to explicitly take into account future variations of the exogenous variables.

In fact, each element already has a local controller that is often standard and preset. The predictive control will be like a supervisor, that is to say, it will provide the power references of each element. This level of supervision will calculate these references by solving a sliding horizon optimization problem. The main goal is to provide the power required by the network manager. Since the cell is made up of several elements, there are a large number of degrees of freedom, which can be used to meet services at lower cost. The objective function of the predictive control must include not only considerations of cost and performance, but also considerations related to the lifetime of the storage elements. The predictive control seems to be a tool adapted to the control of a multi-source cell, but we must find an architecture and a setting that can provide an easily reconfigurable and adjustable supervisor. In order to take into account, the uncertainties, a 10% error on the predictions (24h) of renewable resources has been added. However, statistical forecasting methods, especially for high horizons, applied to the management of multi-source systems are often confronted with large prediction errors in case of rapid fluctuations of solar radiation or wind . Today, users such as wind farm operators, distribution or transmission system operators, electricity companies, who are very interested in predictive tools, recognize that this is the only way to economically manage the intermittency of renewable resources. To date, to our knowledge, no real application of the predictive control has been performed for supervision. Nevertheless, an MPC command used as a local controller has been successfully implemented [46], in order to control a fuel cell. They also applied it as a local controller to control the speed of a combustion engine, finding a compromise between fuel consumption and pollutant emissions.

3.14 Conclusion

In this chapter we have introduced the reader to the very wide field of multi-source systems, we have shown the interest of hybridization of sources. The problem of optimal control concerns several levels of supervision, over the longest periods of time (hours, day, week) to the lowest (fifteen minutes). However, existing solutions like network driving algorithms such as Unit Commitment and Economic Dispatch. The state of the art has been achieved by extending the problem to the energy management of hybrid systems of other applications (transportation, building sector, hybrid vehicle...). Supervision methods can be divided mainly into two categories: expert systems (fuzzy logic, sequential algorithms, etc...) and optimization- based algorithms. Optimization-based methods are based on a deterministic approach, with perfect information on exogenous variables and system characteristics, and a classic constraint optimization problem. However, these approaches are incomplete and do not allow to propose an applicable response as it is in real time. This step is thus often used as a reference to evaluate the performance of the strategy actually used, which must necessarily cover all aspects: very short-term predictions, minimization of the cost, etc.

Chapter 4

Design and Development

The main objective of this project is to create a selection cell that manages a multi-source energy system to ensure a continuous supply of electricity to a load, with the possibility of measuring the electrical energy produced (Currents and voltages). Indeed, an important requirement of the distribution of electrical energy is the need to have an automatic operating system. For this, we have mounted on the card four relays controlled by an Arduino mega card to demonstrate the corresponding failure of this power supply.

4.1 Principle of operation

The figure 4.1 presents the multi-source selection cell flow chart for our project. An Arduino mega board was used to control four relays that allow access to power sources to feed a load. In addition, we integrated a current and voltage sensors to make the measurements, These will be processed by the Arduino board.

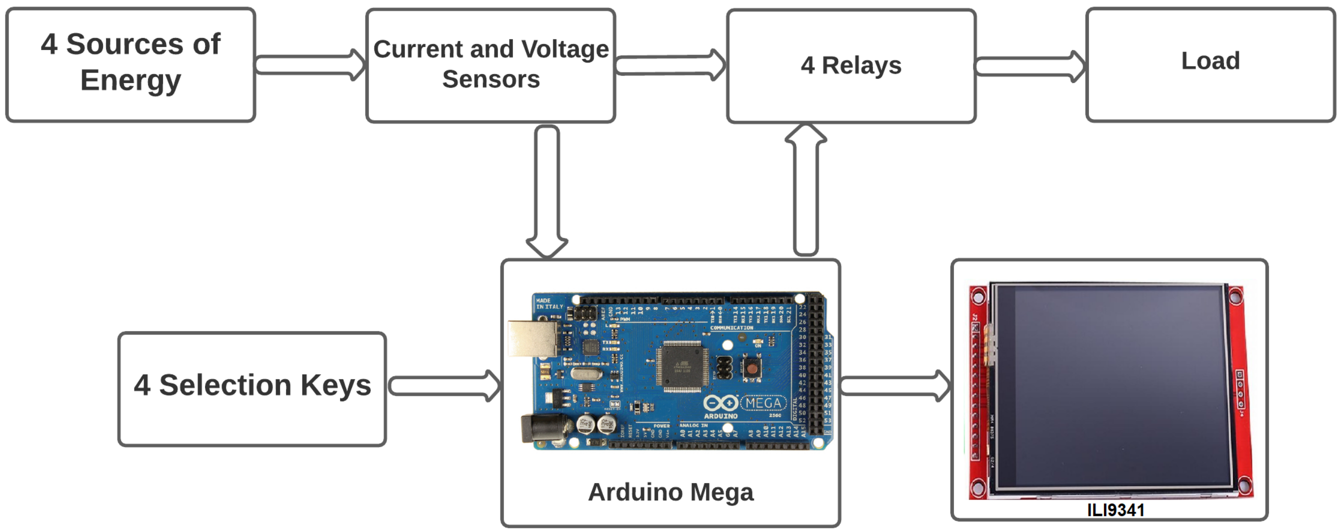


Figure 4.1: System Architecture of the multi-source cell.

The card operates in two modes manual and automatic

4.1.1 Manual command

We use four buttons whose status (open or closed) is detected by the Arduino board (digital input), which will control the 5V relays (through the analog outputs), which allows access to the source we want to make it work. The figure 4.2 represents the flowchart that explains the principle of operation in manual mode of the cell.

Technically speaking, it is possible to select the energy source that you want to use by pressing one of the buttons. The buttons are connected to the analog input of the Arduino.

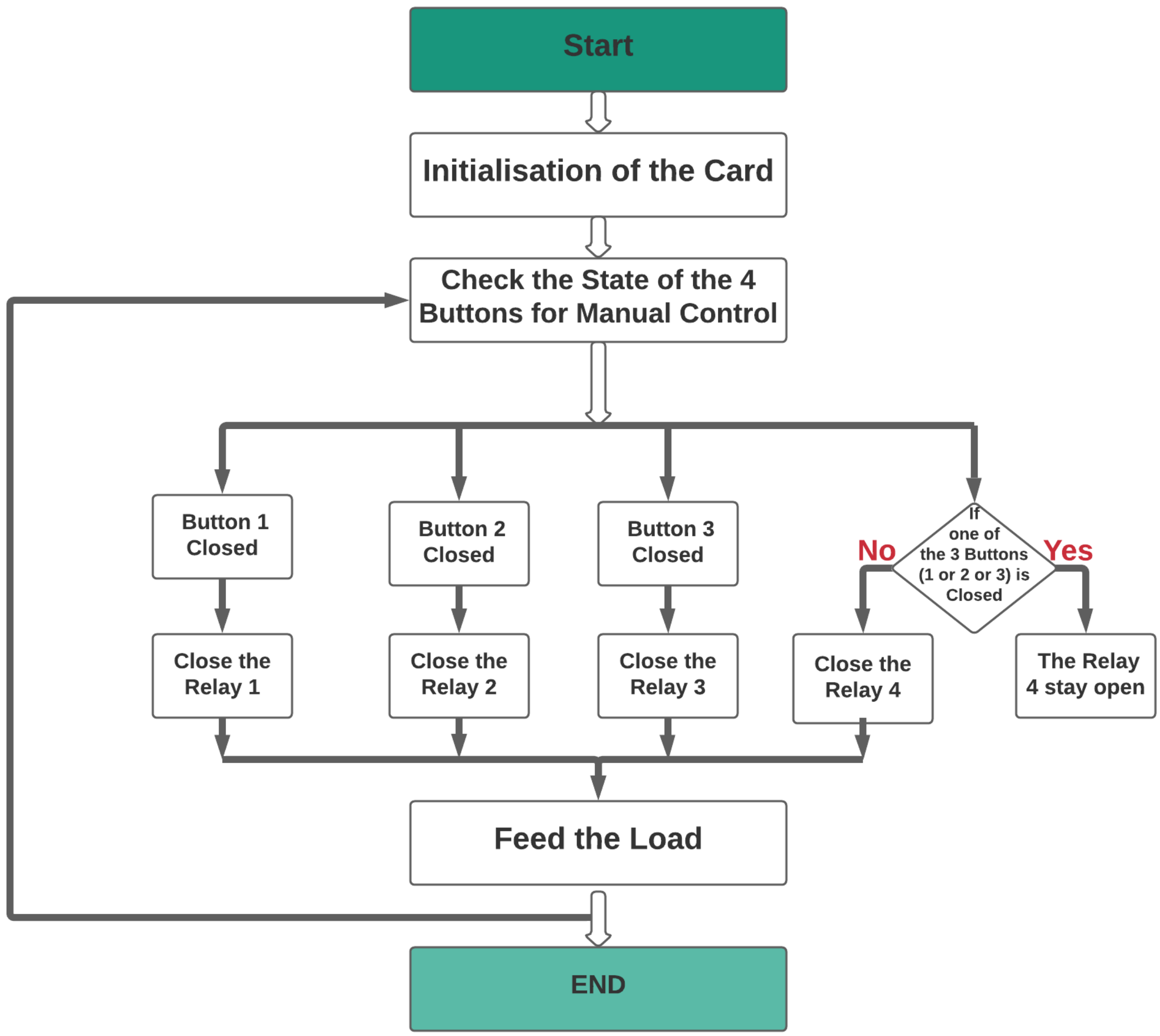


Figure 4.2: Flowchart of operation of the cell in manual mode.

4.1.2 Automatic control

The Arduino board can automatically detect the presence of one of the sources through the voltage sensors connected to the analog inputs of the board. Using an installed program based on if/else algorithm, it is possible to automatically control the four relays that allow access to power sources to supply a load. The figure 4.3 represents the flowchart that explains the principle of operation in automatic mode of the cell.

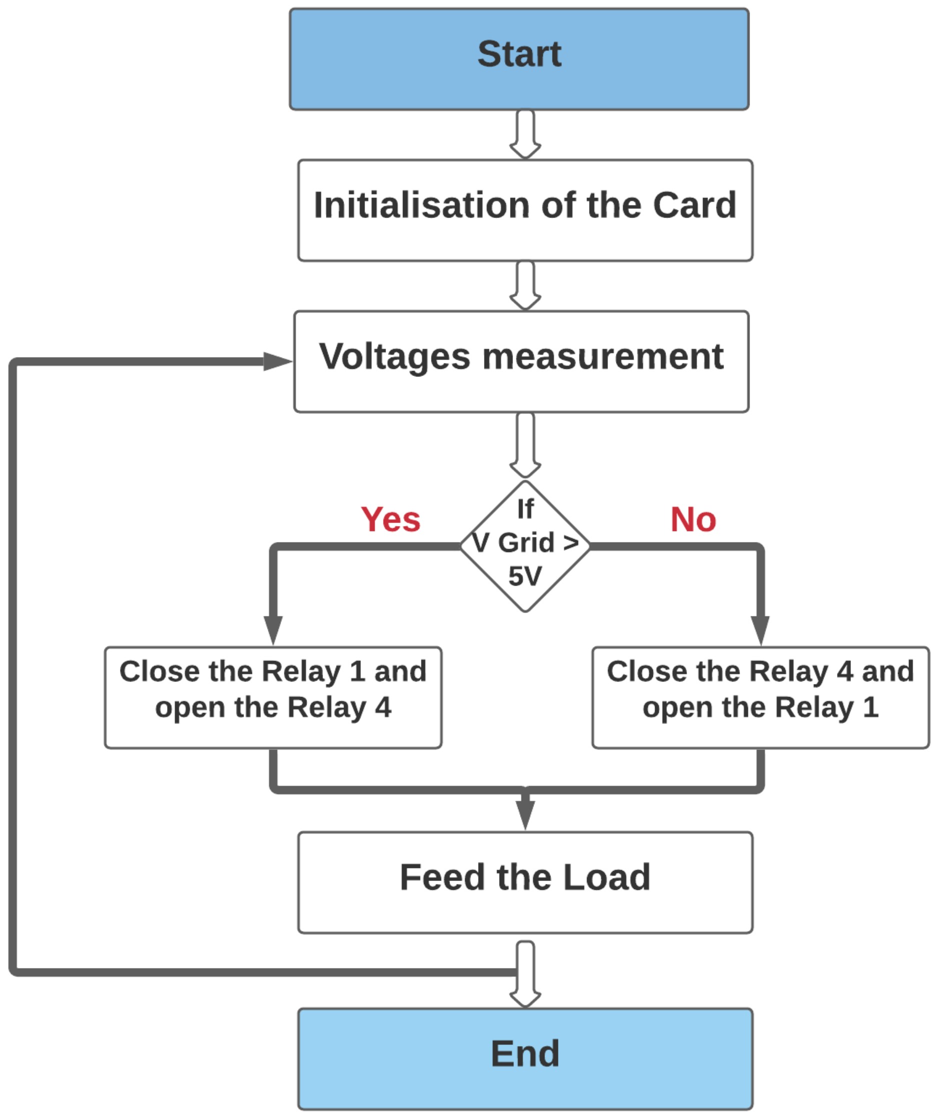


Figure 4.3: Flowchart of cell operation in automatic mode.

Four buttons are connected to the analog inputs of the Arduino Mega board, which checks the status (open or closed) of the switches. The Arduino board is then connected to the four relays (5V) of the energy sources used. These relays allow power from the source selected by the switch. The card also measures the current and voltage at the output of the source in working condition. A display and LEDs are able to indicate the source that is in operational mode.

As mentioned in the first chapter and after research was made [7], we consider the power grid as the main source, because it is the most reliable source that satisfies our energy needs at any time. However, the integration of renewable energy sources depends on the availability and its ability to meet the needs of the load; which allows us to do without or in part the energy provided by the network. In this case, the first three relays (PV, Wind, grid) are putted in the normal open state and that of the diesel group in the normal closed state. As a safety precaution, a program under Arduino must verify that the three relays (PV, Wind and Network) are already in the closed state before the diesel generator source is put into operation.

The cell operates with DC mode for the four sources, with a Low power ranging from 12 to 48 volts for each source of energy.

The aim of the current study is to understand the principle of controlling a multi-source system, so we started with a small capacity. In the future we can develop the card by increasing the capacity.

The main components used are :

1. Arduino Mega board,
2. 5V relays,
3. Optocouplers,
4. ACS712 current sensors,
5. ILI9341 display and LEDs,

4.2 Achievement stages

The figures 4.4, 4.5 and 4.6 present, respectively, the PCB, the printed circuit and two photos in 3D of the power cell realized with a demo version of an electronic software.

The figure 4.7 shows the different main components of the realized cell:

1. connectors to connect the source and the load,
2. 5V relay,
3. circuits for measuring voltages,
4. circuits for measuring the currents,
5. green LEDs to indicate the presence of current sensor,
6. red LEDs to indicate the closed state of the relay,
7. VCC & GND
8. current measurement points
9. voltages measurement points
10. relay control points

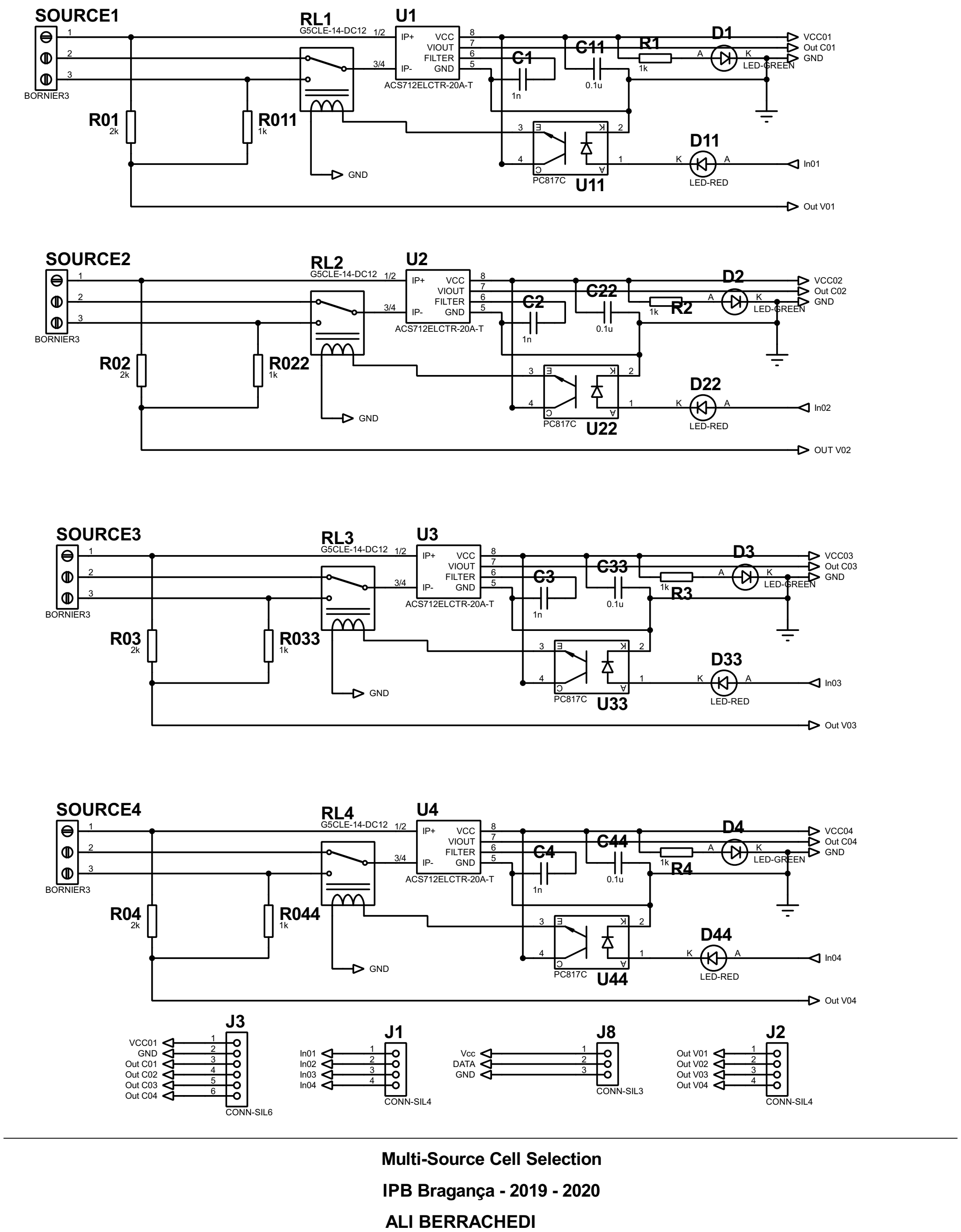
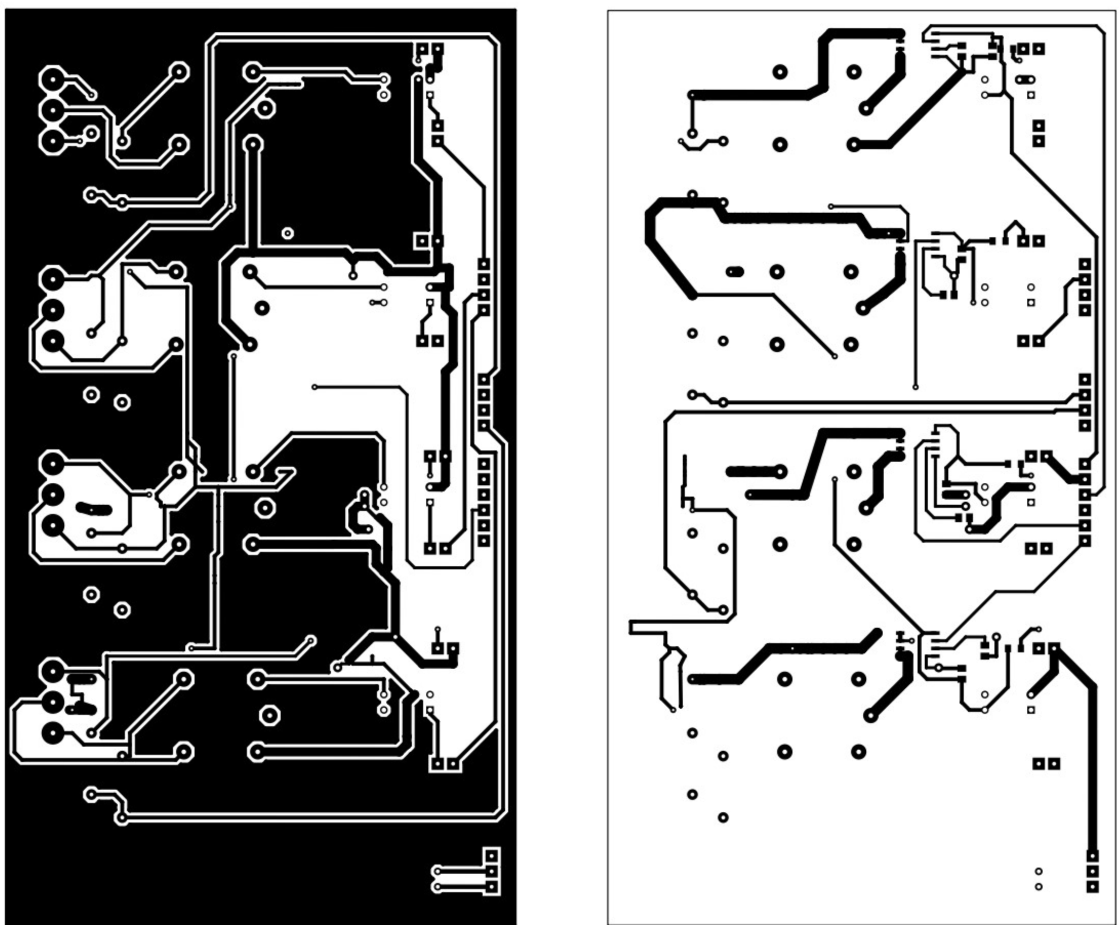
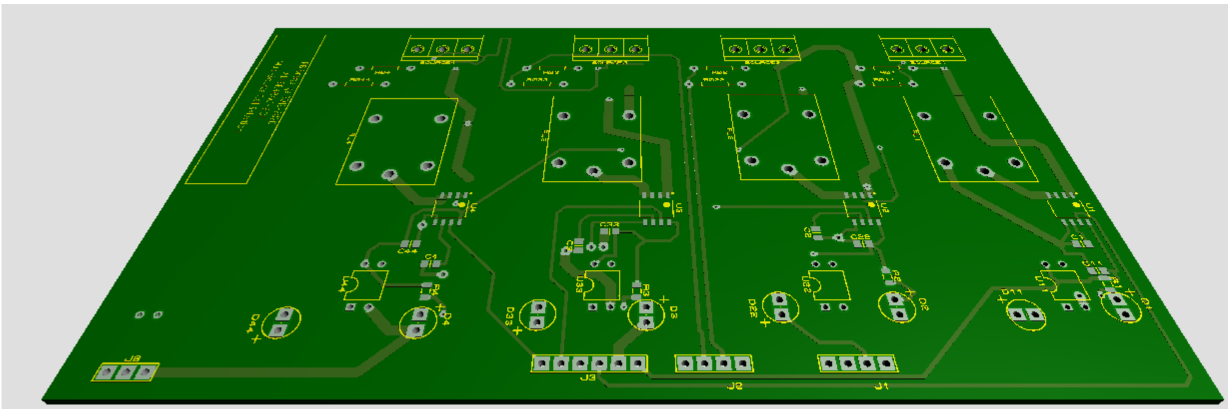


Figure 4.4: The circuit board of the selection cell realized with a demo version of an electronic software.

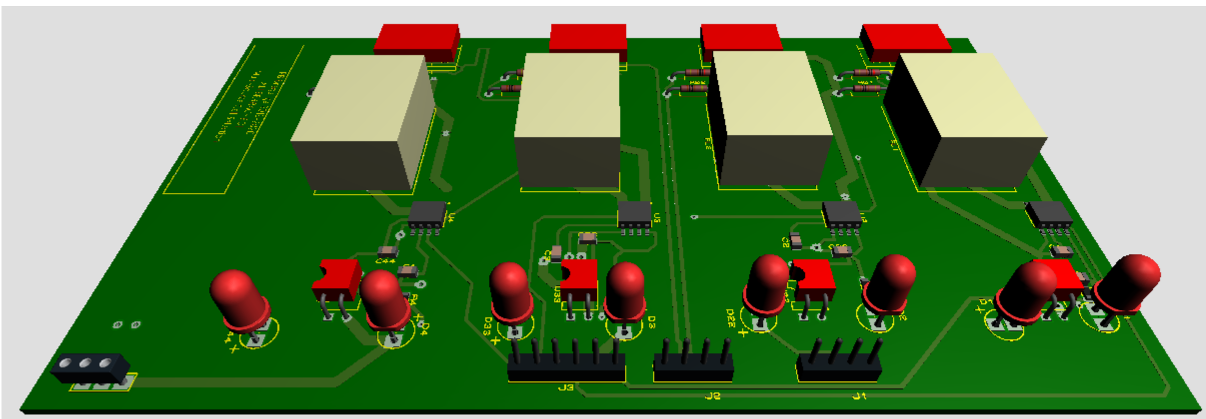


(a) 1 (b) 2

Figure 4.5: Printed circuit board PCB realised with a demo version of an electronic software.



(a) 1



(b) 2

Figure 4.6: 3D pictures of the selection cell realised with a demo version of an electronic software.

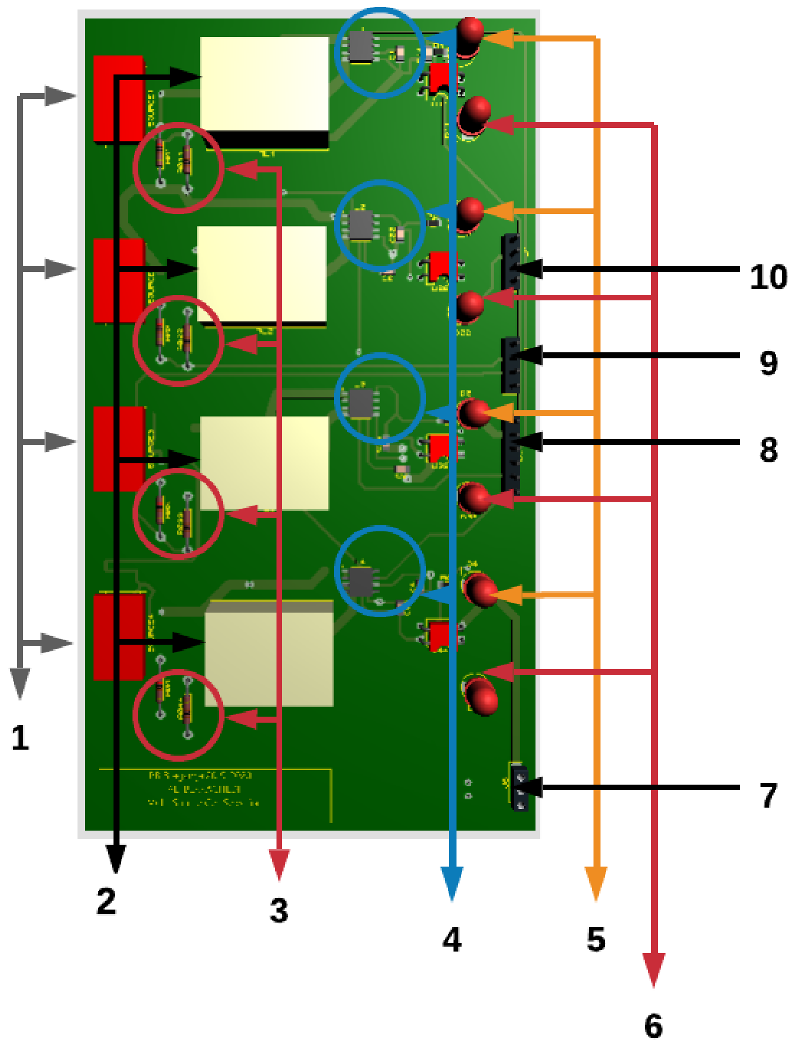


Figure 4.7: The different main components of the selection cell realized with a demo version of an electronic software.

4.3 Results and Discussion

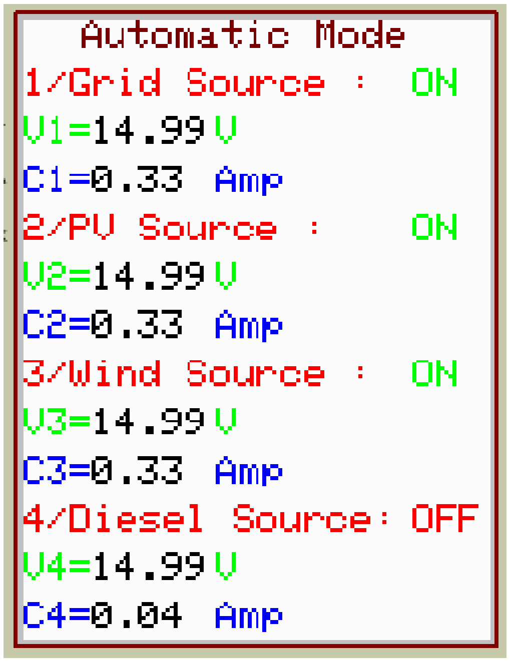
This work is considered as an introduction to the field of the multi-source systems,which is a very wide field.

We presented during this work the design and development of a multi-source cell selection, which will be used as a basis for the study of a multi-source systems and to better understand the real case of the hybrid systems.

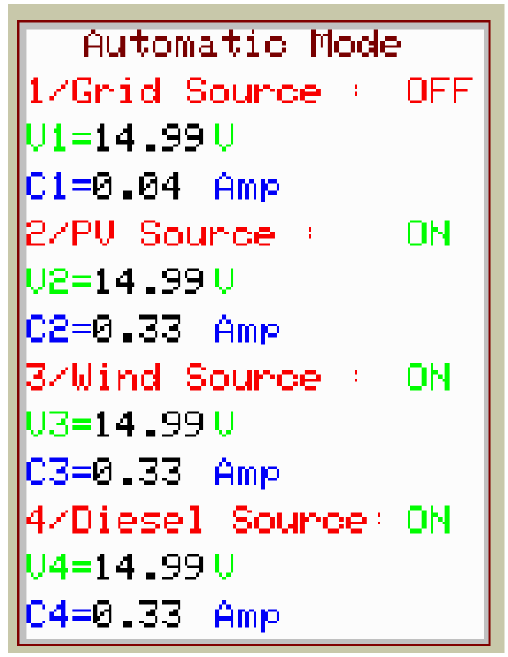
In the following, we will present the results obtained through simulation with a demo version of an electronic software and the curves were made using the Matlab software. The figure 4.8 and 4.9 in perspective present what the ILI9341 display shown after selecting the Automatic mode with the presence of the renewable energies, the Voltages Currents Measurement.

The figure 4.10 and 4.11 in perspective present what the ILI9341 display shown after selecting the Manual mode with the absence of the renewable energies, the Voltages Currents Measurement.

The figure 4.12 and 4.13 in perspective present what the ILI9341 display shown after selecting the Automatic mode with the absence of the renewable energies, the Voltages Currents Measurement.



(a) With the Grid Source as reference



(b) With the Diesel Source as reference

Figure 4.8: Automatic Command with the presence of the renewable energies.

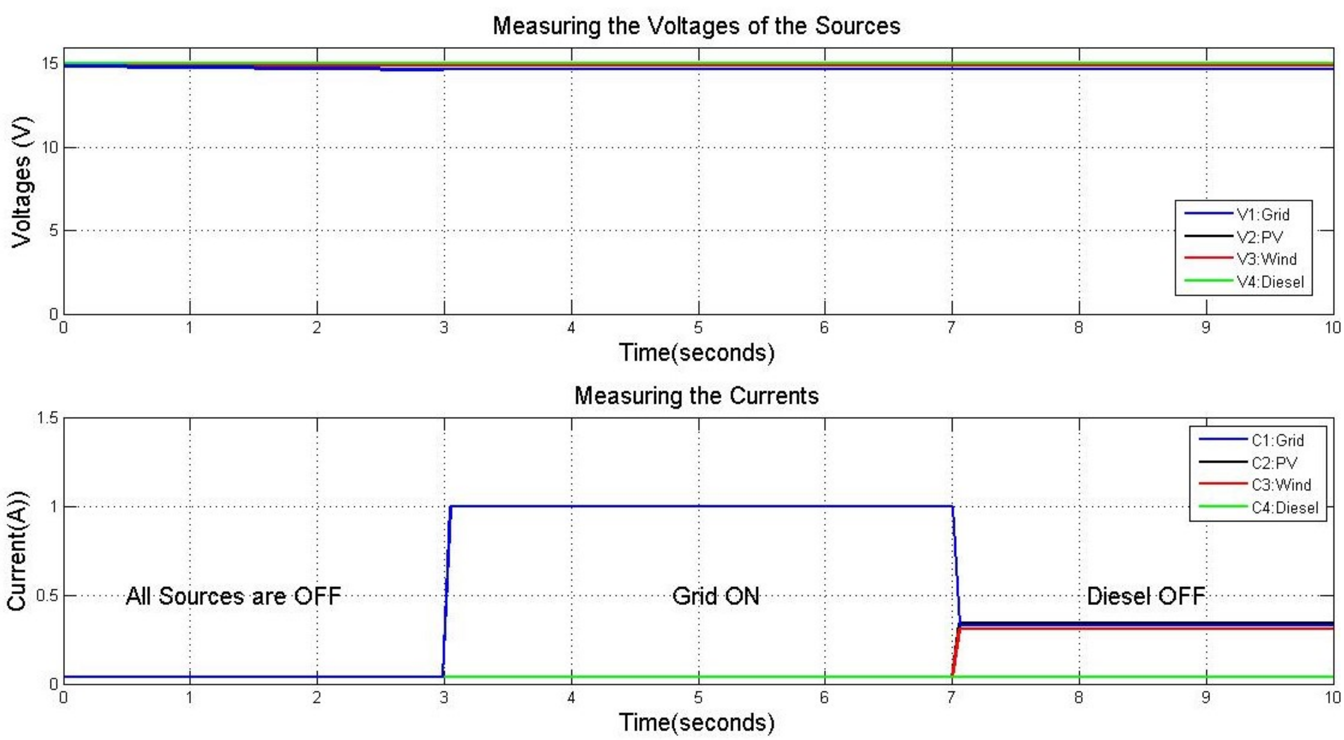
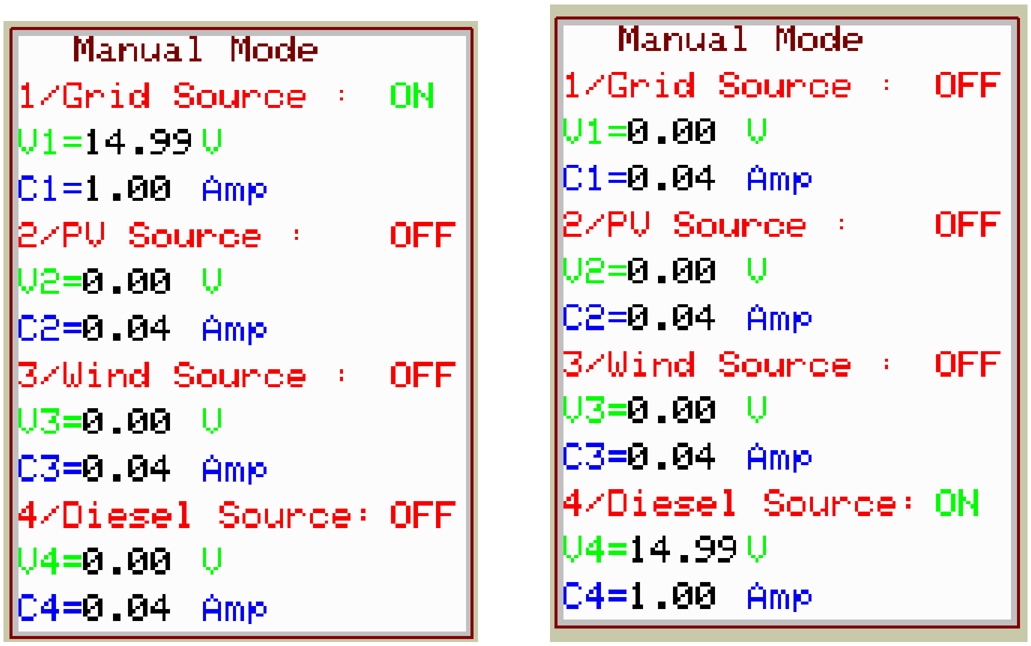


Figure 4.9: Voltages & Currents Measurement with the presence of all the sources while the Automatic Mode.



(a) Grid as the source of energy (b) Diesel as the source of energy

Figure 4.10: Manual Command with the absence of the Renewable Energies.

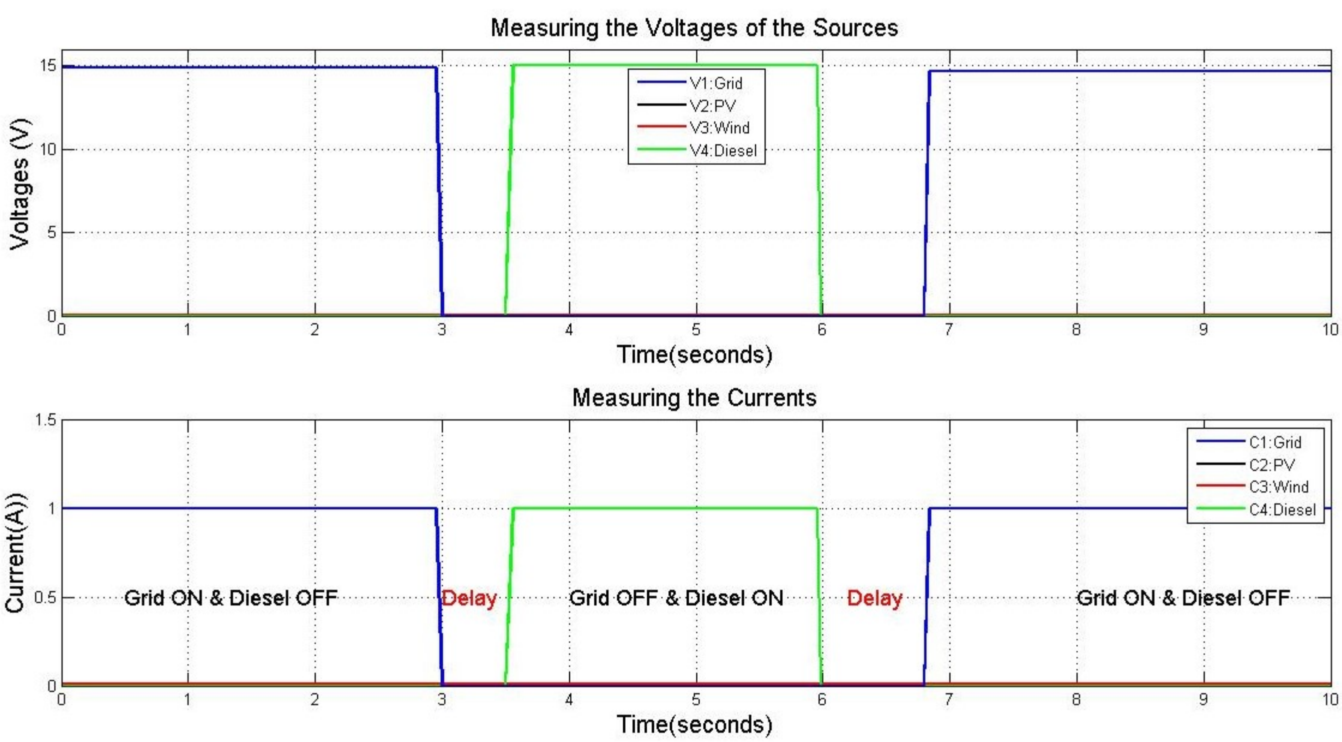
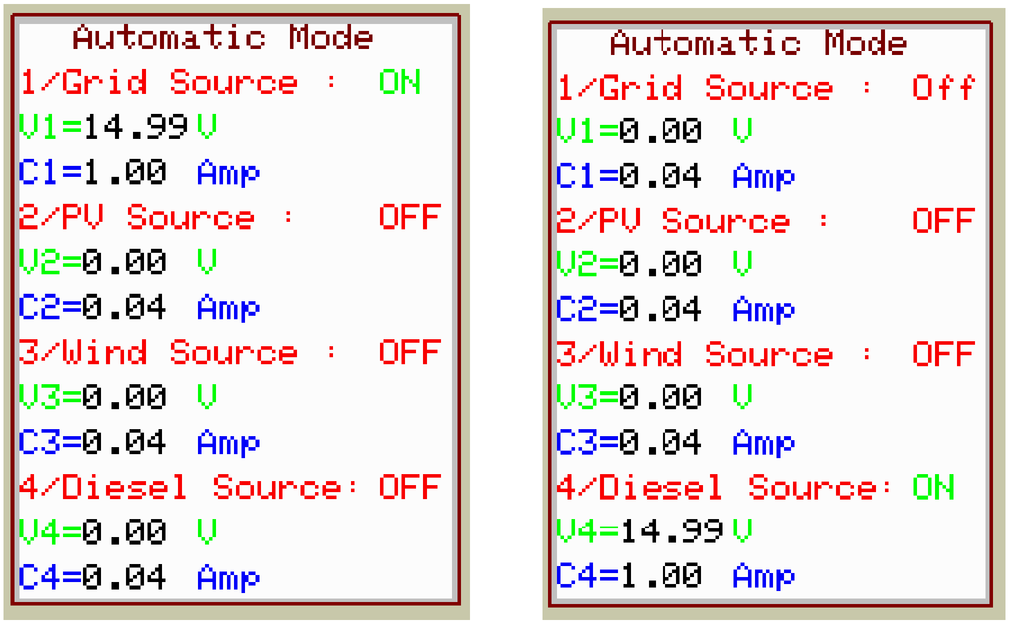


Figure 4.11: Voltages & Currents Measurement with the absence of all the sources While the Manual Mode. .



(a) Grid as the source of energy (b) Diesel as the source of energy

Figure 4.12: Automatic Command with the absence of the Renewable Energies.

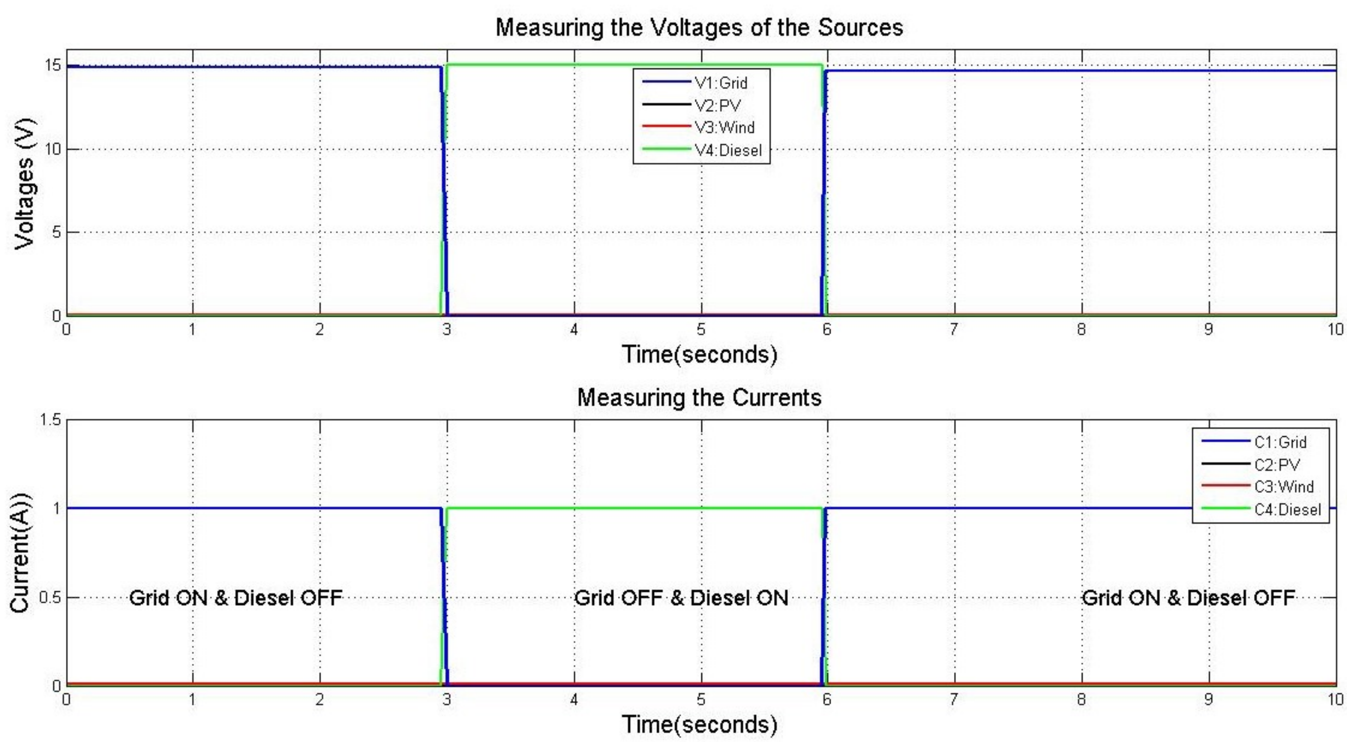


Figure 4.13: Voltages & Currents Measurement with the absence of all the sources While the Automatic Mode. .

As we can see through the results obtained with simulation the automatic mode give better performance by ensuring the permanent feeding of the load while avoiding intermittent periods between transmission from one source to another, as the figure 4.11 shows the presence of delays in the transition from the electrical network to diesel or vice versa. The figure 4.9 present the current feed the load, as we can see the presence of the renewable energies minimise the utilisation of the grid source and this is one of the purposes of this study, to integrate the renewable energies sources which allows to reduce the demand of the energy from the electrical network and thus reduce the dependence on traditional sources of energy production, this enables us reducing emissions and preserving the environment.

After the results achieved, we can consider that the problem posed at the beginning of this dissertation has been answered and we successfully ensured the continues feed to the load and combined several sources of energies also integrate the renewable energy sources.

4.4 Security Measurement

During the manual working system of the cell, an attempt may have occurred to connect the grid with the diesel engine at the same time, so the program on Arduino always checks the four sources status, for example before starting the diesel the program make sure that the grid is not connected and vice versa.the figure 4.14 present the message appear on the ILI9341 display when such case happen.

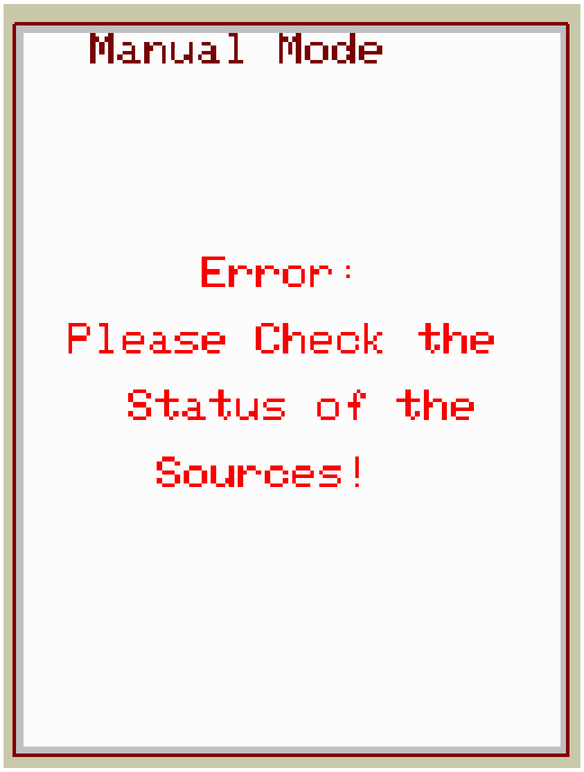


Figure 4.14: Security Measurement with the Manual Mode.

Chapter 5

Conclusion and future work

The aim of this final dissertation is ambivalent: To make a bibliographic research on the multi sources electricity production systems that use several sources (renewable and traditional), which made it possible to understand the functioning and the characteristics of these systems, and to develop, a selection cell allowing the management of a low-power multi-source system.

The card is designed to manually control four power sources (PV,wind, diesel and grid) and display the operational power source, in real time, using LEDs and an ILI9341 display (screen to show the results). An important aspect of the card is that it allows the measurement of the electrical energy produced by each source.

The importance of this project lies in the diversity of its applications. Indeed, a combination of several sources of renewable energy or not is always beneficial to several aspects (reduction of gas emissions, minimize consumption costs) especially for industries, hospitals, banks, schools, etc. It allows to consider an automatic transition to a renewable energy source in case of interruption of the network supply.

The practical work that I carried out also led me to touch on several technical fields related to my research project, namely: The physics of renewable energies, electronics, sensors and instrumentation, smart grids, Arduino, power electronics, etc... As prospects, it would be interesting to develop this control card by increasing its power, using a power controller, instead of an Arduino board. It would also be interesting to establish an algorithm that allows the automation and supervision of the management of the four to carry out the transition from one source to another when one or more sources are not operational.

Also among the points that can be developed is the development of the electronic circuit to control the percentage of use of each energy source in order to allow better control over these sources and supply the exact power required.

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