الجمهورية الجزائرية الديمقراطية الشعبية

**People's Democratic Republic of Algeria**

وزارة التعليم العالي والبحث العلمي

**Ministry of Higher Education and scientific research**

المدرسة الوطنية العليا للتكنولوجيا

**National High School of Technology**

Departement of Industrial Engineering and Maintenance

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**Final Year Project to Obtain the Diploma of Engineering**

- Field –

**Electromechanics**

-Speciality-

**Mechatronics**

- Subject –

# Design and Implementation of Induction Cooker Based on Zero Voltage Switching Inverter

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**Academic year 2022 –2023** **Algiers, the 03/07/2023**

# Gratitude

**T**he preparation of this brief was possible thanks to the assistance of several people, to whom I would like to express our gratitude.

**F**irst of all, I would like to express our gratitude to the director of this brief, **Mr**. **Boussoufa Ahmed,** for his patience, availability and especially his judicious advices, which helped to feed our reflection.

**I** would also like to thank the professors of the University of Dergana, who provided me with the necessary tools for the success of our university studies.

**I** would especially like to thank **Mr Boussoufa Ahmed,** who was the first to introduce me to the subject that guided our dissertation.

**I** would like to express our gratitude to the friends and colleagues who have given me with their moral and intellectual support throughout our process.

**A** big thank you to **Amrane Ahmed and Chaabane Ali** for the useful advices about our writing style,our analysis diagrams and also the help that we get it in our stage periode they greatly facilitated our work, without missing the judges for providing the best respectful discussion including a lot of quations and responses.

## <<THANK YOU>

# Dédicaces

*We have the pleasure of dedicating this modest work.*

*To our dear parents, may they find here all our gratitude for their*

*support throughout our*

*Study, asking God to protect them, a long life inchallah.*

*We also send our dedications to our friends (yasser ouadou; yassser*

*medrar; djaoudi zaid; ziani lokmane; hamou mouhamed; Faiçal Rakade*

*and all our classemate, etc....).*

# ملخص

عندما نتحدث عن تقنيات التسخين، فإن التسخين الحثي هو أحد أهم التقنيات وأكثرها استخدامًا في الوقت الحاضر لأسباب عديدة ، على سبيل المثال ، إنه صديق للبيئة مما يعني عدم وجود تلوث ، وله ميزة التدفئة المتجانسة ، وكذلك يمكن استخدامه في العديد من التطبيقات: التطبيقات الصناعية والطبية والمنزلية. من أجل أن يكون نظام التسخين الحثي فعالاً كما هو مذكور أعلاه ، يجب أن تكون كل من دائرة الإمداد بالطاقة وتقنية التحكم فعالة قدر الإمكان.

تقدم هذه الأطروحة تقرير مشروع التخرج في إطار تدريب مهندس الدولة في المدرسة الوطنية العليا للتكنولوجيا ، خيار الميكاترونكس ، الذي يناقش حول الحث على سطح الموقد الذي نقدم مزاياه ومزايا كل من نظام الحث على سطح الموقد وأنظمة أخرى مماثلة مثل تلك التي تعمل بالغاز وغيرها من الأنظمة التي تعمل بالكهرباء وأيضا مقارنة كل موضوع في مصطلح العديد من العوامل مثل الكفاءة والسلامة والتطبيقات وتكلفة الطاقة وما إلى ذلك ...

ومع ذلك ، فإننا نحقق في الخلفية النظرية وراء التسخين الحثي ، كما يتم ذكر أنواع مختلفة من إمدادات الطاقة وطوبولوجيا المحول المستخدمة في أنظمة التسخين الحثي لتنظيم الطاقة بالتفصيل. ومع ذلك ، فإن كفاءة أنظمة التسخين الحثي لا تعتمد فقط على مصدر الطاقة ، ولكن أيضا على تقنيات التحكم والتعديل ، ولهذا السبب تشرح هذه الأطروحة أيضا تقنيات التعديل المختلفة المستخدمة في محولات التغذية بالجهد.

**كلمات مفتاحية :**

**أنظمة التسخين بالحث ، محولات التردد العالي ، تحويل طاقة الرنين ، التحكم في تغيير الطور ، التحكم في تعديل كثافة النبض ، دورة تشغيل التردد المتغير.**

# Resume

Lorsque nous parlons de technologies de chauffage, le chauffage par induction (IH) est l'une des technologies les plus importantes et les plus utilisées de nos jours pour de nombreuses raisons, par exemple, il est respectueux de l'environnement, ce qui signifie zéro pollution, il a l'avantage d'un chauffage homogène et il est également utilisé dans de nombreuses applications: applications industrielles, médicales et domestiques. Pour qu'un système de chauffage par induction soit aussi efficace que mentionné ci-dessus, le circuit d'alimentation et la technique de contrôle doivent être aussi efficaces que possible.

Cette thèse présente le rapport du projet de fin d'études réalisé dans le cadre de la formation d'ingénieur d'Etat à l'Ecole Nationale Supérieure de Technologie, option Mécatronique,

Qui discutons de l'induction de la cuisinière que nous fournissons les avantages et les inconvénients de chacun des systèmes d'induction de la cuisinière et d'autres systèmes similaires comme celui qui fonctionne avec le gaz et d'autres qui fonctionne avec l'électricité et aussi en comparant chacun des thèmes en termes de nombreux facteurs tels que: efficacité, sécurité, applications, coût de l'énergie etc ...

Cependant, nous étudions le contexte théorique du chauffage par induction, ainsi que différents types d'alimentations et de topologies de convertisseur utilisés dans les systèmes de chauffage par induction pour la régulation de puissance sont mentionnés en détail. Neanmoins, l'efficacité des systèmes de chauffage par induction ne dépend pas seulement de l'alimentation, mais aussi des techniques de contrôle et de modulation, c'est pourquoi cette thèse explique également les différentes techniques de modulation utilisées pour les onduleurs alimentés en tension.

## Mots clés :

**Systèmes de chauffage par induction, convertisseurs de haute fréquence, conversion de puissance résonnante, contrôle de déphasage, contrôle de modulation de densité d'impulsion (PWM), rapport cyclique à fréquence variable.**

# Abstract

When we talk about heating technologies, Induction Heating (IH) is one of the most important and most used technologies nowadays for many reasons, for instance, it's environmentally friendly which means zero pollution, it has the advantage of homogeneous heating, and also it's used in many applications: industrial, medical, and domestic applications. In order for an induction heating system to be as efficient as it's mentioned above, both the power supply circuit and the control technique have to be as efficient as possible

this thesis present the report of the graduation project accomplish in the framework of the state engineer training at the national higher school of technologie,mechatronics option,

which it discuss about induction cooker that we provide the advantages and disadvanteges of each of the induction cooker system and other similar systems like the one that works with gas and others that works with electricite and also comparing each of theme in terme of many factors like : eficiency, safety, applications,energy cost etc...

however we investigates the theoretical background behind IH, also different types of power supplies and converter topologies used in IH systems for power regulation are mentioned in detail. However, the efficiency of IH systems don't just depend on the power supply, but also on the control and modulation techniques, that is why this thesis also explains different modulation techniques used for voltage-fed inverters.

## Keywords:

**Induction heating systems, High frequency converters, resonant power conversion, Phase-Shift Control, Pulse Density Modulation Control, Variable Frequency Duty Cycle**

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# *List of Abbreviations and Terms*

## Roman Items

| | |
|---|---|
| C | Capacitance |
| f | Frequency |
| $f_{sw}$ | Frequency of switching |
| I | Current |
| $I_{RMS}$ | Average value of the steady-state through current |
| L | Inductance |
| lc | Coil length |
| *Vac* | AC source voltage |
| *V* | Voltage |
| $P_{loss(cond)}$ | Conduction losses |
| $P_{loss(sw)}$ | Switching losses |

## Acronyms

| | |
|---|---|
| AC | Alternating Current |
| BJT | Bipolar Junction Transistor |
| CFI | Current-fed inverter |
| DC | Direct current |
| IGBT | Insulated Gate Bipolar Transistor |
| IH | Induction heating |
| RMS | Root Mean Squar |
| CIs | Induction cooker system |

# *General introduction*

# Introduction

An induction cooker is a modern kitchen appliance that utilizes advanced technology to cook food quickly and efficiently. It is based on the principle of electromagnetic induction, which allows for precise and controlled heating of cooking vessels. Induction cookers have gained popularity due to their numerous advantages over traditional gas or electric stoves.

At the heart of an induction cooker is an induction coil made of copper or other conductive materials. When an electric current flows through this coil, it generates a rapidly alternating magnetic field. When a compatible ferromagnetic cooking vessel, such as a stainless steel or cast iron pot, is placed on the cooker's surface, the magnetic field induces electrical currents within the vessel.

These electrical currents, known as eddy currents, flow through the cooking vessel, generating heat due to the electrical resistance of the material. The heat is then transferred directly to the food or liquid inside the vessel, resulting in rapid and efficient cooking. The induction cooker itself remains cool to the touch, as it does not generate heat directly.

One of the key advantages of induction cookers is their speed. The induction process allows for rapid heating, significantly reducing the time required to bring ingredients to the desired temperature. Additionally, the precise control over the magnetic field enables precise temperature adjustments, making it easier to achieve consistent cooking results.

Induction cookers also offer improved energy efficiency compared to traditional stoves. Since the heat is generated directly in the cooking vessel, there is minimal heat loss to the surrounding environment. This efficiency not only saves energy but also helps keep the kitchen cooler during cooking.

Another benefit of induction cookers is their safety features. The absence of an open flame or exposed heating elements reduces the risk of accidental burns or fires. Additionally, induction cookers often include features like automatic shut-off and pan detection, which enhance safety and prevent overheating.

In summary, induction cookers offer a fast, efficient, and safe cooking experience. With precise temperature control, energy efficiency, and easy maintenance, they have become a popular choice in modern kitchens. Their ability to deliver quick and consistent results makes them a versatile and convenient option for both professional chefs and home chefs [1]

# *CHAPTER I*

*Induction cooker System*

## 1.1 Introduction

Induction cooking is a fast, efficient, and safe cooking method that uses magnetic fields to create heat. By heating only the cooking vessel itself, induction cookers are able to offer greater precision and control over cooking temperatures, faster heating times, and energy efficiency.[1][2][13]




**Figure 1 :** induction cooker system

## 1.1 History

The first patents were issued in the early 1900s.Demonstration stoves were shown by the Frigidaire division of General Motors in the mid-1950s on a touring showcase. The induction cooker was shown heating a pot of water with a newspaper placed between the stove and the pot, to demonstrate the convenience and safety. This unit was never put into production.

Modern implementations came in the early 1970s, with work done at the Research & Development Center of Westinghouse Electric Corporation. The work was first put on display at the 1971 National Association of Home Builders convention in Houston, Texas, as part of the Westinghouse Consumer Products Division display.The stand-alone single-burner range was named the Cool Top Induction Range. It used parallel Delco Electronics transistors developed for automotive electronic ignition systems to drive the 25 kHz current.

Westinghouse decided to make a few hundred production units to develop the market. Those were named Cool Top 2 (CT2) Induction ranges. The development work was done by a team led by Bill Moreland and Terry Malarkey. The ranges were priced at $1,500 ($8,260 in 2017 dollars), including a set of high quality cookware made of Quadraply, a new laminate of stainless steel, carbon steel, aluminum and another layer of stainless steel (outside to inside). Production began in 1973 and stopped in 1975.

CT2 had four "burners" of about 1,600 watts each. The surface was a Pyroceram ceramic sheet surrounded by a stainless-steel bezel, upon which four magnetic sliders adjusted four corresponding potentiometers below. That design, using no through-holes, made the range impervious to spills. The electronics section was made of four identical modules cooled by a single quiet, low-speed, high-torque fan.

In each of the electronics modules, the 240 V, 60 Hz domestic line power was converted to between 20 V to 200 V of continuously variable DC by a phase-controlled rectifier. The DC power was in turn converted to 27 kHz 30 A (peak) AC by two arrays of six paralleled Motorola automotive-ignition transistors in a half-bridge configuration driving a series-resonant LC oscillator, of which the inductor component was the induction-heating coil and its load, the cooking pan. The circuit design, largely by Ray Mackenzie, successfully dealt with overload problems.

Control electronics included functions such as protection against over-heated cook-pans and overloads. Provision was made to reduce radiated electrical and magnetic fields, Magnetic pan detection was provided.

CT2 was UL Listed and received Federal Communications Commission (FCC) approval, both firsts. Numerous patents were issued. CT2 won several awards, including *Industrial Research Magazine*'s IR-100 1972 best-product award and a citation from the United States Steel Association. Raymond Baxter demonstrated the CT2 on the BBC series *Tomorrow's World*. He showed how the CT2 could cook through a slab of ice.

Sears Kenmore sold a free-standing oven/stove with four induction-cooking surfaces in the mid-1980s (Model Number 103.9647910). The unit also featured a self-cleaning oven, solid-state kitchen timer and capacitive-touch control buttons (advanced for its time). The units were more expensive than standard cooking surfaces.

In 2009 Panasonic developed an all-metal induction cooker that used frequencies up to 120 kHz, three to five times higher than other cooktops, to work with non-ferrous metal cookware.

## 1.2 **Principles**

The main function of an induction cooker is to use electromagnetic induction to generate heat for cooking food. This is done by creating a magnetic field in the cooking zone, which in turn generates heat in the ferromagnetic material of the cooking vessel. The heat is then transferred to the food inside the cooking vessel, allowing it to be cooked.

The key components of an induction cooker include the power electronics that create the electromagnetic field, the cooking zone that contains the field, and the control system that allows users to adjust the temperature and cooking time. Some cookers induction also come with additional features like automatic shut-off, child safety locks, and timer functions.

Overall, the primary function of an induction cooker is to provide a fast, efficient, and precise cooking experience that allows users to cook their food quickly and easily while using less energy than traditional cooking methods.[3][4]

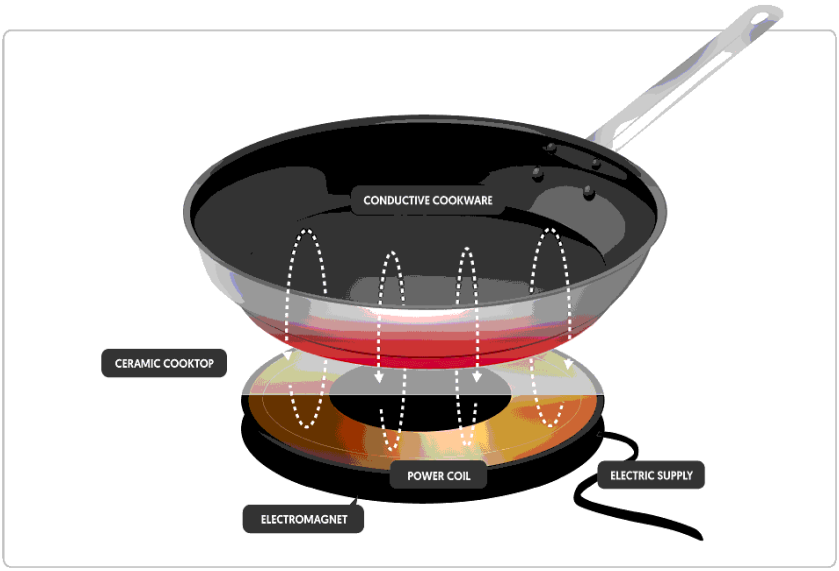



**Figure 2 :** principale function of induction cooker

### 1.2.1 Electromagnetic phenomenon

The non-uniform distribution of current inside an inductor and workpiece leads to temperature variations, causing temperature gradients in the workpiece. This non-uniform current distribution is associated with various electromagnetic phenomena that have a significant impact on the performance of an induction heating (IH) system. Understanding the electromagnetic properties of heated materials is crucial for examining the factors that affect magnetic field distribution and the flow of eddy currents.

#### 1.2.1.1 Electromagnetic induction

Electromagnetic or magnetic induction refers to the generation of an electromotive force (emf) across an electrical conductor when it is exposed to a changing magnetic field.
The discovery of induction is commonly attributed to Michael Faraday in 1831.

Faraday's law of induction, mathematically described by James Clerk Maxwell, provides an explanation for this phenomenon. Lenz's law complements Faraday's law by determining the direction of the induced field. Over time, Faraday's law was further generalized and incorporated into the Maxwell–Faraday equation, which is one of the fundamental equations in Maxwell's theory of electromagnetism.

The practical applications of electromagnetic induction are widespread. It is utilized in various electrical components, such as inductors and transformers, which are essential in electrical systems. Additionally, devices like electric motors , induction heating and generators rely on electromagnetic induction for their operation.

#### 1.2.1.2 Maxwell–Faraday equation

The Maxwell-Faraday equation, also known as Faraday's law of electromagnetic induction, is one of the fundamental equations in electromagnetism. It describes the relationship between a changing magnetic field and the induction of an electric field.

In general, the relation between the emf $\boldsymbol{\varepsilon}$ in a wire loop encircling a surface Σ, and the electric field **E** in the wire is given by :

$$\boldsymbol{\varepsilon} = \oint \boldsymbol{E}.\boldsymbol{dl}$$

where dℓ is an element of contour of the surface Σ, combining this with the definition of flux

$$\emptyset_{\boldsymbol{B}} = \int \boldsymbol{B}\, \boldsymbol{dA}$$

we can write the integral form of the Maxwell–Faraday equation

$$\oint \boldsymbol{E}.\boldsymbol{dl} = -\frac{\boldsymbol{\partial}}{\boldsymbol{\partial t}} \int \boldsymbol{B}\, \boldsymbol{dA}$$

Mathematically, the Maxwell-Faraday equation can be stated as follows :

$$\boldsymbol{\nabla} \times \boldsymbol{E} = -\frac{\boldsymbol{\partial B}}{\boldsymbol{\partial t}}$$

Where:

$\boldsymbol{\nabla} \times \mathbf{E}$ represents the curl of the electric field **E**.

$\boldsymbol{\partial B}/\boldsymbol{\partial t}$ represents the partial derivative of the magnetic field B with respect to time.

This equation states that a changing magnetic field induces a circulating electric field, forming closed loops. It implies that a time-varying magnetic field can generate an electric field, leading to the phenomenon of electromagnetic induction.

The Maxwell-Faraday equation is an essential component of Maxwell's equations, which provide a unified description of electric and magnetic fields and their interactions. These equations form the foundation of classical electrodynamics and have numerous applications in fields such as telecommunications, power systems, and electromagnetic wave propagation.

### 1.2.1.3 Electromagnetic properties of metallic materials

Metallic materials possess electromagnetic properties that have practical applications. They have high electrical conductivity, making them useful for electricity transmission and wiring. Some metals can be easily magnetized due to their magnetic permeability. Eddy currents, generated in metallic materials by changing magnetic fields, are utilized in induction heating. At high frequencies, metals exhibit the skin effect, concentrating current near the surface. Metallic materials are reflective and can effectively shield against electromagnetic radiation. Certain metals have resonance and antenna properties for wireless communication systems. Understanding these electromagnetic properties is crucial for designing efficient devices in various fields like electronics and power transmission.

### 1.2.1.4 Electrical resistivity

Electrical resistivity, often denoted as **ρ** (**rho**), is a fundamental property of materials that quantifies their ability to resist the flow of electric current. It is a measure of how strongly a material opposes the movement of electric charges through it.

Mathematically, resistivity is defined as the ratio of the electric field (**E**) to the current density (**J**) in a material:

$$\rho = E / J$$

The unit of resistivity is typically expressed in ohm-meters (**Ω·m**).

Materials with high resistivity impede the flow of electric current, while materials with low resistivity allow for easier current flow. Metals, such as copper and aluminum, are known for their low resistivity and are commonly used as conductors in electrical wiring and transmission lines.

In contrast, insulating materials like rubber or plastic have high resistivity, preventing or limiting the flow of electric current. This property makes them suitable for electrical insulation purposes.

Resistivity depends on various factors, including the material's atomic structure, temperature, and impurity content. It is often specified in material data sheets and is an essential parameter

in designing electrical circuits, determining the power dissipation in conductors, and calculating voltage drops across different components.

Resistivity is related to another electrical property known as conductivity (σ), which is the reciprocal of resistivity (**$\sigma = 1/\rho$**). Conductivity measures how easily a material allows electric current to pass through it. Materials with high conductivity have low resistivity, and vice versa.

## 1.3 **Induction cooker properties**

Cookers induction are known for their energy efficiency, speed, precision, safety, and ease of cleaning. They use electromagnetic induction to generate heat, which means that they only heat the cooking vessel itself and not the surrounding air, making them highly energy-efficient. They are also very fast at heating up and cooling down, which makes them ideal for cooking meals quickly. Additionally, they offer precise temperature control, which allows for more precise cooking. They are very safe to use because the cooktop itself doesn't get hot, which reduces the risk of burns and other accidents. Finally, induction cookers are easy to clean because spills and splatters don't get baked on, making them a great choice for busy households.[3]

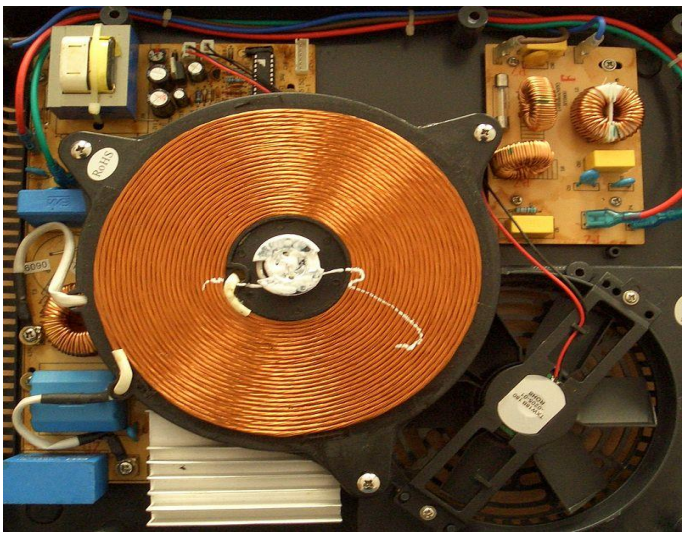


**Figure 3 :** Diffrent elements of induction cooker

## 1.4 **Power and control**

Induction cooking provides fast heating, improved thermal efficiency, and more consistent heating than cooking by thermal conduction, An induction cooker transfers electrical energy by induction from a coil of wire into a metal vessel trough a ceramic glass, without wasting higher heat all of that because of the induction and the magnatique field advantage [5][14]

## 1.5 **Materials**

Induction cookware is specifically designed to work with induction cookers, which require the use of magnetic materials to create the electromagnetic field that generates heat. Induction cookware is typically made from materials like stainless steel or cast iron, which have magnetic properties that allow them to interact with the magnetic field created by the induction cooker. Non-magnetic materials like aluminum, copper, and glass are not suitable for use with induction cookers and will not work properly. Induction cookware is available in a variety of shapes and sizes, including pots, pans, griddles, and woks, and can be used for a wide range of cooking tasks. When choosing induction cookware, it's important to look for high-quality materials and sturdy construction to ensure that the cookware can withstand the high heat and rapid temperature changes that can occur when cooking with an induction cooker.[3]

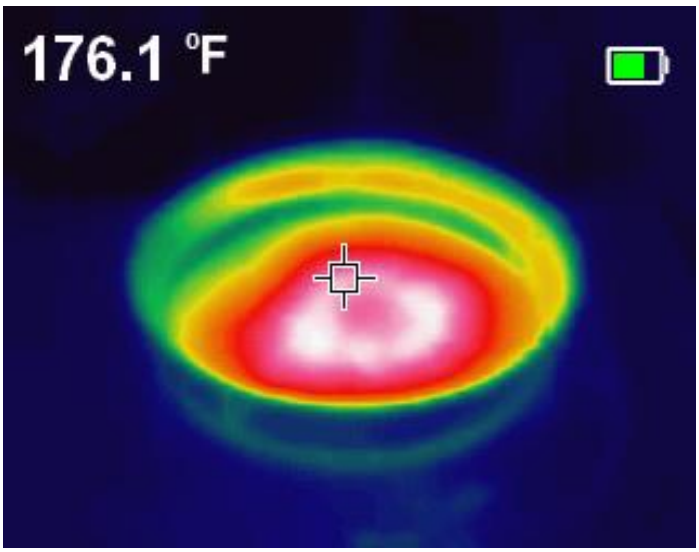



**Figure 4 :** Thermal image of cookware

## 1.6 Energy efficiency

Induction cookers are highly energy-efficient because they only heat the cooking vessel itself, rather than heating the air around the vessel, as traditional gas or electric stovetops do. This means that less heat is wasted, and more of it is transferred to the food.[7]

## 1.7 Speed:

Induction cookers are very fast at heating up and cooling down, which makes them ideal for cooking meals quickly. They are also more responsive than traditional stovetops, as they can quickly adjust the temperature to match changes in cooking requirements.

## 1.8 Precision:

Induction cookers offer precise temperature control, which allows for more precise cooking. They also heat up and cool down quickly, which makes it easier to control the temperature and avoid overcooking or undercooking food.[8][9]

## 1.9 Safety

Induction cookers are very safe to use because the cooktop itself doesn't get hot, which reduces the risk of burns and other accidents. They also come with various safety features such as automatic shut-off, child safety locks, and pan detection.[10]



**Figure 5 :** Image present the safty of induction cooker

## 1.10 **Easy to clean**

Induction cookers are easy to clean because the cooktop doesn't get hot, which means that spills and splatters don't get baked on. They are also easy to wipe down and maintain, making them a great choice for busy households.

## 1.11 **Noise**

Induction cookers typically make very little noise when in use. The most common sound you may hear from an induction cooker is a faint hum or buzzing noise that comes from the power electronics that create the magnetic field. This noise is usually not very loud and can be easily drowned out by other ambient sounds in the kitchen.

However, some induction cookers may produce a higher-pitched noise when the cooking zone is turned on or off. This noise is usually caused by the vibration of the metal components inside the cooker and can be more noticeable than the humming sound. However, the noise is still relatively quiet and is unlikely to be a major distraction.

Overall, induction cookers are generally very quiet when in use, which can be a big advantage for home cooks who want to be able to cook without disturbing others in the household.[11]

## 1.12 **Ventilation**

Induction cookers do not produce smoke or combustion byproducts like gas stoves, but they still produce heat and moisture that can build up in the kitchen and cause discomfort. As a result, ventilation is still important when using an induction cooker.

It's important to choose the right type of ventilation system for your induction cooker to ensure that the kitchen remains comfortable and free from smoke and moisture. Additionally, regular cleaning of the ventilation system is important to maintain its effectiveness and prevent the buildup of grease and other cooking residues.[12]

## 1.13 **Induction cooker VS alternative systems comparison**

| | Induction Cooker | Gas System | Electric System |
|---|---|---|---|
| Heating Technology | Uses electromagnetic induction to heat cookware directly. | Uses open flames produced by burning gas. | Uses heating elements to transfer heat to cookware indirectly. |
| Heat Generation | Rapid and precise heating. | Instantaneous heating with open flames. | Slower heating and less precise temperature control. |
| Energy Efficiency | Highly efficient. | Efficient but some heat is lost to the surroundings. | Less efficient due to heat loss during heat transfer. |
| Cooking Speed | Heats up quickly, reducing cooking time. | Provides instant high heat for fast cooking. | Takes longer to heat up and may prolong cooking time. |
| Safety | Cooktop remains cool to touch, reducing the risk of burns. | Flames present a burn and fire hazard. | Cooktop gets hot during and after cooking, posing a burn risk. |
| Heat Distribution | Even heat distribution across the cookware surface. | Heat distribution may vary depending on the flame and cookware position. | Heat distribution may be uneven, leading to hot spots. |
| Cleaning | Smooth, flat surface makes it easy to clean spills and | Requires cleaning of gas burners, grates, and potentially more | Requires more effort to clean due to heating elements and |

| | | | |
|---|---|---|---|
| | splatters. | maintenance. | drip pans. |
| Cookware Compatibility | Requires magnetic cookware (ferrous materials) for induction to work. | Compatible with a wide range of cookware materials. | Compatible with a wide range of cookware materials. |
| Energy Source | Requires electricity. | Requires natural gas or LPG (liquefied petroleum gas). | Requires electricity. |
| Environmental Impact | More energy-efficient, reducing carbon footprint. | Natural gas is a fossil fuel and contributes to carbon emissions. | Less energy-efficient, resulting in a higher carbon footprint. |
| Cost | Generally more expensive. | Less expensive. | Generally less expensive. |

## 1.14 **Conclusion**

In conclusion, the electromagnetic field is a fundamental concept in physics and plays an important role in many modern technologies, including induction cookers. By creating a magnetic field that interacts with magnetic materials in cookware, induction cookers are able to generate heat quickly and efficiently, making them a popular choice for many home cooks. Understanding the principles of electromagnetic fields can help us better understand the operation of induction cookers and other electromagnetic devices, and can inform the development of new technologies in the future. [13]

# *Chapter II*

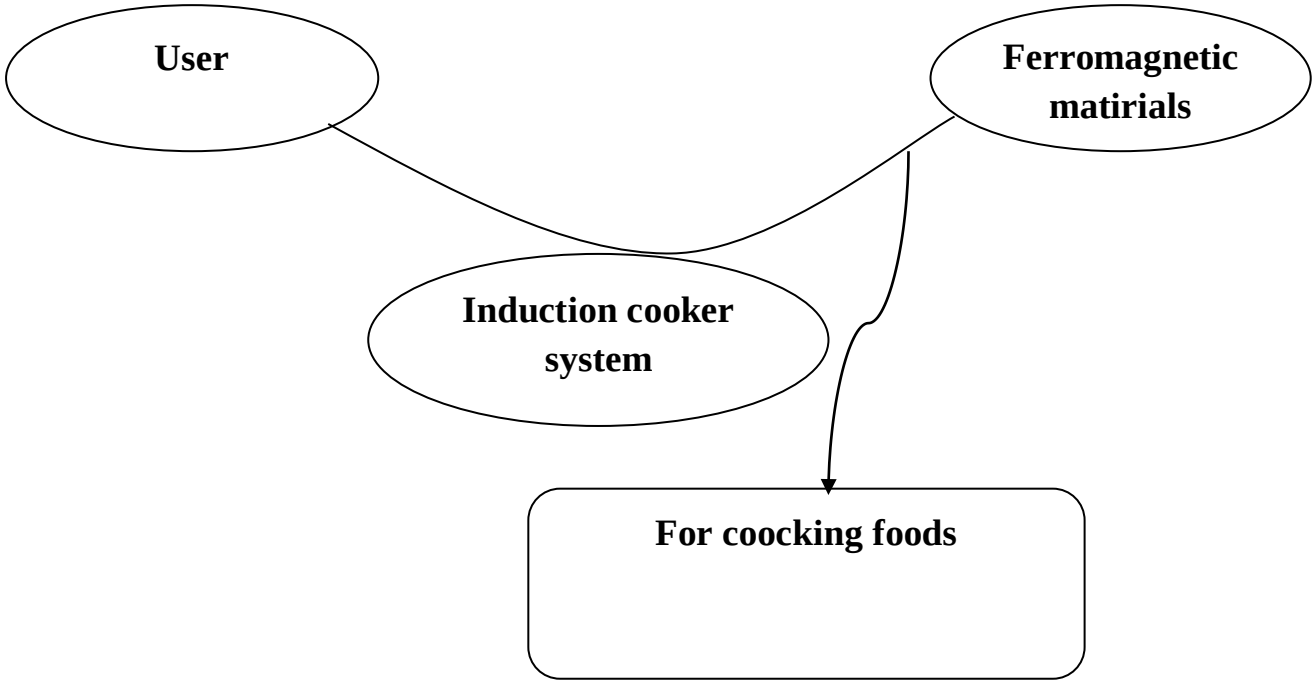
## *Functional analysis*

## 2.1 Introduction

The second chapter of an induction cooker system analysis typically focuses on functional analysis, which involves breaking down the system into its individual components and analyzing their respective functions and interactions. This chapter often begins with a description of the system's overall goals and objectives, such as providing efficient and safe cooking capabilities for users. The chapter then proceeds to examine each component of the system, including the induction cooker, cookware, and ventilation system, and analyzes how they contribute to achieving the system's overall goals. This analysis may involve detailed examinations of the system's performance under various operating conditions, as well as consideration of factors such as energy efficiency, safety, and ease of use. The functional analysis chapter is an important component of the overall analysis of an induction cooker system, as it provides a detailed understanding of the system's operation and can inform efforts to improve its performance, efficiency, and safety.

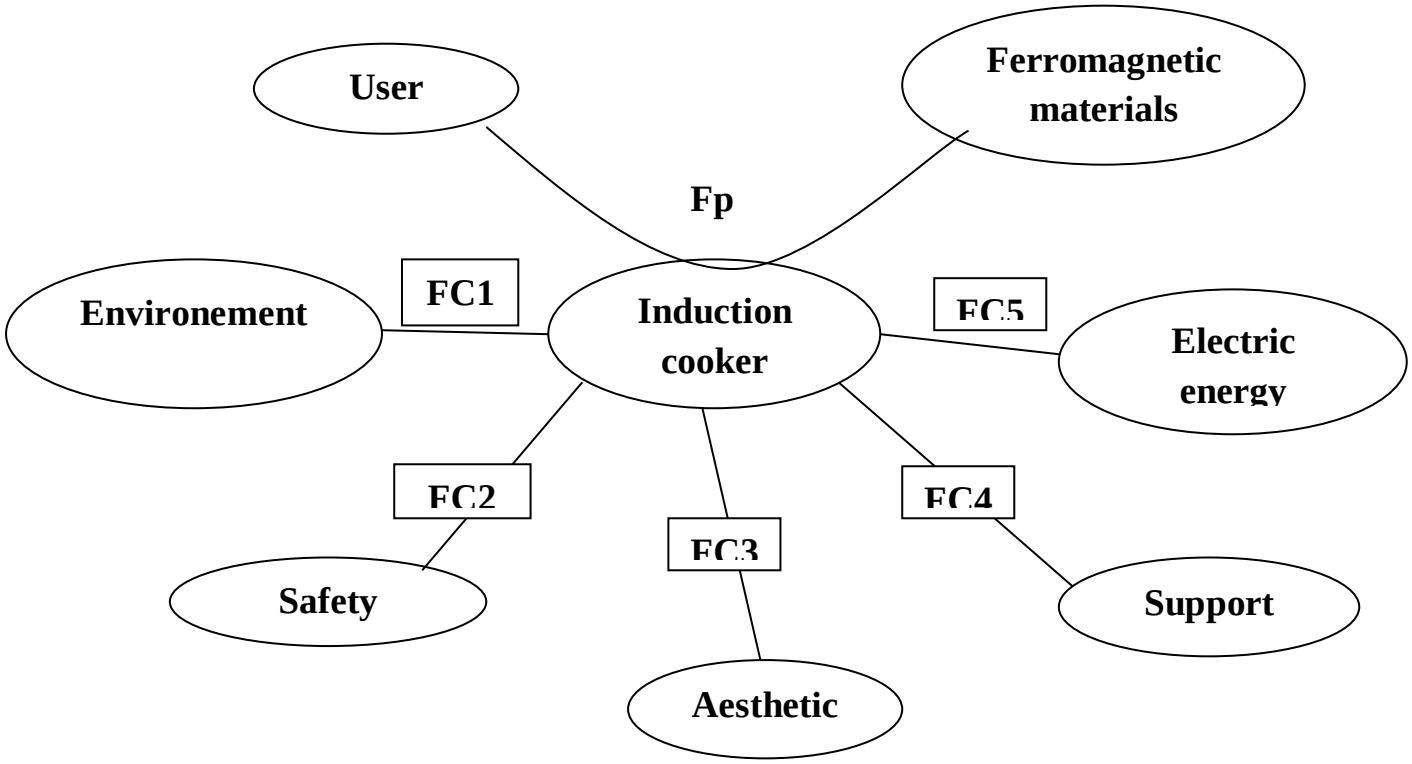
## 2.2 External functional analysis

### 2.2.1 beta-kernal plot



| Questions | Answers |
|---|---|
| To whom the product renders it services ? | For users |
| What does the product act on ? | On ferromagnetic materials |
| For what purpose ? | For cooking foods |

### 2.2.2 Octopus diagram



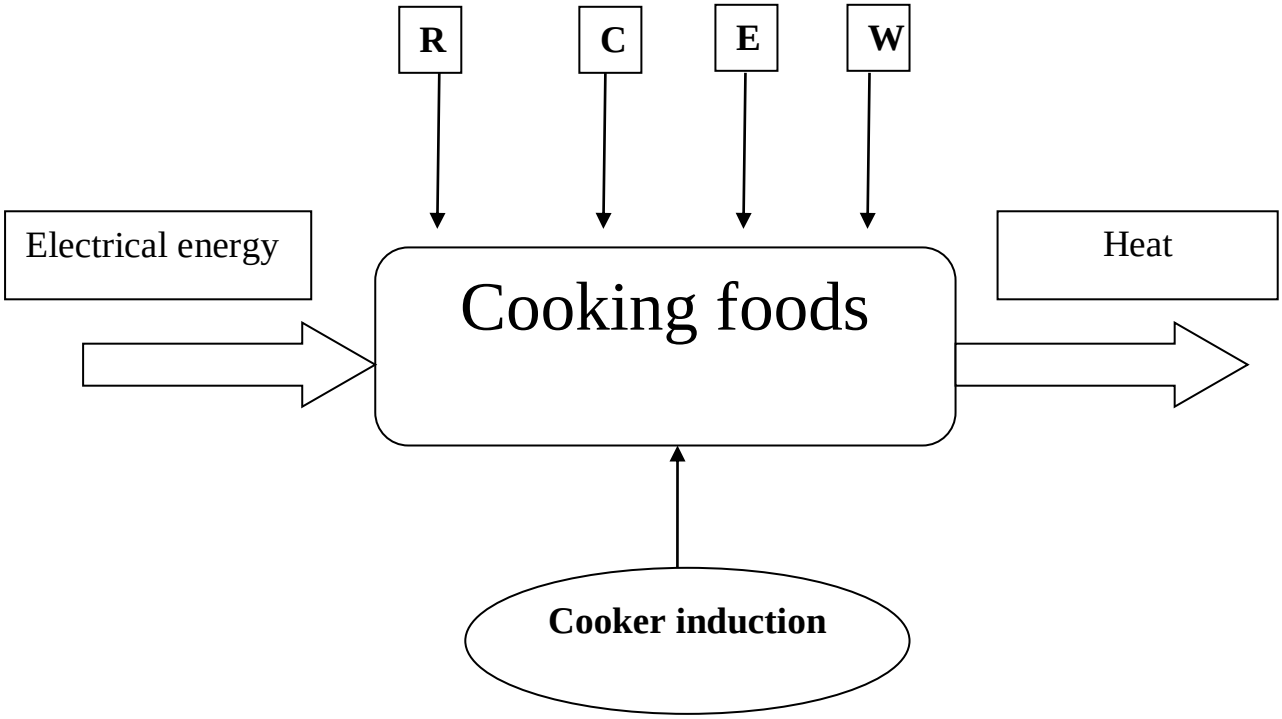

| Function | Designation |
|---|---|
| FP | Converting electrical energy to magnetic field |
| FC1 | To respect environement |
| FC2 | To respect safety norms |
| FC3 | To satisfy the user |
| FC4 | To have a support for moving the system |
| FC5 | To use energy in rational way |

### 2.2.3 Functional specifications document

| Reference point | Functions | Parameters | Levels | Flexibility |
|---|---|---|---|---|
| FP | Converting electrical energy to magnetic field | Coil | | 1 |
| FC1 | To respect environement | Norms | Iso 14000 | 0 |
| FC2 | To respect safety norms | Norms | Iso 15000 | 0 |
| FC3 | To satisfy the user | Form<br>Color | Squar<br>Black | 1<br>1 |
| FC4 | To have a support for moving the system | Chassis | L=20cm<br>H=6cm<br>W=20cm | 1<br>1<br>1 |
| FC5 | To use energy in rational way | Tension<br>Current<br>Frequency | 220V<br>0.5A<br>50Hz | 0<br>0<br>0 |

## 2.3 Internal functional analysis

2.3.1 A-0 Diagram



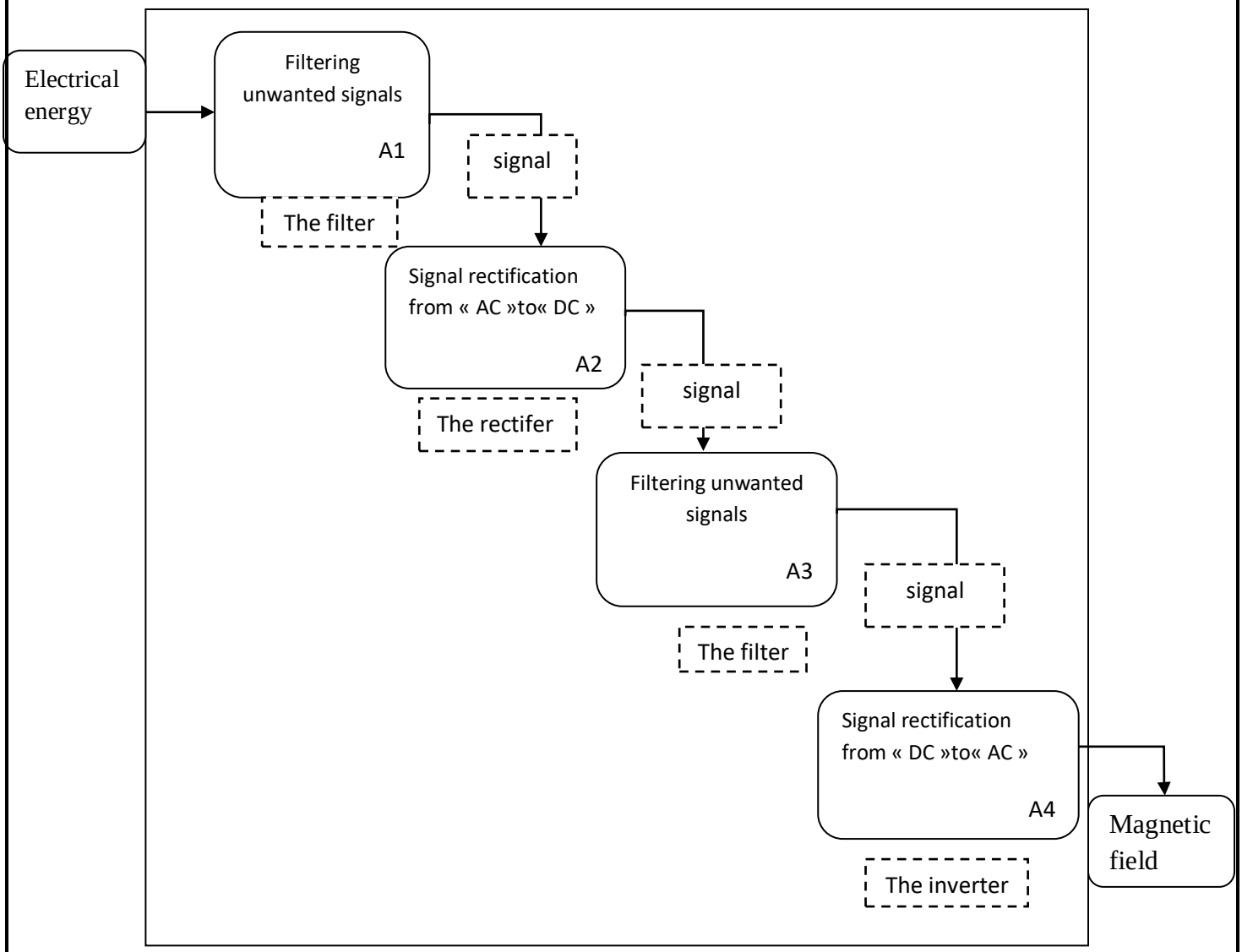
**R :** Setting parameter.

**W :** energy ordering.

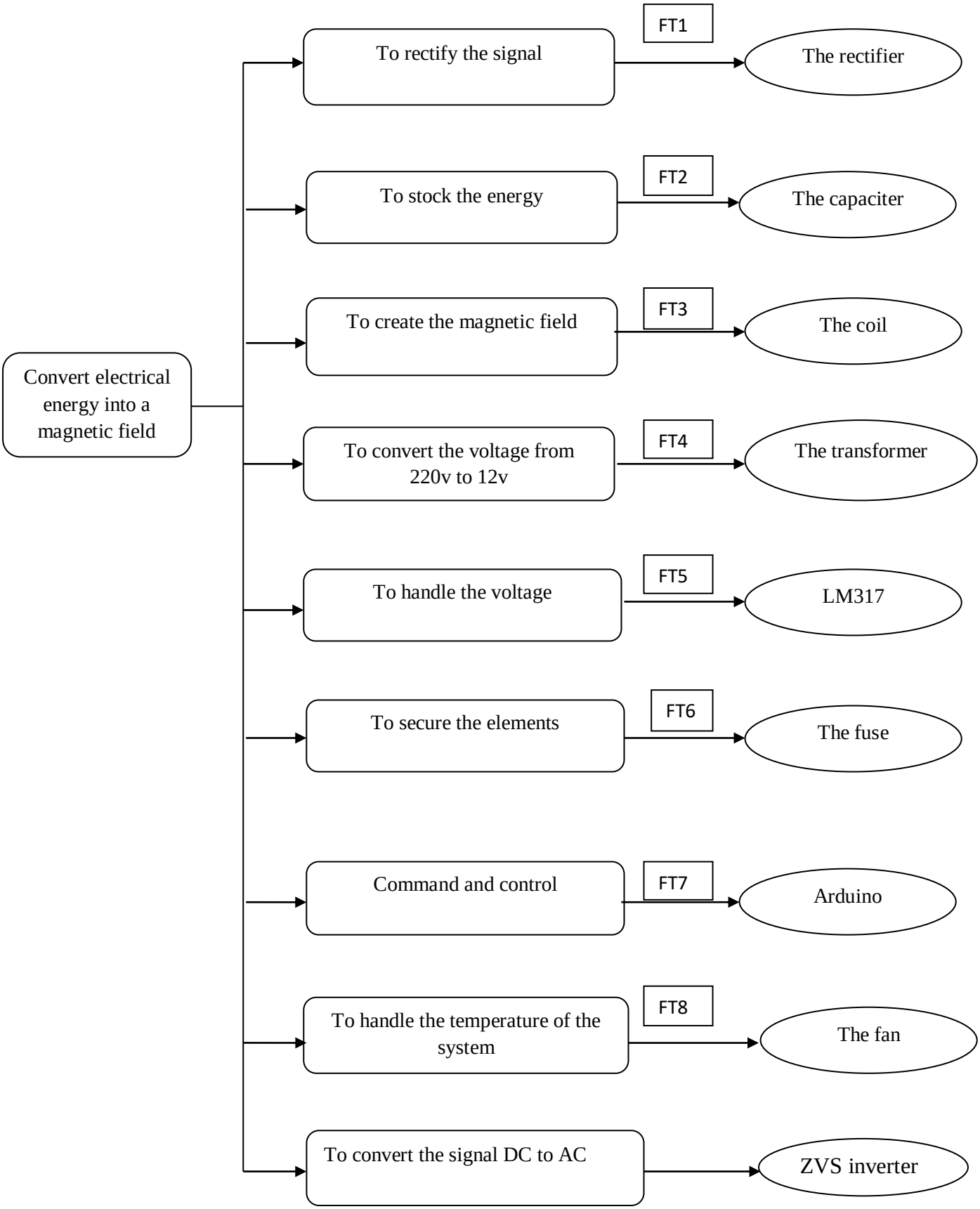
**C :** Configuration parameter.

**E :** Operational data.

### 2.3.2 A0 Diagram



### 2.3.3 FAST Diagram



### 2.3.4 Technical document

| function | Technical function | Technical criteria |
|---|---|---|
| **FT 1** | Rectifier | Diode –THT : diode –Bridge<br>Vishay –GBL |
| **FT2** | Capacitor | Capacitor THT : CP-Radial<br>D =14,00mm, p=7.50mm<br>C =0.3 uF |
| **FT 3** | Coils | L= |
| **FT4** | Transformer | Transformer<br>Trans 220 to 12v |
| **FT5** | LM317 | V Input = 12v<br>V Output = 1.2 – 37v |
| **FT6** | Fuse | V =220v, 230v<br>I=1A<br>F= 50Hz à 500 Hz |
| **FT7** | Arduino | Cpu = Atmega328<br>V = 5v<br>Flash = 32 KB<br>RAM = 2 KB<br>Clock Speed=16MHz |
| **FT8** | Fan | Dimension 120*120*25 mm<br>2pin=12v |
| **FT9** | ZVS inverter | Vin = 310DC<br>Vout=400 AC<br>F= 50kHz |

## 2.4 Conclusion

The analysis diagram for an induction cooker is a useful tool for understanding the different components involved in the cooking process and how they work together to provide efficient and precise cooking. The diagram can help users troubleshoot issues with their induction cookers and help manufacturers optimize the design and performance of their products.

# *Chapter III*

## *Power Supply and Control Techniques*

## 3.1 Introduction

Induction cooker is a popular technology used in modern cooktops that relies on power electronics to convert electrical energy into heat. Induction cooktops use a high-frequency alternating current (AC) to create a magnetic field, which induces eddy currents in the cookware, generating heat. This process is highly efficient and allows for precise temperature control, making induction cooktops a popular choice for modern kitchens. To generate the high-frequency AC required for induction cooking, various types of power converters are utilized, including AC-DC, DC-DC, DC-AC, and AC-AC converters. In addition to power converters, power inverters are also employed to control the power output to the induction coils. Half-bridge inverters, full-bridge inverters, zero voltage switching (ZVS) ,and multi-level inverters are among the commonly used power inverters in induction cooktops. These power electronics devices enable efficient and precise control over the induction coils for optimal cooking performance.[19]

## 3.2 Inverters DC-AC

A DC-AC inverter consists of a power conversion stage, a control circuit, and an output filter. The power conversion stage uses power switches like IGBTs to convert the DC input voltage into an AC voltage. The control circuit monitors the output voltage and current,

and adjusts the switching frequency and duty cycle of the power switches to maintain a stable output voltage. An output filter is also used to remove high-frequency components in the output waveform and to smooth out the waveform to produce a sine wave or modified sine wave. The inverter gain is the ratio between the AC output voltage and the DC input voltage. By adjusting the gain of the inverter through Pulse Width Modulation (PWM) control, a variable output voltage can be achieved even if the DC input voltage is fixed and cannot be controlled. In summary, DC-AC inverters are essential in transforming DC input voltage into a symmetric AC output voltage with a desired magnitude and frequency, with the ability to produce a fixed or variable output voltage and frequency depending on the application requirements.[15]

## 3.3 Different Types of a DC-AC inverters

There are various techniques used in the design of inverters, each with its advantages and limitations. Some of the common techniques used in inverters are full-bridge, half-bridge, and zero-voltage switching (ZVS) inverters.

### 3.3.1 Full Bridge Inverter

A full bridge inverter uses four switches to convert DC voltage to AC voltage. The switches are typically made up of insulated gate bipolar transistors (IGBTs) or MOSFETs. The full bridge inverter is capable of producing an AC voltage with a magnitude equal to the DC input voltage. It is also capable of producing both positive and negative AC voltages.[16]

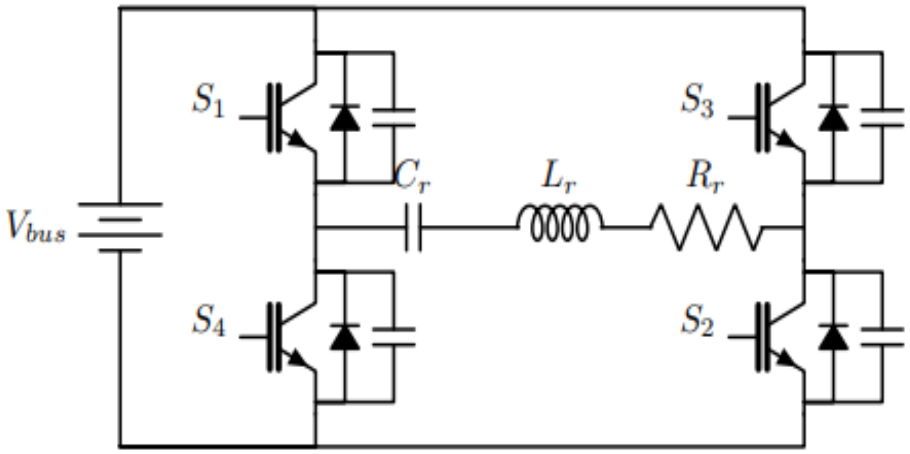



**Figure 6 :** Full Bridge Inverter

### 3.3.1.1 Single phase full bridge inverters

The diagram (Fig. 7) illustrates the most common configuration of an inverter known as the full bridge or H bridge. This configuration consists of four legs, each equipped with a switch. When switches S1 and S2 are closed, electricity flows from the DC supply through the output circuit in a left-to-right direction. Conversely, when switches S1 and S2 are open and switches S3 and S4 are closed, the current flows in the opposite direction, from right to left. By controlling the opening and closing of these switches, the frequency of the generated alternating current can be determined as this cycle repeats.

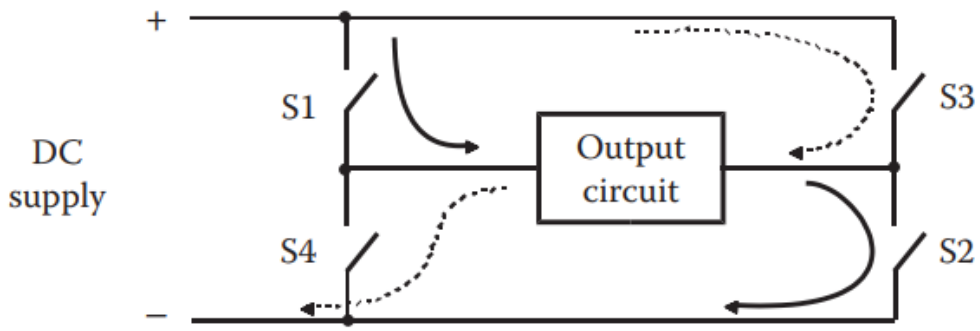



**Figure 7 :** Basic full-bridge inverter

In the single-phase full bridge inverter, there are four switches or power devices connected in a bridge formation. The switches are typically semiconductor devices such as MOSFETs or IGBTs (Insulated Gate Bipolar Transistors). The bridge configuration consists of two pairs of switches, with each pair forming a leg of the bridge.

When operated, the switching sequence of the four switches determines the direction and magnitude of the AC output voltage. By appropriately opening and closing the switches in a specific pattern, the DC input voltage is switched across the output load, resulting in an AC waveform.

For example, when switches S1 and S4 are closed while switches S2 and S3 are open, the current flows from the positive terminal of the DC source through the load and returns to the negative terminal. This creates a positive half-cycle of the AC waveform. Reversing the switching states of the pairs of switches generates the negative half-cycle of the AC waveform.

By controlling the switching frequency and duty cycle of the switches, the desired AC waveform frequency and voltage magnitude can be achieved. Single-phase full bridge inverters are commonly used in various applications, including residential and commercial power systems, renewable energy systems, and motor drives.

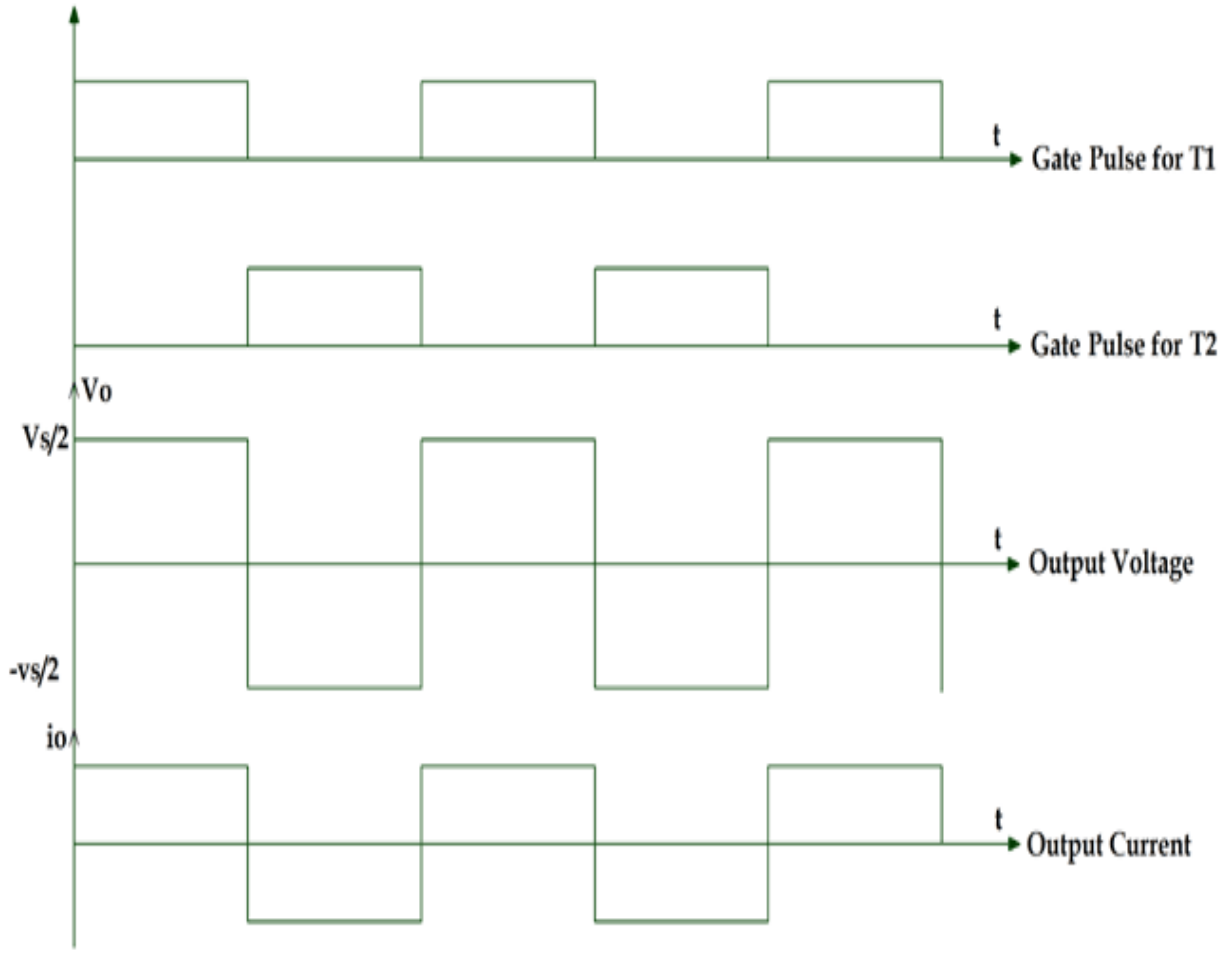



**Figure 8 :** Single phase full bridge inverter

### 3.3.1.2 Full Bridge Inverter Functionality

The full bridge inverter is a power electronic device used to convert DC (direct current) power into AC (alternating current) power. It utilizes a full bridge configuration, also known as an H bridge, to perform the inversion process. Here's a breakdown of the functionality of a full bridge inverter:

1) Power Conversion: The primary function of a full bridge inverter is to convert the DC input voltage into AC output voltage. The DC input is typically obtained from a DC power source such as a battery or a rectifier.

2) Switching Operation: The full bridge inverter consists of four switches or power devices, usually semiconductor devices like MOSFETs or IGBTs. The switches are arranged in a bridge formation, with two switches connected in series on each side of the bridge. The switching operation of these devices controls the flow of current through the inverter.

3) Pulse Width Modulation (PWM): To generate the desired AC waveform, the full bridge inverter employs Pulse Width Modulation techniques. By adjusting the switching states and durations of the switches, the inverter can control the magnitude and frequency of the output AC waveform.

4) Switching States: The switches in the full bridge inverter can be in one of four possible states: ON, OFF, or in transition between ON and OFF. The specific switching pattern determines the polarity and timing of the AC waveform.

5) Output Voltage Control: The full bridge inverter allows for precise control of the output AC voltage. By adjusting the pulse widths and timing of the switches, the inverter can regulate the magnitude and waveform of the output voltage according to the desired requirements.

6) Output Filtering: Since the inverter generates an AC waveform that consists of multiple harmonics, an output filter is often used to smooth the waveform and remove unwanted harmonics. The filter typically includes components such as capacitors and inductors to achieve a cleaner AC output.

7) Applications: Full bridge inverters find applications in various fields such as power systems, renewable energy systems (e.g., solar or wind power), motor drives, uninterruptible power supplies (UPS), and electric vehicle systems.

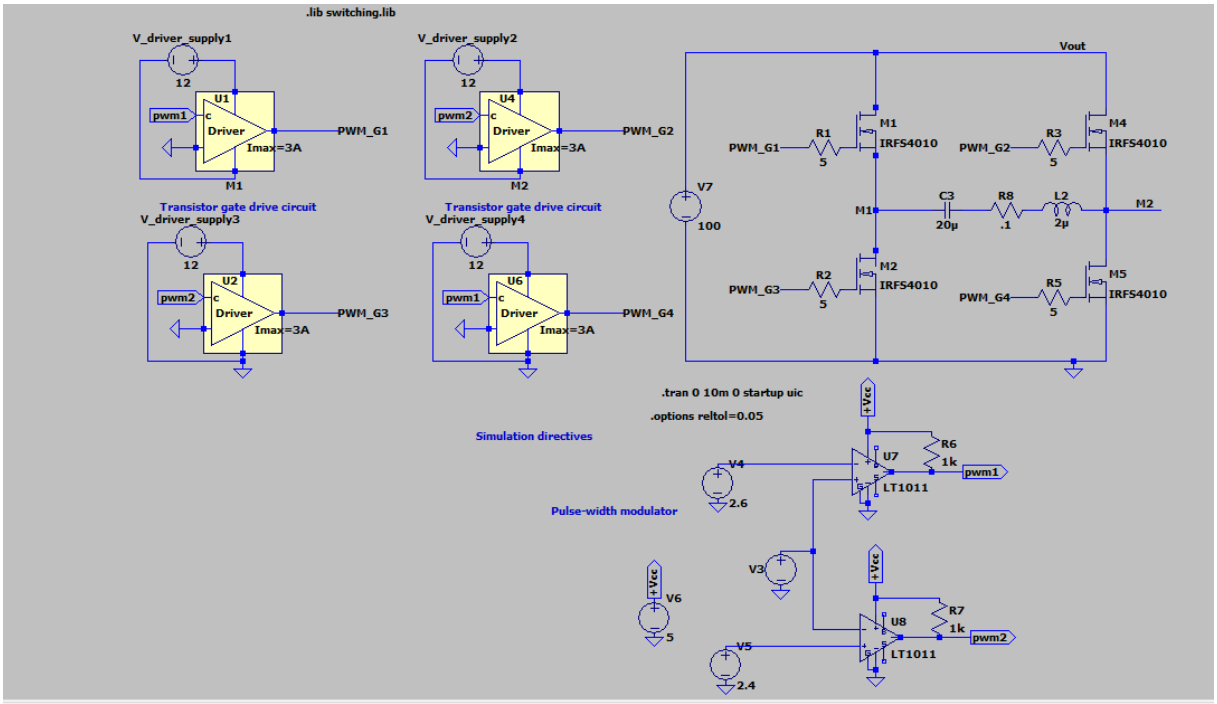



**Figure 9 :** Full Bridge Inverter Simulation

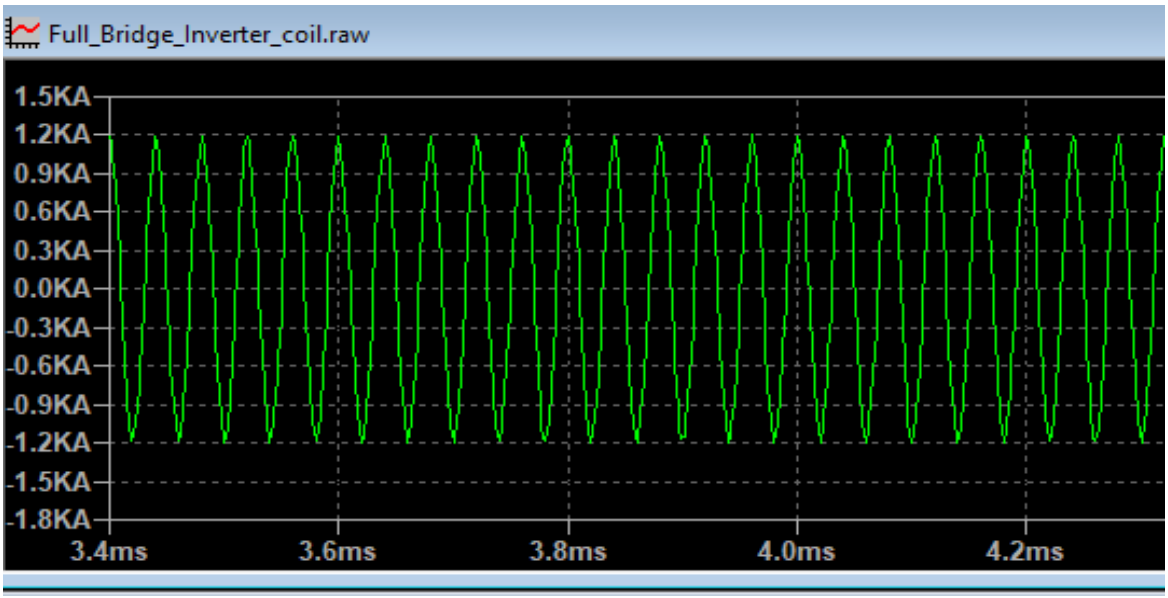



**Figure 10 :** Coil Current Signal

In summary, the full bridge inverter functions by switching the DC input voltage across the output load using a bridge configuration of switches. Through precise control of the switching states and durations, it generates an AC output waveform with adjustable magnitude and frequency, making it a versatile device for power conversion applications

### 3.3.2 Half Bridge Inverter

A half bridge inverter is a type of DC-AC inverter similar to full bridge inverter,However it uses two switches,the circuitry is relatively simple and cost-effective, making it a popular choice for Low-power applications.[17]

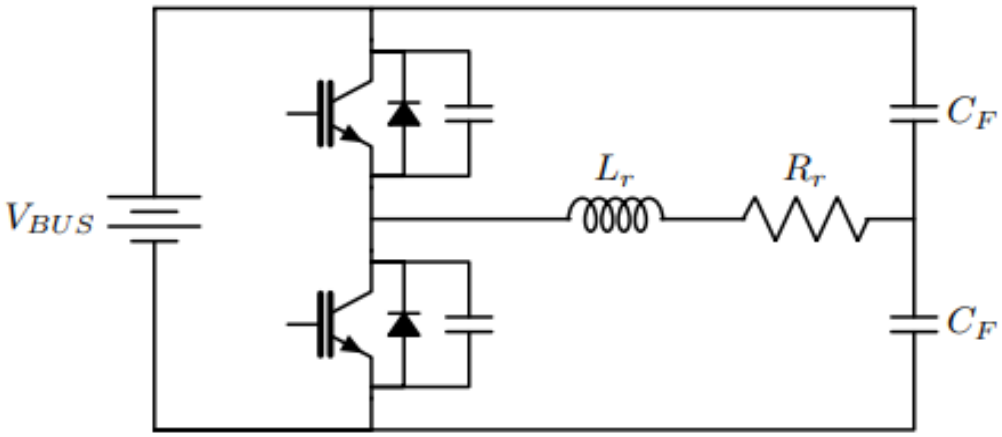



**Figure 11 :** Half Bridge Inverter

#### 3.3.2.1 Single phase falf bridge inverters

A single-phase half bridge inverter is a type of power inverter that converts a DC (direct current) input into a single-phase AC (alternating current) output. It is a simpler version of the full bridge inverter, utilizing only two switches or power devices instead of four. Here's an overview of the functionality of a single-phase half bridge inverter:

1) Power Conversion: Similar to other inverters, the single-phase half bridge inverter converts the DC input voltage into AC output voltage. The DC input is typically obtained from a DC power source such as a battery or a rectifier.

2) Switching Operation: The half bridge inverter consists of two switches or power devices, typically semiconductor devices like MOSFETs or IGBTs. These switches are connected in a half bridge configuration, with one switch connected to the positive terminal of the DC source and the other switch connected to the negative terminal.

3) Pulse Width Modulation (PWM): The half bridge inverter uses Pulse Width Modulation techniques to control the output AC waveform. By adjusting the switching states and durations of the switches, the inverter can vary the width of the pulses to generate the desired AC waveform.

4) Switching States: The switches in the half bridge inverter can be in one of three possible states: ON, OFF, or in transition between ON and OFF. The specific switching pattern determines the polarity and timing of the AC waveform.

5) Output Voltage Control: The half bridge inverter allows for control of the output AC voltage by adjusting the pulse widths and switching frequencies of the switches. This enables regulation of the magnitude and waveform of the output voltage according to the desired requirements.

6) Output Filtering: Similar to other inverters, the half bridge inverter may require an output filter to smooth the AC waveform and remove unwanted harmonics. The filter components such as capacitors and inductors help achieve a cleaner AC output.

7) Applications: Single-phase half bridge inverters find applications in various low-power and cost-sensitive applications where single-phase AC power is required. These include small motor drives, household appliances, lighting systems, and small renewable energy systems.

It's important to note that while single-phase half bridge inverters are simpler and more cost-effective than full bridge inverters, they have limitations in terms of power handling capacity and harmonic content. For higher power applications or improved waveform quality, full bridge inverters are typically preferred.

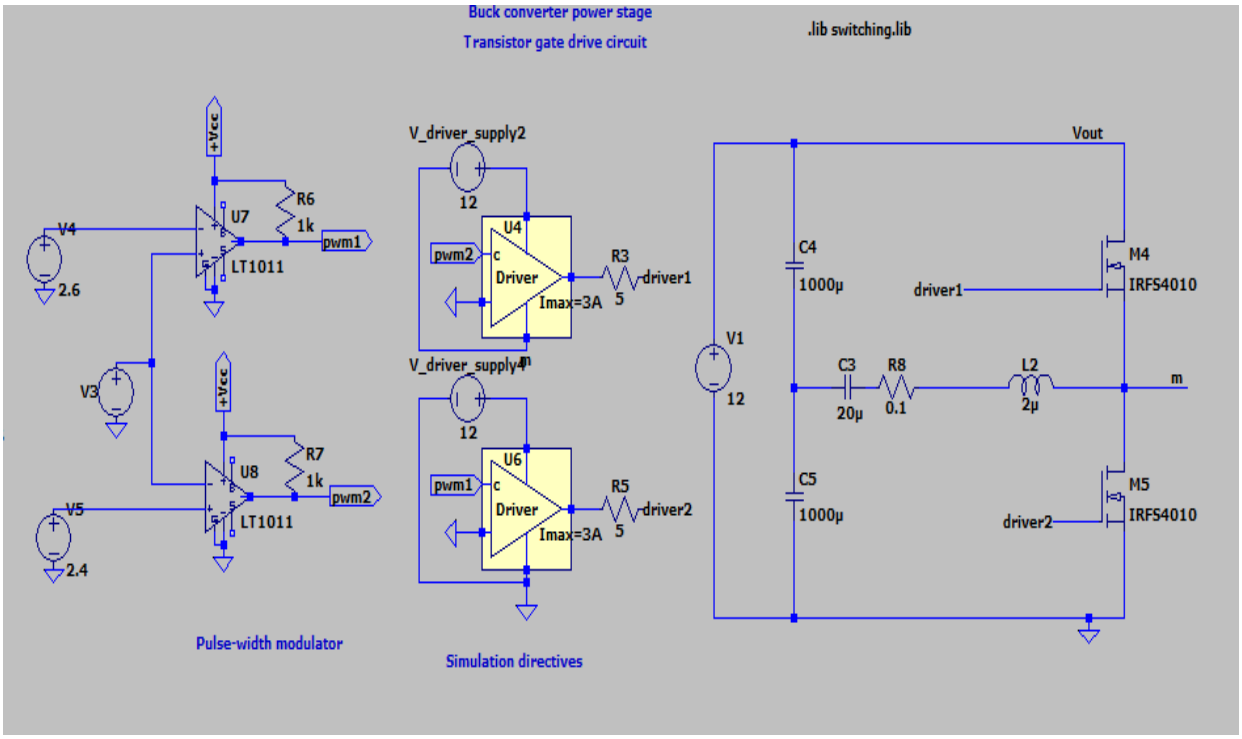



**Figure 12 :** Half Bridge Inverter

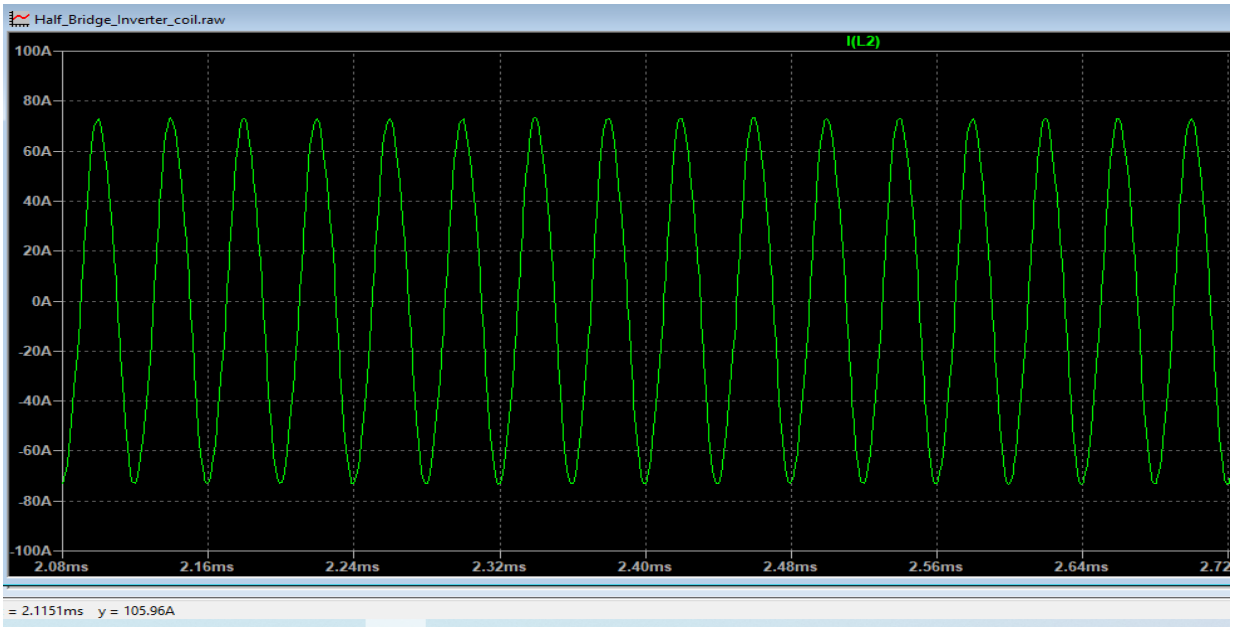



**Figure 13 :** Coil Current Signal

### 3.3.3 Zero voltage switching (ZVS)

A ZVS (Zero Voltage Switching) inverter is a type of power electronic inverter that operates with zero voltage switching for improved efficiency and reduced switching losses. It is commonly used in applications such as renewable energy systems, uninterruptible power supplies (UPS), and high-frequency induction heating.

In a ZVS inverter, the switching devices (typically insulated gate bipolar transistors or IGBTs) are turned on and off at zero voltage crossings of the input voltage waveform. This switching technique minimizes the energy loss associated with switching transitions, leading to improved efficiency and reduced stress on the switching devices.[18]

#### 3.3.3.1 The benefits of ZVS inverters

- **Reduced Switching Losses:** By switching the devices at zero voltage crossings, ZVS inverters significantly reduce the switching losses, which are primarily caused by voltage and current spikes during the switching transitions. This leads to higher efficiency and lower heat generation.

- **Improved Power Quality:** ZVS inverters offer improved power quality due to the reduced switching losses and minimized voltage and current distortions during the switching transitions. This results in lower harmonic content and better overall performance.

- **Higher Switching Frequencies :** ZVS inverters can operate at higher switching frequencies compared to conventional inverters. The reduced switching losses enable faster switching speeds, allowing for higher-frequency operation, which can be advantageous in certain applications such as induction heating and high-frequency power supplies.
- **Enhanced Reliability** : The reduced stress on the switching devices and improved thermal management contribute to increased reliability and lifespan of the inverter.

Lower heat generation and optimized switching reduce the risk of device failure and enhance the overall system reliability.

- **Lower Electromagnetic Interference (EMI) :** ZVS inverters tend to generate less electromagnetic interference compared to conventional inverters. The reduced voltage and current spikes during switching transitions minimize EMI emissions, making them suitable for applications with strict EMI regulations.[24]

It's worth noting that ZVS inverters require careful design considerations, including control strategies and circuit topologies, to ensure proper operation and maximize the benefits of zero voltage switching. Advanced control techniques and circuit optimization are often employed to achieve optimal performance and efficiency.[18][19]

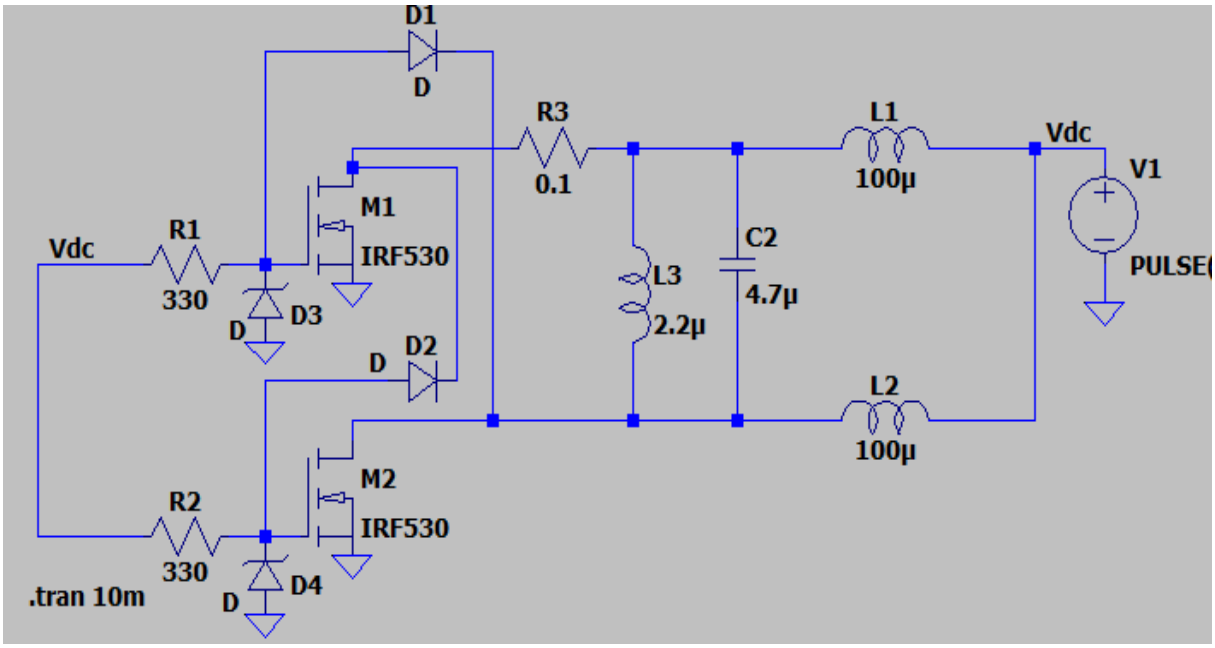



**Figure 14 :** Zero Voltage Switch Inverter (ZVS)

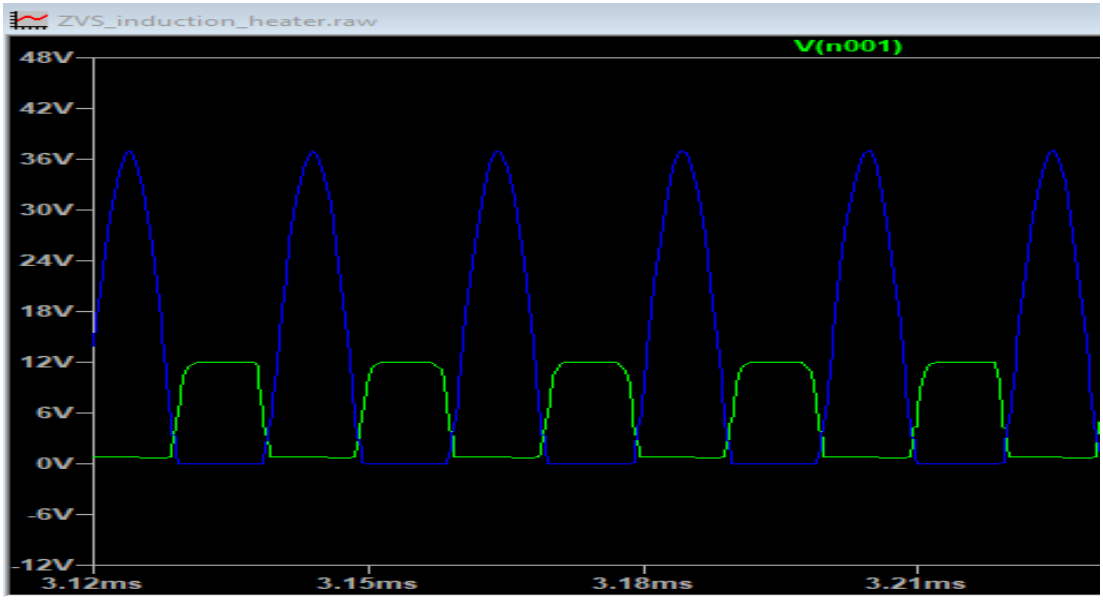



**Figure 15 :** ZVS Simulation

## 3.4 Performance comparison of different converter topology

| Name | Advateges | Diadvateges | Application |
|---|---|---|---|
| Single -switch | ➢ **Simple topology.**<br>➢ **Minimum loss.**<br>➢ **Small size.** | ➢ **Low power capacity(less then 2 kw).**<br>➢ **More switching stress.** | ➢ **Domestic** |
| Half -bridge | ➢ **Easy to control**<br>➢ **Less conducting and switching losses** | ➢ **Medium power capacity(2 – 5 KW)** | ➢ **Domestic** |
| Full-bridge | ➢ **Higher power capacity(more than 5 KW)** | ➢ **High losses**<br>➢ **High cost** | ➢ **Industry** |

## 3.5 Conclusion

In this chapter, we have explored the significance of DC-AC inverters in various applications. By converting DC power to AC power, these inverters enable the seamless integration of DC sources into AC-based systems. The choice of inverter topology, such as full bridge, half bridge, or H-bridge, depends on factors like power requirements, control complexity, and voltage rating. Each topology offers distinct advantages tailored to specific power levels. The selection of the appropriate inverter topology ensures efficient power conversion and successful integration of DC and AC technologies.[19][18][17]

# *CHAPTER V*

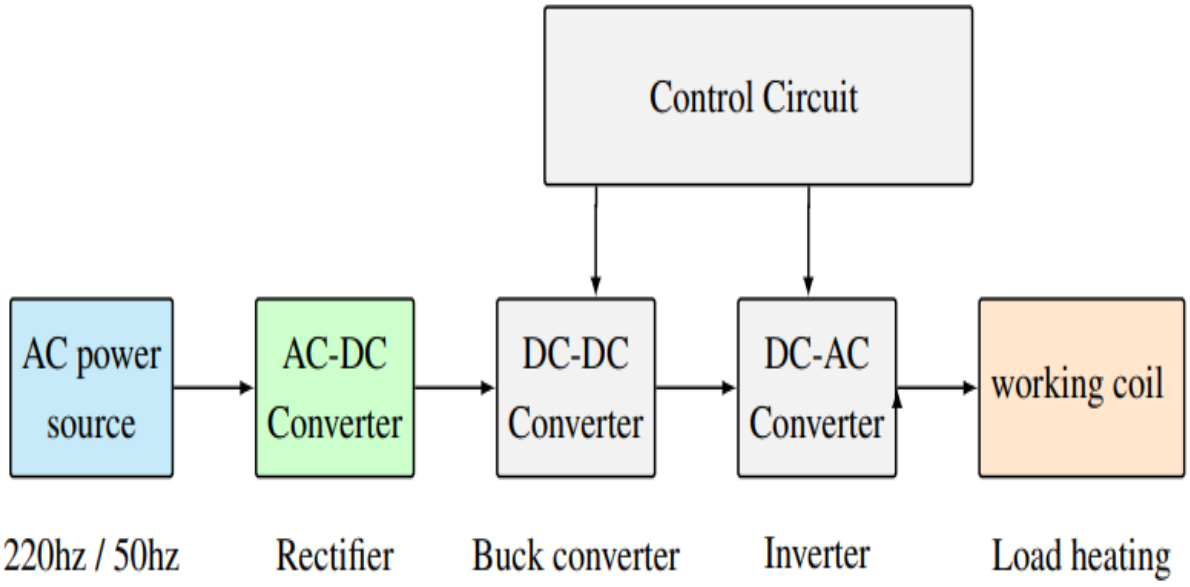
## *Simulation & Experimental Results*

## 4.1 Introduction

After understanding the different advantages of induction cooking and studying all the theoretical information needed to understand, simulate, and build an induction cooker system, in this chapter we will choose a specific application in order to simulate and build a small prototype based on the fixed requirements. First, we will start by the power estimation stage, and then move to simulate the different parts of the induction cooker power supply, and then we will interpret the simulation results, and finally we will build a small prototype aiming to achieve the fixed requirements.

## 4.2 The general setup used in the simulation and the experimentation

In the simulation and experimentation of an induction cooker, the general setup typically involves the following components:



## 4.3 System Architecture

### 4.3.1 Hardware

#### 4.3.1.1 Arduino Uno

The Arduino UNO is a microcontroller board based on the ATmega328P chip that has 14 digital input/output pins and 6 analog inputs. It also features a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. The board can be powered with a USB cable, AC-to-DC adapter, or a standard 9V battery. It is easy to use and suitable for tinkering without worrying about making a mistake. The board can be programmed using the Arduino IDE, which provides built-in examples and libraries. The Uno is an open-source microcontroller board released in 2010 and is one of the more popular boards in the Arduino family, making it a great choice for beginners.

In several applications, which are powered by inverters, it is necessary to control the output voltage, PWM is one of the most efficient techniques to vary the voltage gain. Modern microcontrollers (PIC Microcontroller, ARM Cortex M, PIC, ARDUINO UNO card ARDUINO ATmega2560 card, etc.) all have peripherals or pins dedicated specifically to PWM generation.[20]

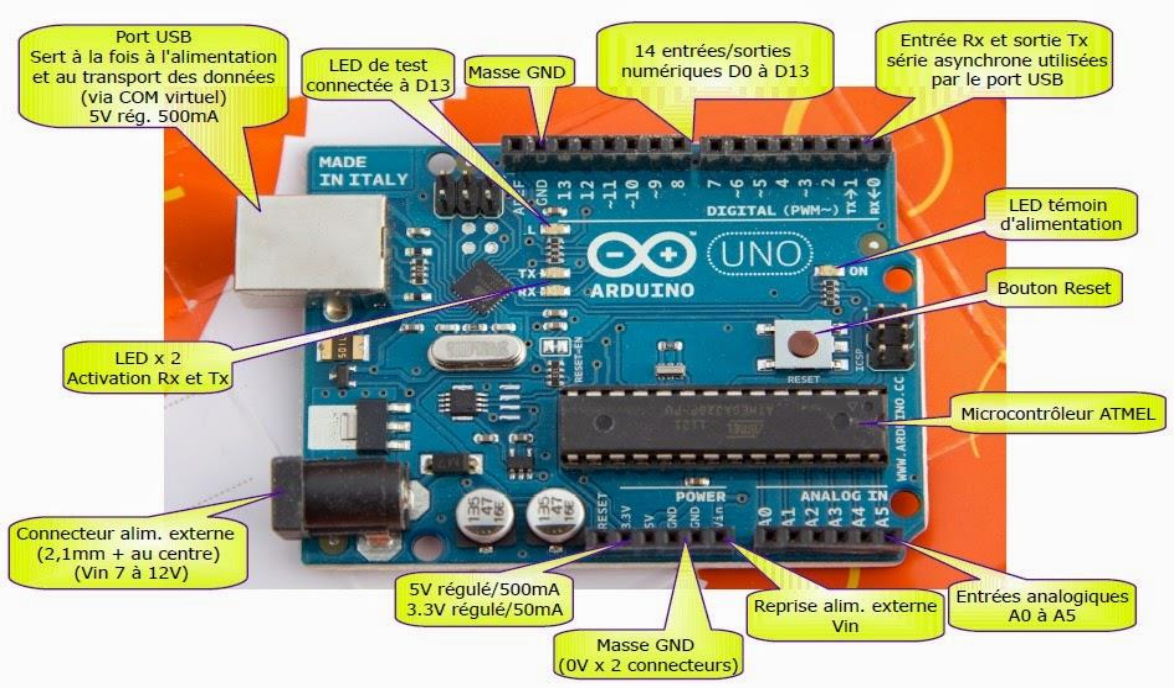



**Figure 16 :** Arduino UNO

## 4.4 Computation and analysis

### 4.4.1 Loss analysis and calculation

The total power loss of converters can be calculated by summing up the projected power losses from various components and stages within the converter circuit. Here are some common sources of power loss in converter circuits:

- **Conduction loss.**
- **Switching loss.**

#### 4.4.1.1 Conduction loss

Conduction losses occur in converter circuits when there is a voltage drop across the conducting elements, such as power MOSFETs, diodes, or other semiconductor devices. These losses are primarily caused by the resistance of the conducting element and the current flowing through it.

The power loss due to conduction losses can be calculated using the following formula:

$$P_{loss(cond)} = R_{CE(ON)} \times I^2_{RMS} = V_{CE(cond)} \times I_{RMS}$$

- $V_{CE(cond)}$ : Voltage traversing power semiconductors during onstate.
- $I_{RMS}$ : Average value of the steady-state through current.
- $R_{CE(ON)}$ : Resistance of the conducting element.

#### 4.4.1.2 Switching losses

It seems that you are referring to a specific figure (fig15) that illustrates the concept of ideal hard switching in a converter circuit. In this ideal scenario, during the turning-on transition, the voltage across the device drops to zero, and the through current jumps to the rated level without any delay. Similarly, during the turning-off transition, the through current drops to

zero, and the voltage across the device builds up to the rated level without any delay. [25]

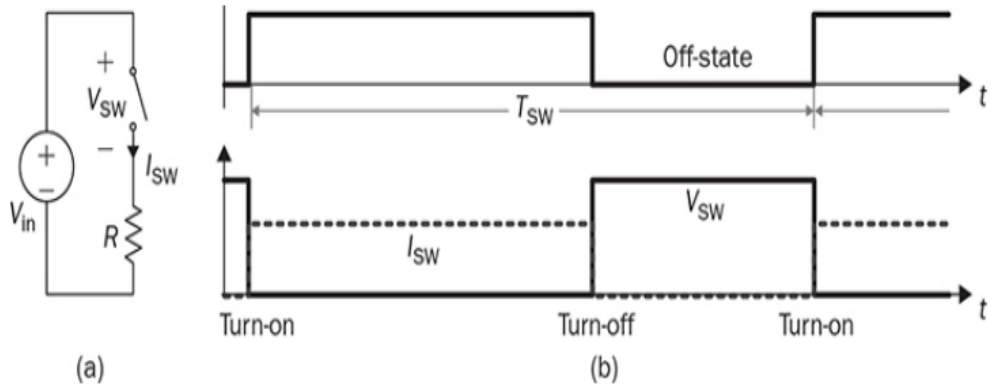



**Figure 17 :** Demonstration of ideal hard switching operation: (a) switching circuit; (b) waveforms

However, modern power semiconductor technology cannot reach the desired hard switching. Fig16 below demonstrates the principle that leads to switching loss when a power MOSFET is switched on and off. The power switch initiates current flow without reducing the voltage to zero. Voltage and current values that are simultaneously nonzero result in power consumption and power loss, and the same holds true for the turning-off phase. The overlap between the on and off phases of each switching cycle produces energy loss and power dissipation within the device.[25]

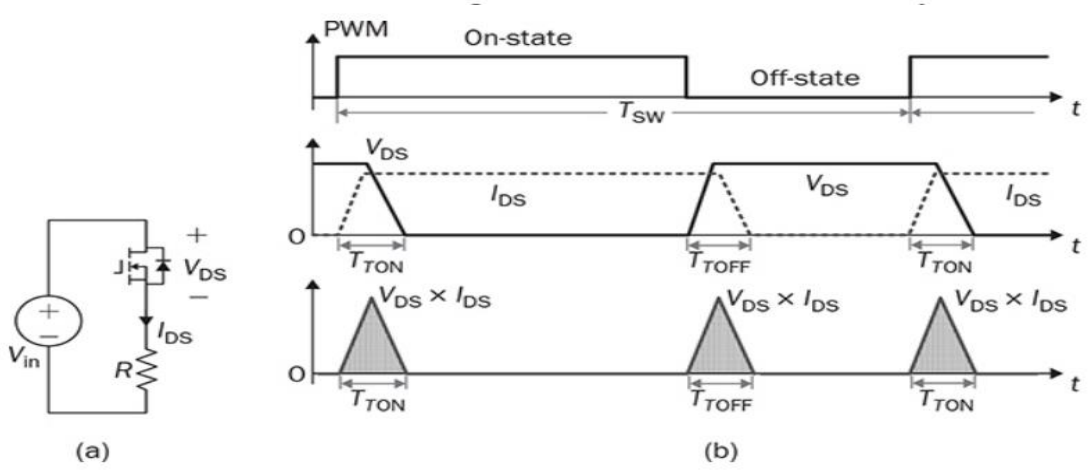



**Figure 18 :** Demonstration of switching loss of a MOSFET.

### 4.4.1.3 Minimization of switching losses

The switching loss minimization should focus on reducing the size of the overlapping areaand that's by reducing these parameters:

1. **Transition time: $T_{TON}$ and $T_{TOFF}$**
2. **Voltage amplitude during each transition: $V_{CE}$**
3. **Current amplitude during each transition: $I_{CE}$**

As seen in the preceding equation, the switching loss is zero when either $V_{CE}$ or $I_{CE}$ is zero during the transition. Soft switching results from the lowering of voltage and current preceding a transition. Zero voltage switching (*ZVS*) is accomplished by reducing the voltage level to zero just prior to activating the switch for switching. Accordingly, Zero current switching (*ZCS*) can be accomplished by reducing the current level to zero just prior to applying the gate signal.

## Switching loss can be determined by:

$$P_{loss(switching)} = (E_{ON,T} + E_{OFF,T}) \times f_w$$

As it was stated before, there are two types of losses when using electronic devices, conduction losses and switching losses. To calculate the losses of the inverter we need to calculate both the switching and conduction losses for each IGBT and each diode. From the IGBT's datasheet we can find the following parameters:

**$E_{ON(IGBT)}$ : 16 mj (600v)**

**$E_{OFF(IGBT)}$: 8 mj (600v)**

**$V_{CE\ sat\ (IGBT's\ voltage\ DROP)}$ : 2.1 v**

**$f_{sw}$ : 25 K Hz**

$I_{AVG}$ : $4A/\pi$

Digital Application:

$$P_{loss(cond)} = R_{CE(ON)} \times I^2{}_{RMS} = V_{CE(cond)} \times I_{RMS}$$

$$= 2.1 \times 1.28$$

$$= 2.69W$$

$$P_{loss(switching)} = (E_{ON,T} + E_{OFF,T}) \times f_{sw} \times \frac{V_{DC}}{V_{DC\,test}} \times \frac{I_{DC}}{I_{DC\,test}}$$

$$= (16+8) \times 50 \times \frac{300}{600} \times \frac{4}{60}$$

$$= 40\ W$$

$$P_{tot(IGBT)} = (P_{loss(cond)} + P_{loss(switching)})$$

$$= 2.69+40$$

$$= 43W$$

Total losses of IGBTs is:

$$P_{tot(IGBT)} = (P_{loss(cond)} + P_{loss(switching)}) \times 2$$

$$= (2.69+40) \times 2$$

$$= 86W$$

#### 4.4.1.2 Conduction loss LM317

$$P_{loss(LM317)} = \Delta V_{(LM317)} \times I_O$$

$$P_{loss(LM317)} = 4.5 \times 0.5$$

$$=2.25W$$

### 4.4.2 Heat sinks and thermal calculations

Conduction and switching losses occur in electronic devices, as stated above. These losses indicate the conversion of electrical energy to thermal energy, and the removal of thermal energy is critical for maintaining the device's interior temperature below its maximum rated value. The difference in temperature between two points is typically a function of thermal power and thermal resistance. Thermal resistance is defined by the following:

$$R_\theta = \frac{T_J - T_A}{P_\theta}$$

where:

- $R_\theta$ Thermal resistance [◦C/W] (also listed as [K/W] on some datasheets)
- **Tj** and **TA**: Temperature difference [◦C]
- $P_\theta$ Thermal power [W]

The junction temperature of an electrical switching device refers to its internal temperature. When a device absorbs power, it can lead to an increase in the junction temperature, potentially exceeding safe operating limits. To address this issue, a heat sink is often employed.

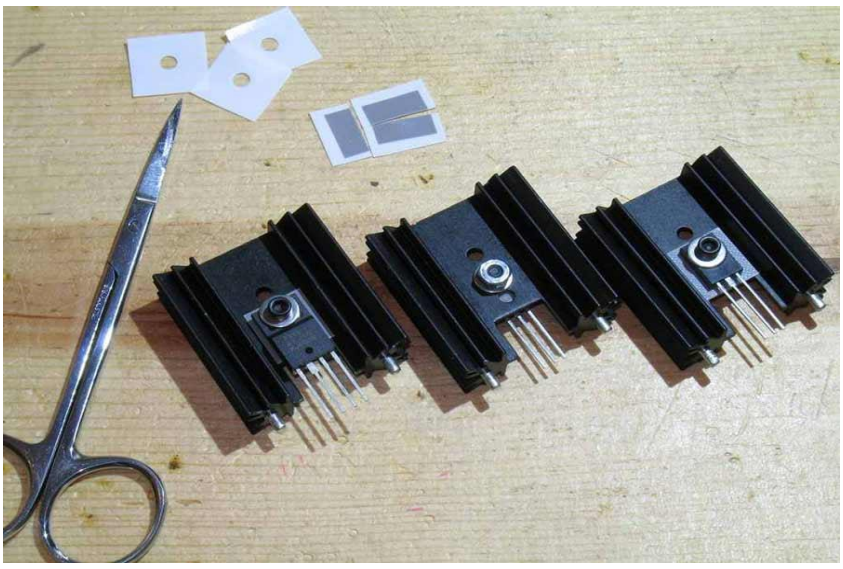


**Figure 19 :** Power transistors mounted on heat sinks.

In an electronic device equipped with a heat sink, thermal power flows from the junction to

the case, then from the case to the heat sink, and finally from the heat sink to the ambient. The temperature at the device junction is calculated via this formula:

$$T_J = P_\theta\left(R_{\theta,JC} + R_{\theta,CS} + R_{\theta,SA}\right) + T_A$$

**TA** : **25 C°**
**TJ : 100 C°**
$R_{\theta,JC}$**: 0.6 C°/W**
$P_\theta$ **: 43 W**
$R_{\theta,CS}$ **:0.9 C°/W**

$$R_{\theta,SA} = \frac{T_J - T_A}{P_\theta} - (R_{\theta,JC} + R_{\theta,CS})$$

Digital Application:

$$R_{\theta,SA} = \frac{\mathbf{100 - 25}}{\mathbf{43}} - (\mathbf{0.6 + 0.9})$$

$$= \mathbf{0.25\ C°/W}$$

Heat sink resistance for LM 317

$$R_{\theta,SA} = \frac{T_J - T_A}{P_{loss(LM317)}} - (R_{\theta,JC} + R_{\theta,CS})$$

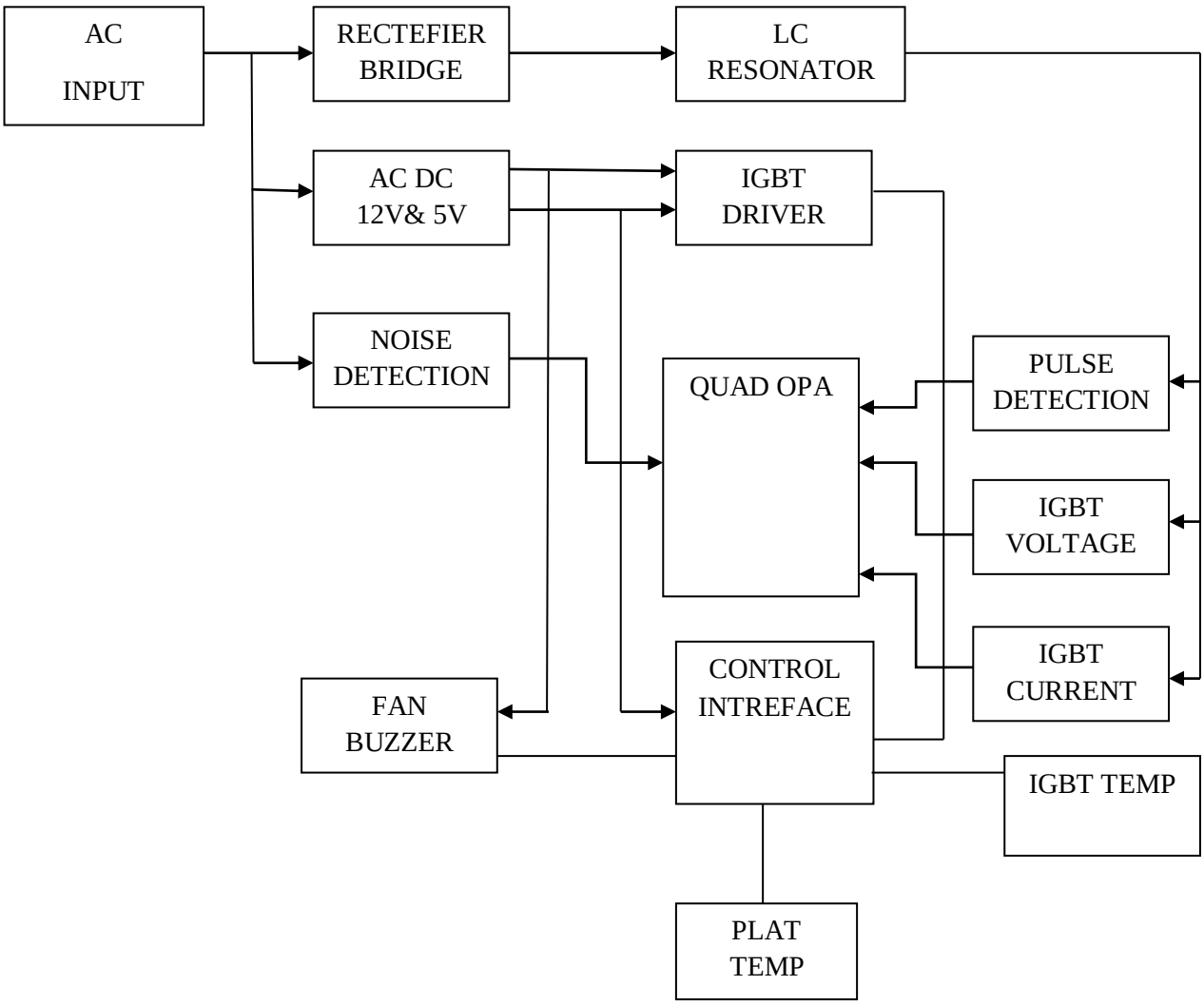
Digital Application:

$$R_{\theta,SA} = \frac{\mathbf{100 - 25}}{\mathbf{2.25}} - (\mathbf{5 + 0.9})$$

$$\mathbf{= 28\ C°/W}$$

## 4.5 System Overview

The power board block diagram consists of several components and their connections. The AC input is initially converted to approximately +310V using a bridge rectifier. This high voltage is then regulated down to +12V through the ACDC module. The LC resonator, which generates the magnetic field for cooking, is powered by a +310V source. The LC resonant driver circuit and the cooling fan are both powered. The +5V power supply serves as the main source for the entire system. Additionally, the Quad Operation Amplifier (OPA) plays a crucial role in forming the front-end circuits responsible for pulse detection, noise detection, as well as voltage and current measurement.



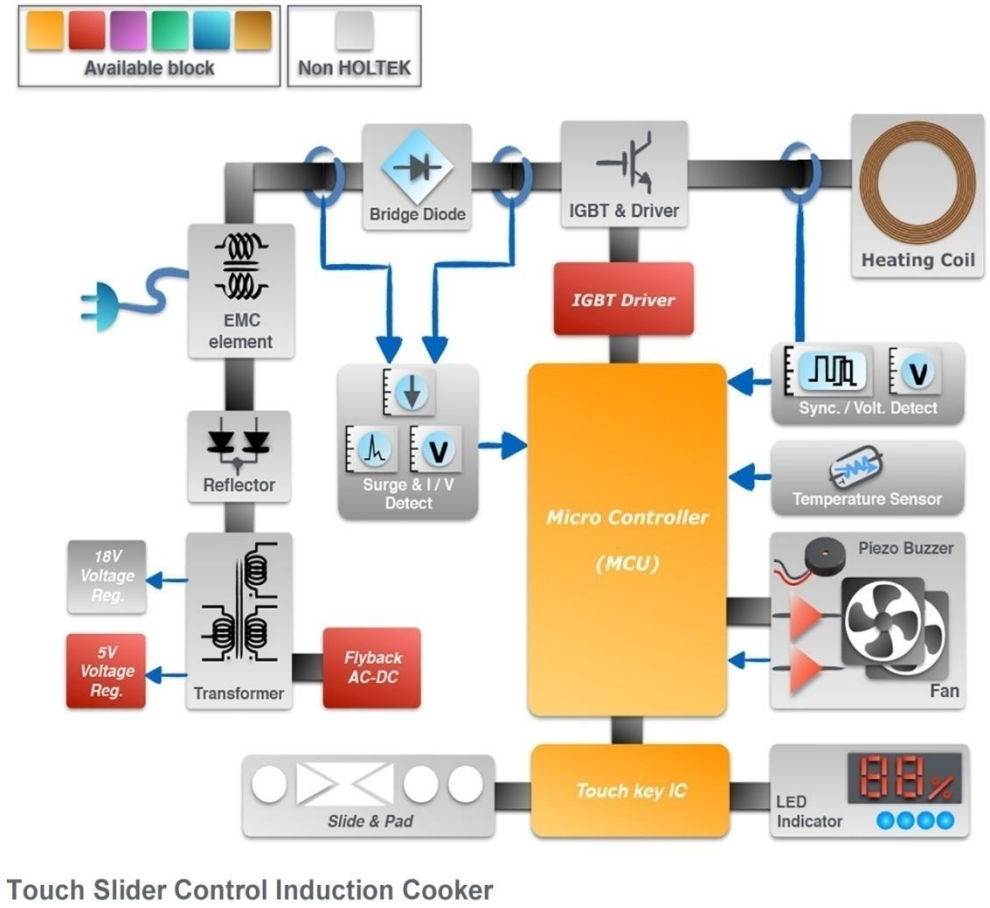



**Figure 20 :** Power board block diagram

### 4.5.1 Temperature sensing and voltage/current measurement

The temperature sensing and voltage/current measurement input circuitry. It utilizes the MCU internal ADC (Analog-to-Digital Converter) for various important measurements related to safety detection, protection, cooking profile control, and power control. Specifically, the MCU ADC is used to measure the temperature of the IGBT (Insulated Gate Bipolar Transistor), the temperature of the cooker plate, as well as the voltage and current of the IGBT. These measurements play a crucial role in monitoring and controlling the cooking process while ensuring safety and efficient power management.

### 4.5.2 Cooling fan/buzzer driver

The cooling fan/buzzer driver circuitry. In order to minimize the number of connection wires between the control board and the power board, both the cooling fan and the buzzer are driven using the same General Purpose Input/Output (GPIO) pin. This consolidation allows for a more streamlined and simplified wiring configuration

### 4.5.3 Noise detection

The noise detection circuitry. When the AC input experiences high frequency or high voltage noise, the comparator output on the NOISE_DET line becomes low. NOISE_DET is then logically ANDed with IGBT_PWM to prevent the IGBT driver from activating the LC resonator when noise is detected. Additionally, NOISE_DET is fed into the keyboard interrupt (KBI) input, generating an interrupt to facilitate further noise detection handling. To enhance electromagnetic compatibility (EMC) performance, an RC filter is incorporated on the input and positioned near the corresponding MCU input pin on the PCB, as recommended in LM 324. This design helps improve noise suppression and overall circuit performance.

### 4.5.4 Pulse detection

The pulse detection circuitry. It operates by differentiating the IGBT Vce voltage, which is derived from the +310 V power input, when the LC resonator is excited by the IGBT. This differentiation results in pulse signals being generated and outputted on the PULSE_DET line. The PULSE_DET signal is connected to the MCU's FTM2 input, where it is utilized for valid cookware detection and configuration of the IGBT PWM parameters. To enhance electromagnetic compatibility (EMC) performance, an RC filter is incorporated on the input. This filter is placed in close proximity to the corresponding MCU input pin on the PCB, as recommended in LM324. The inclusion of this filter helps to improve noise suppression and overall circuit performan

### 4.5.5 LC resonator

A Typical LC Resonant Circuit. It consists of an induction coil and the cookware, which together form the resonant Lr. The LC resonant equivalent circuit and its corresponding waveform are illustrated in Figure 11. In this configuration, Lr is variable and depends on the specific cookware used for cooking. It is essential to select appropriate values for Lr and the capacitance Cr to ensure that the LC resonant frequency $f_0 = \frac{1}{2\pi}\sqrt{C_r L_r}$ is higher than 20 KHz to avoid audio frequencies. This frequency requirement helps to ensure optimal performance and avoids unwanted audio interference during the cooking process.

### 4.5.6 Main loop and scheduler

The flowchart of the main loop and scheduler is shown in Figure 19. In the schematic, we have three main conditions. The first one is for frequency measurement to determine whether the cooktops are present or not. The second one is for temperature measurement, which allows us to control the fan for cooling the system down if the temperature goes over 100°C. The last one is to ensure that the system works in optimal conditions, so we always measure the voltage and frequency coming from the grid.

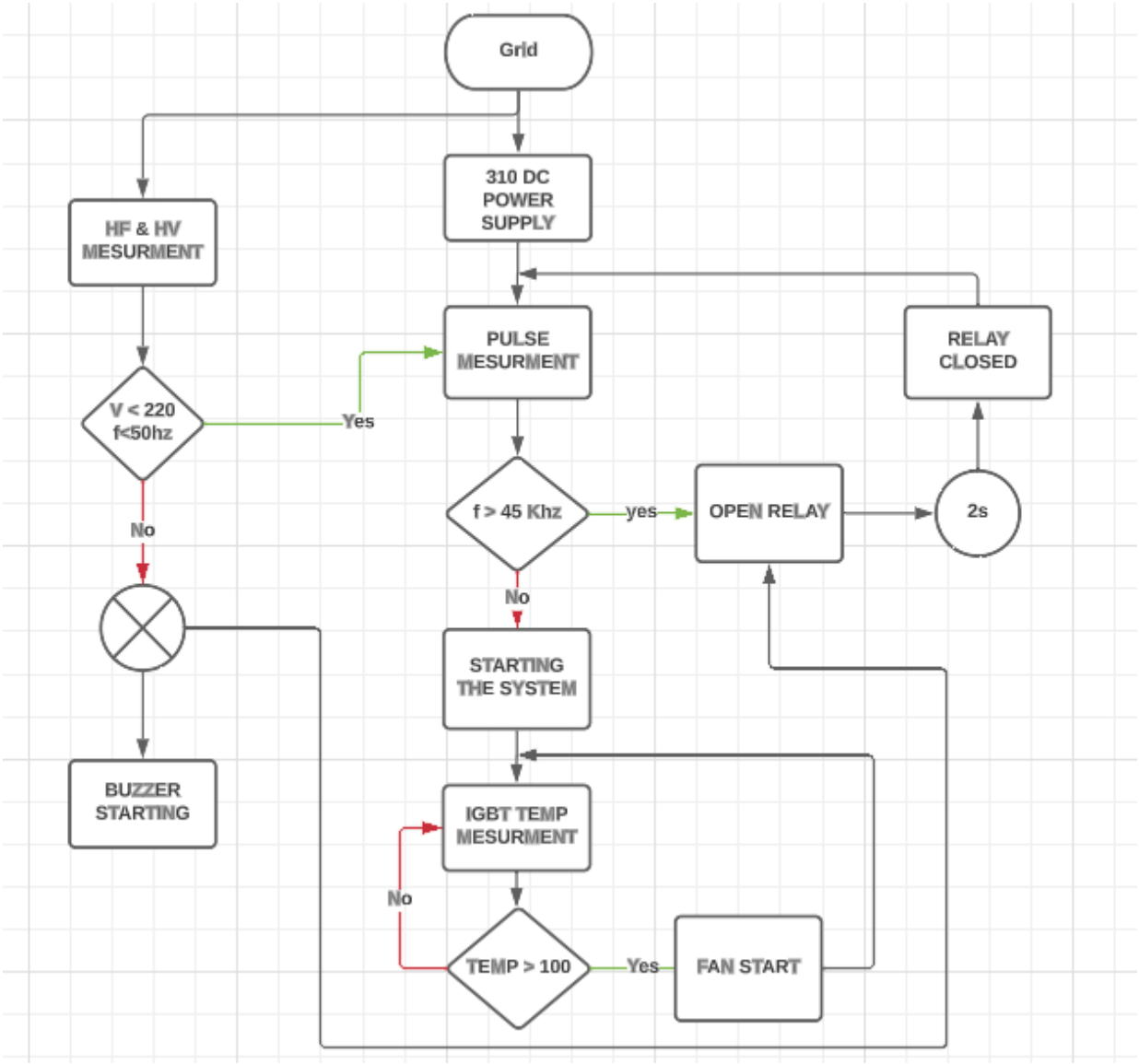



**Figure 21 :** Main loop and scheduler flowchart

## 4.6 Simulation Part and Results

### 4.6.1 Circuit Design

Our circuit design was crafted utilizing the powerful design software, KiCad. With its comprehensive suite of tools and a user-friendly interface, KiCad facilitated the creation of a highly efficient and robust circuit for our project. By harnessing the capabilities of KiCad, we were able to seamlessly translate our design concept into a practical implementation.

KiCad's schematic and PCB layout modules provided us with the necessary tools to design the circuit, starting from conceptualizing the circuitry to the final placement and routing of components on the printed circuit board (PCB). The schematic editor allowed us to construct and organize the circuit diagram with precision, incorporating all the necessary components and connections.

The PCB layout module in KiCad enabled us to transform the schematic into a physical representation, carefully arranging the components and optimizing the trace routing for minimal signal interference and improved performance. With KiCad's advanced design rules and real-time design rule checking, we ensured that our circuit layout adhered to industry standards and best practices.

### 4.6.1.1 Power Supply Circuit Design

At the input, we have an alternative 220V power source that is divided into two different voltage requirements.

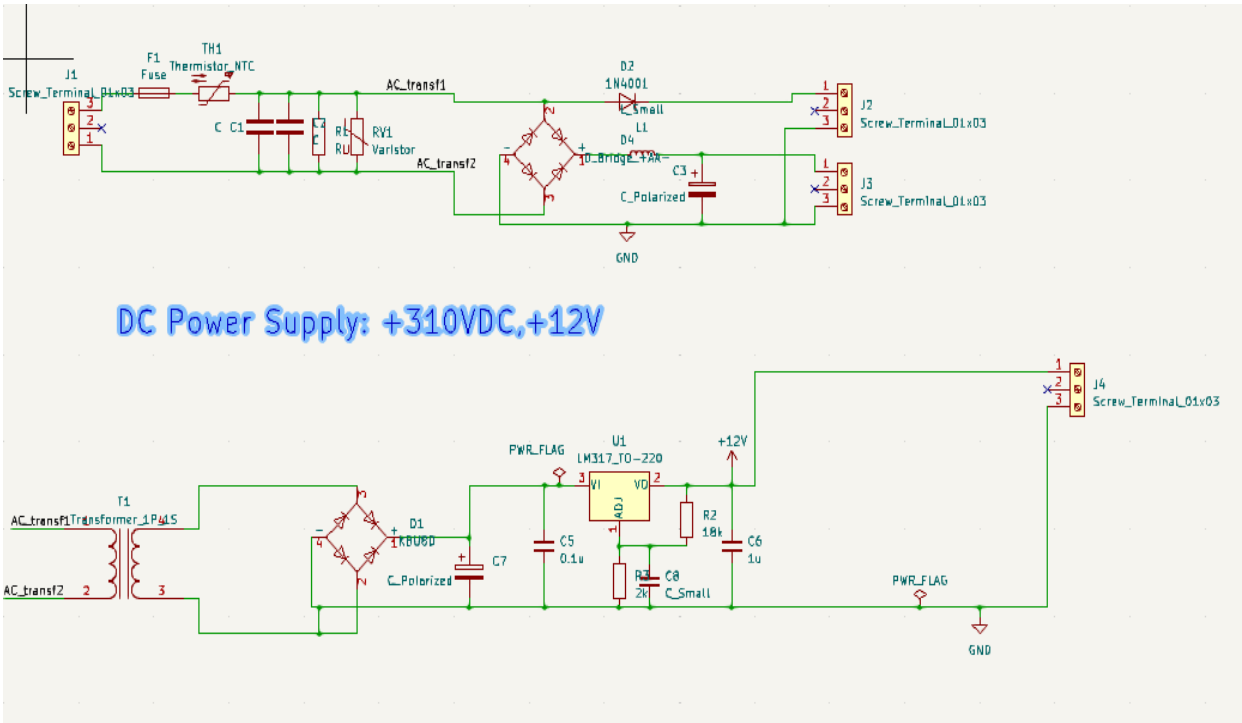



**Figure 22 :** Power Supply Schematic Circuit

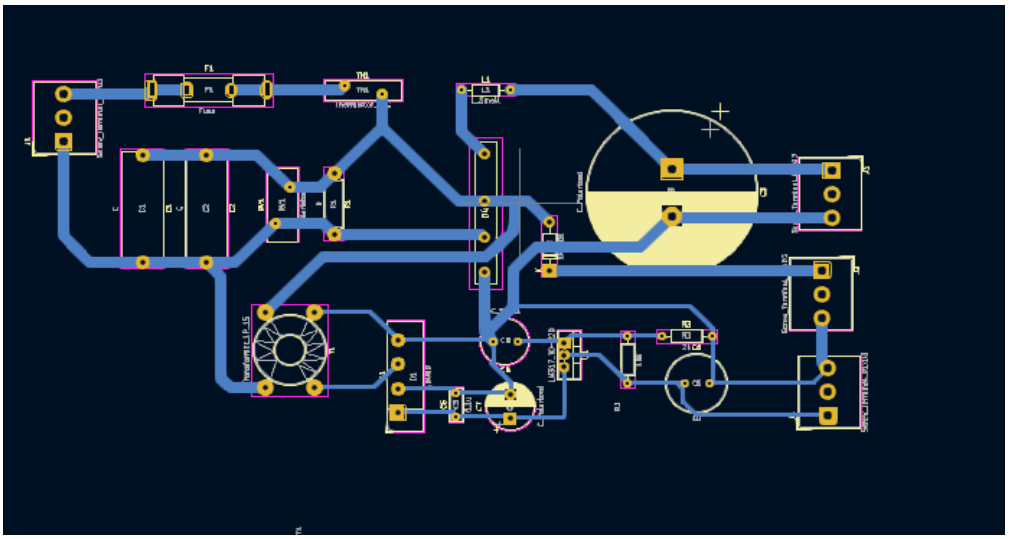


**Figure 23 :** Power Supply PCB Circuit

The first part involves a rectifier circuit that converts the 220V AC input into a high-voltage DC output of 310V. This rectified DC power is specifically used for the induction cooker coil.

The second part of the circuit utilizes a transformer and a rectifier to convert the 220V AC input into a lower voltage of 12V AC. The transformer acts as a step-down transformer, reducing the voltage to 12V.

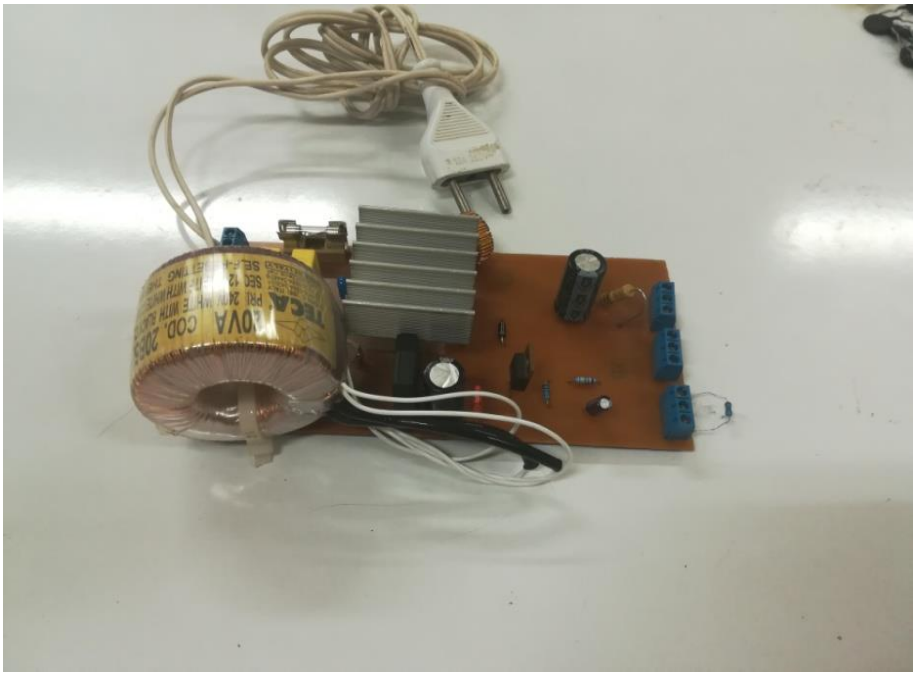


**Figure 24 :** Power Supply Circuit Realised

To ensure a stable output voltage for the control circuit, a voltage regulator is incorporated. The voltage regulator regulates the pulsating DC from the rectifier and maintains a constant 12V output voltage, eliminating fluctuations or variations that could potentially affect the performance of the control circuit.

### 4.6.1.2 Control Circuit Design

The control circuit of the induction cooker harnesses the 12V power supply obtained from the previously mentioned circuit. This circuit is responsible for managing various functionalities of the induction cooker. Key components integrated into the control circuit include a fan, a buzzer, an LM324 operational amplifier for pulse control and noise reduction, and an Arduino ATmega microcontroller.

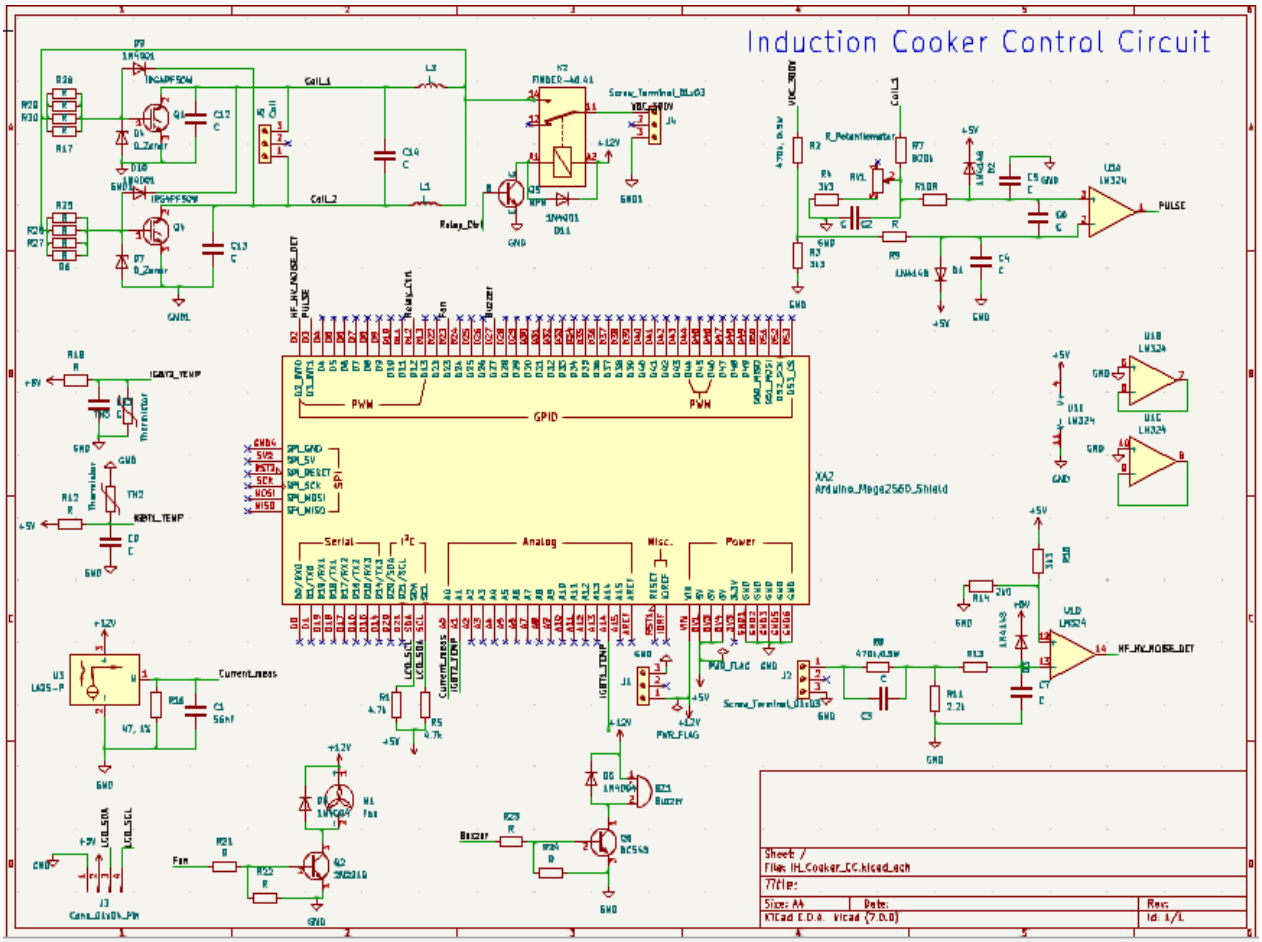



**Figure 25 :** Control Schematic Circuit

The control circuit of the induction cooker incorporates the Arduino ATmega microcontroller, which serves as its central processing unit for the system. The ATmega receives inputs from various sources, including the LM324 for pulse and noise signals, a thermistor for temperature sensing, and the LA125p current sensor that measures the current passing through the induction cooker coil.

Using this input data, the ATmega microcontroller employs intelligent algorithms to make informed decisions. For instance, when the temperature surpasses a predefined threshold, as detected by the thermistor, the ATmega triggers the activation of the fan to provide efficient cooling. Simultaneously, based on the current sensed by the LA125p, the ATmega can activate the relay to cut off the power supply, ensuring safety in case of abnormal conditions or emergencies.

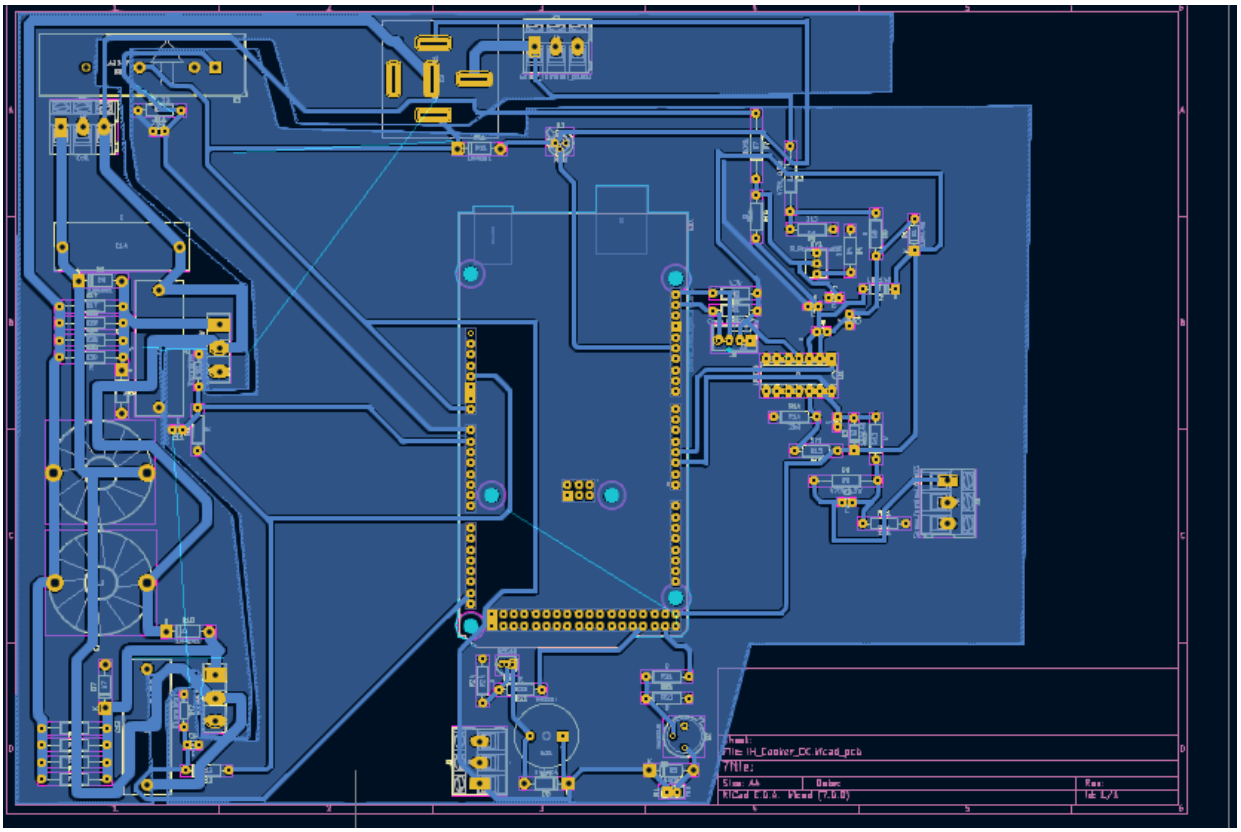


**Figure 26 :** PCB Control Circuit

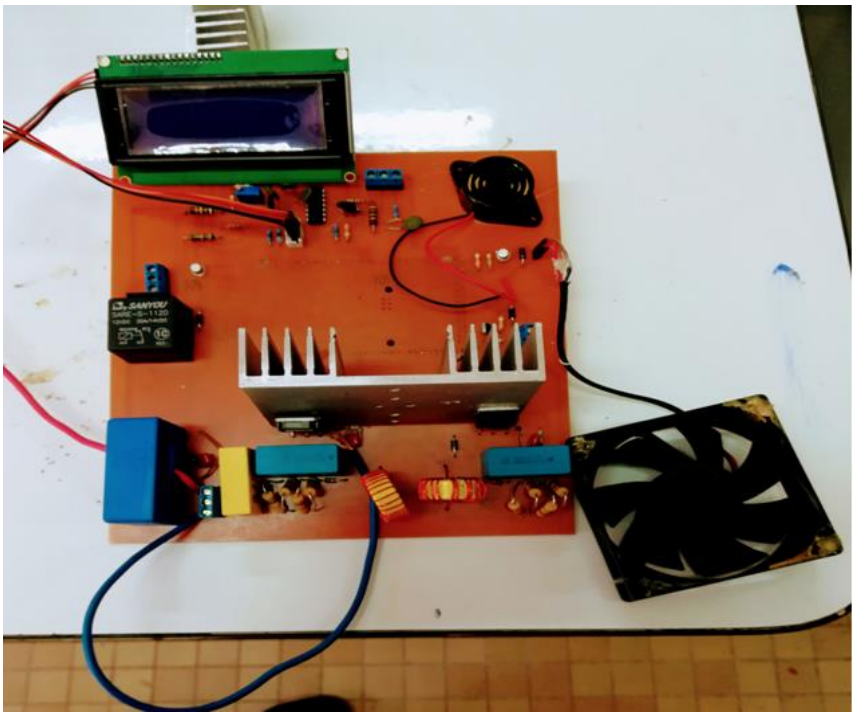


**Figure 27 :** control Circuit Realised

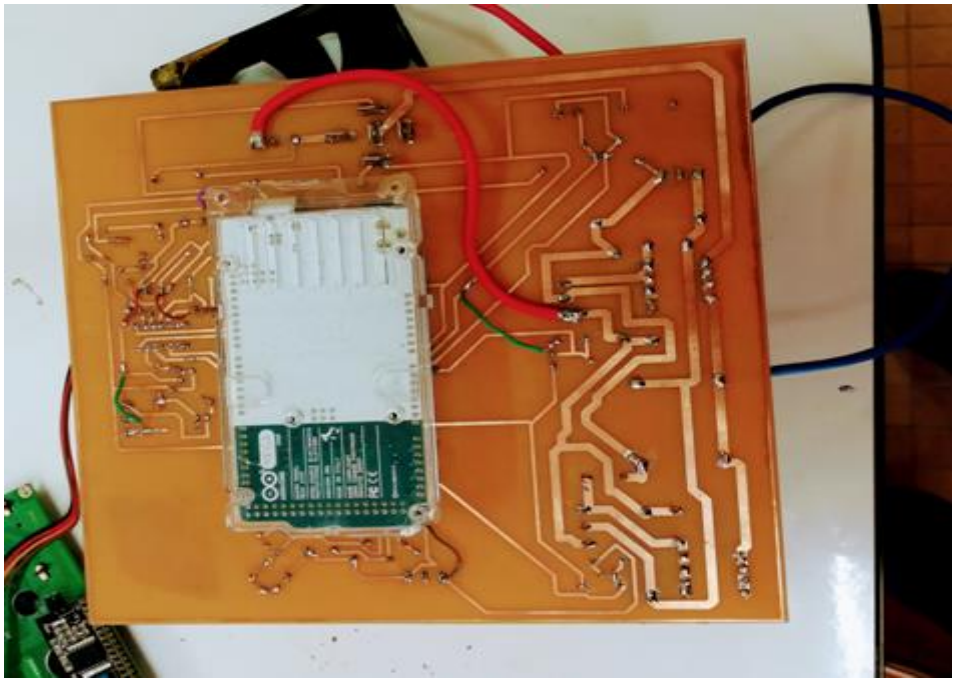


**Figure 28 :** control Circuit Realised and Arduino

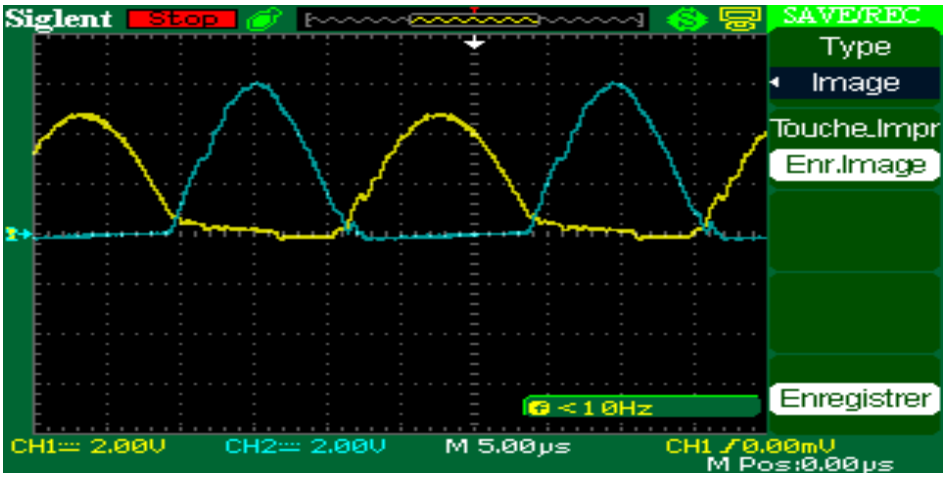



**Figure 29 :** IGBT Driver Output Signal

The IGBT driver output signal in a ZVS inverter is designed to achieve zero-voltage switching (ZVS) operation, minimizing switching losses and improving overall efficiency. The signal typically consists of pulses or waveforms that control the gate voltage of the IGBTs

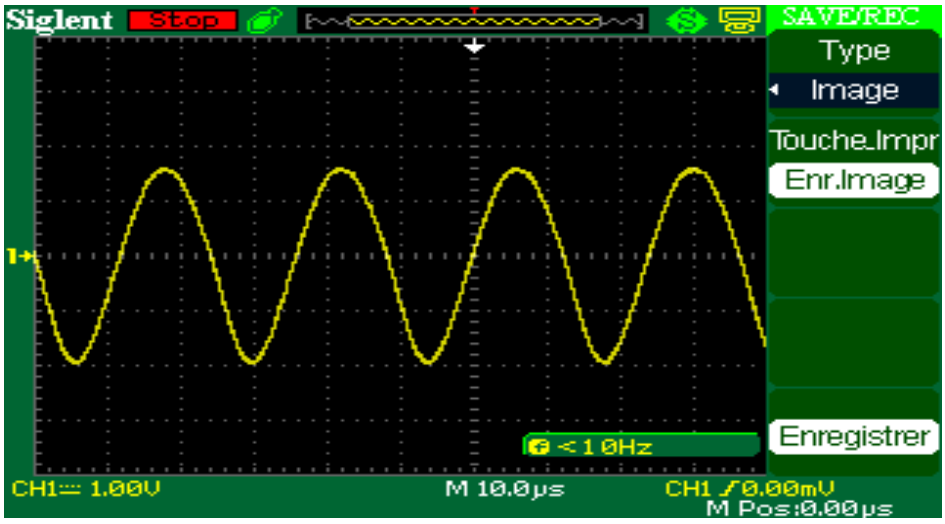



**Figure 30 :** Voltage acroos the load

When a ZVS inverter is used to generate an AC signal for a load, such as a coil, the voltage across the load will depend on various factors, including the design of the ZVS inverter circuit, the load impedance, and the operating conditions. Let's consider a simplified scenario where a ZVS inverter is used to generate a sinusoidal AC signal across a resistive load.

# *General Conclusion*

# Conclusion

In this work, we have successfully designed, implemented, and analyzed an induction cooker system, utilizing the induction heating technique.

Our work focuses on introducing and explaining the induction heating process, its underlying principles, and its wide range of applications in various fields. We thoroughly investigated the power supply circuit, which plays a crucial role in delivering the required power to the induction coil.

Our exploration covered different power devices such as diodes, transformers, and transistors used in power conversion applications and power supplies. Furthermore, we delved into the different types of induction heating power supplies, examining each component of the power supply circuit from rectification to inversion.

While the power supply circuit is crucial, we also emphasize the significance of modulation techniques and control circuits to optimize the performance of the induction system. Moving to the experimental phase, we defined the project requirements and conducted comprehensive simulations of the power supply circuits, successfully validate our theoretical studies.

Finally, we have designed and implemented a (ZVS) series resonant inverter for our induction cooker system. The results were highly promising, as we achieved our project requirements and verified the accuracy of our simulations and theoretical analyses.

This work showcases the successful realization of an induction cooker system, demonstrating the efficiency of the induction heating technique and its potential for practical applications in kitchen appliances.

# Recapitulation

This project focused on designing and developing an energy-efficient induction cooker for the Algerian market. Through the integration of modern technologies, including high-quality induction coils, power electronics, and user-friendly features, the induction cooker offers numerous advantages compared to traditional gas cookers.

The project highlighted the cooker's energy efficiency, precise heat transfer, and safety features such as overheat protection and automatic shut-off. The user-friendly interface, including temperature control settings and cooking modes, enhances the overall cooking experience.

The introduction of the induction cookers in Algeria presents a market opportunity to address rising energy costs, promote sustainability, and cater to the evolving needs of Algerian consumers.

The induction cooker project in Algeria showcased the successful design and development of an energy-efficient and user-friendly cooking appliance. The project's findings demonstrated the potential benefits of the induction cooker, including reduced energy consumption, improved cooking efficiency, enhanced safety, and a positive impact on the environment.

The introduction of the induction cookers in Algeria aligns with the country's focus on energy efficiency and sustainability, making it a promising market opportunity. Future work can delve into optimizing the product, conducting market analysis, and devising strategies for mass production and market penetration.

## Further Work:

- Implement a graphic interface.
- Implement a remote monitoring and control.
- Simulate and implement a PID controler.
- Install a water coling circuit for the system.
- Design and build a proper case.

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# *Appendices*

TAIWAN SEMICONDUCTOR

RoHS COMPLIANCE

# TSG60N100CE

N-Channel IGBT with FRD.

**TO-264**




**Pin Definition:**
1. Gate
2. Collector
3. Emitter

**PRODUCT SUMMARY**

| $V_{CES}$ (V) | $V_{GES}$ (V) | $I_C$ (A) |
|---|---|---|
| 1000 | ±20 | 60 |

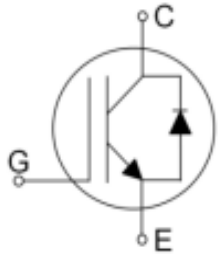
## General Description

The TSG60N100CE using proprietary trench design and advanced NPT technology, the 1000V NPT IGBT offers superior conduction and switching performances, high avalanche ruggedness and easy parallel operation. This device is well suited for the resonant or soft switching application such as induction heating, microwave oven, etc.

## Features

- 1000V NPT Trench Technology
- High Speed Switching
- Low Conduction Loss

## Block Diagram




NPT Trench IGBT

## Ordering Information

| Part No. | Package | Packing |
|---|---|---|
| TSG60N100CE C0 | TO-264 | 25pcs / Tube |

## Absolute Maximum Rating ($T_A$=25°C unless otherwise noted)

| Parameter | | Symbol | Limit | Unit |
|---|---|---|---|---|
| Collector-Emitter Voltage | | $V_{CES}$ | 1000 | V |
| Gate-Emitter Voltage | | $V_{GES}$ | ±20 | V |
| Continuous Current | $T_C$=25°C | $I_C$ | 60 | A |
| | $T_C$=100°C | | 42 | A |
| Pulsed Collector Current * | | $I_{CM}$ | 200 | A |
| Diode Continuous Forward Current ($T_C$=100℃) | | $I_F$ | 15 | A |
| Max Power Dissipation | $T_J$=25°C | $P_D$ | 208 | W |
| | $T_J$=100°C | | 83 | |
| Operating Junction Temperature | | $T_J$ | -55 to +150 | °C |
| Storage Temperature Range | | $T_{STG}$ | -55 to +150 | °C |

* Repetitive rating: Pulse width limited by max. junction temperature

TAIWAN SEMICONDUCTOR

RoHS COMPLIANCE

# TSG60N100CE

N-Channel IGBT with FRD.

## Thermal Performance

| Parameter | | Symbol | Limit | Unit |
|---|---|---|---|---|
| Thermal Resistance - Junction to Case | IGBT | $R\Theta_{JC}$ | 0.6 | °C/W |
| | DIODE | | 2.2 | |
| Thermal Resistance - Junction to Ambient | | $R\Theta_{JA}$ | 25 | |

## Electrical Specifications (Tc=25°C unless otherwise noted)

| Parameter | Conditions | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **Static** | | | | | | |
| Collector-Emitter Breakdown Voltage | $V_{GE}$ = 0V, $I_C$ = 1mA | $BV_{CES}$ | 1000 | -- | -- | V |
| Zero Gate Voltage Collector Current | $V_{CE}$ = 1000V, $V_{GE}$ = 0V | $I_{CES}$ | -- | -- | 1 | mA |
| Gate-Emitter Leakage Current | $V_{GE}$ = 20V, $V_{CE}$ = 0V | $I_{GES}$ | -- | -- | ±250 | nA |
| Gate-Emitter Threshold Voltage | $V_{GE}$ = $V_{CE}$, $I_C$ = 60mA | $V_{GE(TH)}$ | 3.5 | 5.5 | 7.5 | V |
| Collector-Emitter Saturation Voltage | $V_{GE}$ = 15V,$I_C$ =60A, $T_J$=25°C | $V_{CE(SAT)}$ | -- | 2.1 | 2.5 | V |
| | $V_{GE}$ = 15V,$I_C$ =60A, $T_J$=125°C | $V_{CE(SAT)}$ | -- | 2.6 | -- | V |
| **Dynamic** | | | | | | |
| Input Capacitance | $V_{CE}$ = 30V, $V_{GE}$ = 0V, f = 1.0MHz | $C_{IES}$ | -- | 5600 | -- | pF |
| Output Capacitance | | $C_{OES}$ | -- | 150 | -- | |
| Reverse Transfer Capacitance | | $C_{RES}$ | -- | 115 | -- | |
| **Switching** | | | | | | |
| Turn-On Delay Time | $V_{CC}$ = 600V, $I_C$ = 60A, $R_G$ = 10Ω, $V_{GE}$ = 15V Inductive Load, $T_J$=25°C | $t_{d(on)}$ | -- | 230 | -- | nS |
| Rise Time | | $t_r$ | -- | 210 | -- | |
| Turn-Off Delay Time | | $t_{d(off)}$ | -- | 1250 | -- | |
| Fall Time | | $t_f$ | -- | 120 | 230 | |
| Turn-On Switching Loss | | $E_{on}$ | -- | 14.5 | 22 | mJ |
| Turn-Off Switching Loss | | $E_{off}$ | -- | 7.0 | 11 | |
| Total Switching Loss | | $E_{ts}$ | -- | 21.5 | 33 | |
| Turn-On Delay Time | $V_{CC}$ = 600V, $I_C$ = 60A, $R_G$ = 10Ω, $V_{GE}$ = 15V Inductive Load, $T_J$=125°C | $t_{d(on)}$ | -- | 210 | -- | nS |
| Rise Time | | $t_r$ | -- | 260 | -- | |
| Turn-Off Delay Time | | $t_{d(off)}$ | -- | 1350 | -- | |
| Fall Time | | $t_f$ | -- | 160 | -- | |
| Turn-On Switching Loss | | $E_{on}$ | -- | 16 | 24 | mJ |
| Turn-Off Switching Loss | | $E_{off}$ | -- | 8.0 | 12 | |
| Total Switching Loss | | $E_{ts}$ | -- | 24 | 36 | |
| Total Gate Charge | $V_{CC}$ = 600V, $I_C$ = 60A, $V_{GE}$ = 15V | $Q_g$ | -- | 270 | 405 | nC |
| Gate-Emitter Charge | | $Q_{ge}$ | -- | 45 | 68 | |
| Gate-Collector Charge | | $Q_{gc}$ | -- | 100 | 150 | |

# LM317

# 1.5 A Adjustable Output, Positive Voltage Regulator

## THREE–TERMINAL ADJUSTABLE POSITIVE VOLTAGE REGULATOR

**SEMICONDUCTOR TECHNICAL DATA**

The LM317 is an adjustable 3–terminal positive voltage regulator capable of supplying in excess of 1.5 A over an output voltage range of 1.2 V to 37 V. This voltage regulator is exceptionally easy to use and requires only two external resistors to set the output voltage. Further, it employs internal current limiting, thermal shutdown and safe area compensation, making it essentially blow–out proof.

The LM317 serves a wide variety of applications including local, on card regulation. This device can also be used to make a programmable output regulator, or by connecting a fixed resistor between the adjustment and output, the LM317 can be used as a precision current regulator.

- Output Current in Excess of 1.5 A
- Output Adjustable between 1.2 V and 37 V
- Internal Thermal Overload Protection
- Internal Short Circuit Current Limiting Constant with Temperature
- Output Transistor Safe–Area Compensation
- Floating Operation for High Voltage Applications
- Available in Surface Mount $D^2PAK$, and Standard 3–Lead Transistor Package
- Eliminates Stocking many Fixed Voltages

**T SUFFIX**
PLASTIC PACKAGE
CASE 221A

Heatsink surface connected to Pin 2.



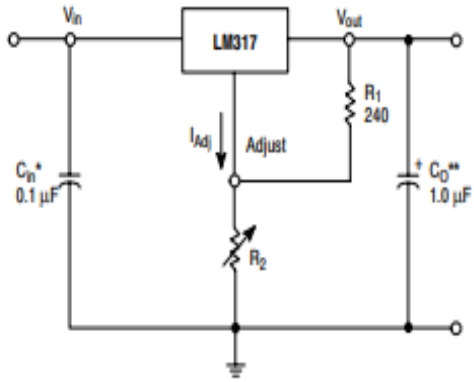

Pin 1. Adjust
2. $V_{out}$
3. $V_{in}$

**D2T SUFFIX**
PLASTIC PACKAGE
CASE 936
($D^2PAK$)




Heatsink surface (shown as terminal 4 in case outline drawing) is connected to Pin 2.

**Standard Application**




* $C_{in}$ is required if regulator is located an appreciable distance from power supply filter.
** $C_O$ is not needed for stability, however, it does improve transient response.

$$V_{out} = 1.25\,V\left(1 + \frac{R_2}{R_1}\right) + I_{Adj}R_2$$

Since $I_{Adj}$ is controlled to less than 100 µA, the error associated with this term is negligible in most applications.

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| LM317BD2T | $T_J$ = –40° to +125°C | Surface Mount |
| LM317BT | | Insertion Mount |
| LM317D2T | $T_J$ = 0° to +125°C | Surface Mount |
| LM317T | | Insertion Mount |

## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Input–Output Voltage Differential | $V_I–V_O$ | 40 | Vdc |
| Power Dissipation | | | |
| Case 221A | | | |
| $T_A$ = +25°C | $P_D$ | Internally Limited | W |
| Thermal Resistance, Junction–to–Ambient | $\theta_{JA}$ | 65 | °C/W |
| Thermal Resistance, Junction–to–Case | $\theta_{JC}$ | 5.0 | °C/W |
| Case 936 ($D^2PAK$) | | | |
| $T_A$ = +25°C | $P_D$ | Internally Limited | W |
| Thermal Resistance, Junction–to–Ambient | $\theta_{JA}$ | 70 | °C/W |
| Thermal Resistance, Junction–to–Case | $\theta_{JC}$ | 5.0 | °C/W |
| Operating Junction Temperature Range | $T_J$ | –40 to +125 | °C |
| Storage Temperature Range | $T_{stg}$ | –65 to +150 | °C |

## ELECTRICAL CHARACTERISTICS ($V_I–V_O$ = 5.0 V; $I_O$ = 0.5 A for D2T and T packages; $T_J = T_{low}$ to $T_{high}$ [Note 1]; $I_{max}$ and $P_{max}$ [Note 2]; unless otherwise noted.)

| Characteristics | Figure | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Line Regulation (Note 3), $T_A$ = +25°C, 3.0 V ≤ $V_I–V_O$ ≤ 40 V | 1 | $Reg_{line}$ | – | 0.01 | 0.04 | %/V |
| Load Regulation (Note 3), $T_A$ = +25°C, 10 mA ≤ $I_O$ ≤ $I_{max}$ | 2 | $Reg_{load}$ | | | | |
| $V_O$ ≤ 5.0 V | | | – | 5.0 | 25 | mV |
| $V_O$ ≥ 5.0 V | | | – | 0.1 | 0.5 | % $V_O$ |
| Thermal Regulation, $T_A$ = +25°C (Note 6), 20 ms Pulse | | $Reg_{therm}$ | – | 0.03 | 0.07 | % $V_O$/W |
| Adjustment Pin Current | 3 | $I_{Adj}$ | – | 50 | 100 | µA |
| Adjustment Pin Current Change, 2.5 V ≤ $V_I–V_O$ ≤ 40 V, 10 mA ≤ $I_L$ ≤ $I_{max}$, $P_D$ ≤ $P_{max}$ | 1, 2 | $\Delta I_{Adj}$ | – | 0.2 | 5.0 | µA |
| Reference Voltage, 3.0 V ≤ $V_I–V_O$ ≤ 40 V, 10 mA ≤ $I_O$ ≤ $I_{max}$, $P_D$ ≤ $P_{max}$ | 3 | $V_{ref}$ | 1.2 | 1.25 | 1.3 | V |
| Line Regulation (Note 3), 3.0 V ≤ $V_I–V_O$ ≤ 40 V | 1 | $Reg_{line}$ | – | 0.02 | 0.07 | % V |
| Load Regulation (Note 3), 10 mA ≤ $I_O$ ≤ $I_{max}$ | 2 | $Reg_{load}$ | | | | |
| $V_O$ ≤ 5.0 V | | | – | 20 | 70 | mV |
| $V_O$ ≥ 5.0 V | | | – | 0.3 | 1.5 | % $V_O$ |
| Temperature Stability ($T_{low}$ ≤ $T_J$ ≤ $T_{high}$) | 3 | $T_S$ | – | 0.7 | – | % $V_O$ |
| Minimum Load Current to Maintain Regulation ($V_I–V_O$ = 40 V) | 3 | $I_{Lmin}$ | – | 3.5 | 10 | mA |
| Maximum Output Current | 3 | $I_{max}$ | | | | A |
| $V_I–V_O$ ≤ 15 V, $P_D$ ≤ $P_{max}$, T Package | | | 1.5 | 2.2 | – | |
| $V_I–V_O$ = 40 V, $P_D$ ≤ $P_{max}$, $T_A$ = +25°C, T Package | | | 0.15 | 0.4 | – | |
| RMS Noise, % of $V_O$, $T_A$ = +25°C, 10 Hz ≤ f ≤ 10 kHz | | N | – | 0.003 | – | % $V_O$ |
| Ripple Rejection, $V_O$ = 10 V, f = 120 Hz (Note 4) | 4 | RR | | | | dB |
| Without $C_{Adj}$ | | | – | 65 | – | |
| $C_{Adj}$ = 10 µF | | | 66 | 80 | – | |
| Long–Term Stability, $T_J = T_{high}$ (Note 5), $T_A$ = +25°C for Endpoint Measurements | 3 | S | – | 0.3 | 1.0 | %/1.0 k Hrs. |
| Thermal Resistance Junction to Case, T Package | | $R_{\theta JC}$ | – | 5.0 | – | °C/W |

**NOTES:** 1. $T_{low}$ to $T_{high}$ = 0° to +125°C, for LM317T, D2T. $T_{low}$ to $T_{high}$ = –40° to +125°C, for LM317BT, BD2T.