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MOTOR DRIVE USING MULTI-CELLULAR CONTROL OF ELECTRIC VEHICLE

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Abstract

This study deals with a somewhat new field, or rather a new stage in the automotive field, which is the transition from the traditional car to the electric car. In the first volume, we discussed electric cars, their types and classifications, and their advantages and disadvantages in various fields. We've talked at length about energy storage systems and their types, to transformers that transfer energy. Finally, we have mentioned some of the big companies in this field. In the second volume, we mentioned electrical transformers in general, then we discussed one type of these transformers called the multicell transformer which is the subject of this study about its types, advantages, and some problems that arise from it, then we moved on to the math side and focused on the three cells electrical transformer and modeled it. In the third volume, we moved on to the calculation and mathematical simulation of two types of control, the first control is the so-called natural theory PWM (pulse width modulation) and its modeling, the second type is the control of the sliding mode (SMC) and modeling it, we used a simulator called MATALAB-simulink, then we compared the two controls to control the optimal main load current (in this case, it is the electric motor).

Keywords are: electric motor - multi-cell transformer - natural control - non-linear control

Résumé

Cette étude traite d'un domaine un peu nouveau, ou plutôt d'une nouvelle étape dans le domaine automobile, qui est le passage de la voiture traditionnelle à la voiture électrique. Dans le premier volume, nous avons discuté des voitures électriques, de leurs types et classifications, ainsi que de leurs avantages et inconvénients dans divers domaines. Nous avons longuement parlé des systèmes de stockage d'énergie et de leurs types, jusqu'aux transformateurs qui transfèrent l'énergie. Enfin, nous avons mentionné quelques-unes des grandes entreprises dans ce domaine. Dans le deuxième volume, nous avons évoqué les transformateurs électriques en général, puis nous avons abordé un type de ces transformateurs appelé transformateur multicellulaire qui fait l'objet de cette étude sur ses types, avantages, et certains problèmes qui en découlent, puis nous sommes passés à le côté mathématique et s'est concentré sur le transformateur électrique à trois cellules et l'a modélisé. Dans le troisième volume, nous sommes passés au calcul et à la simulation mathématique de deux types de commande, la première commande est la théorie dite naturelle PWM (modulation de largeur d'impulsion) et sa modélisation, le deuxième type est la commande du mode glissant (SMC) et en le modélisant, nous avons utilisé un simulateur appelé MATALAB, puis nous avons comparé les deux commandes pour contrôler le courant de charge principal optimal (dans ce cas, il s'agit du moteur électrique).

Les mots clés sont : moteur électrique - transformateur multicellulaire - commande naturelle - commande non linéaire

ملخص

تتناول هذه الدراسة مجالًا جديدًا نوعًا ما ، أو بالأحرى مرحلة جديدة في مجال السيارات ، وهي الانتقال من السيارة التقليدية إلى السيارة الكهربائية. ناقشنا في المجلد الأول السيارات الكهربائية وأنواعها وتصنيفاتها ومزاياها وعيوبها في مختلف المجالات. لقد تحدثنا بإسهاب عن أنظمة تخزين الطاقة وأنواعها والمحولات التي تنقل الطاقة. أخيرًا ، ذكرنا بعض الشركات الكبرى في هذا المجال. في المجلد الثاني ذكرنا المحولات الكهربائية بشكل عام ، ثم ناقشنا نوع واحد من هذه المحولات يسمى المحولات متعددة الخلايا وهي موضوع هذه الدراسة حول أنواعها ومزاياها وبعض المشاكل التي تنشأ عنها ، ثم انتقلنا إلى الجانب الرياضي وركز على المحولات الكهربائية الثلاث للخلايا ونمذجته. في المجلد الثالث ، انتقلنا إلى الحساب والمحاكاة الرياضية لنوعين من التحكم ، أولهما هو ما يسمى بالنظرية الطبيعية عوا (تعديل عرض النبضة) ونمذجه ، والنوع الثاني هو التحكم في وضع الانزلاق (صيث) ونمذجته ، استخدمنا جهاز محاكاة يسمى پاۋاسا ، ثم قمنا بمقارنة عنصري التحكم للتحكم في تيار الحمل الرئيسي الأمثل (في هذه الحالة ، هو المحرك الكهربائي).

الكلمات المفتاحية هي : محرك كهربائي ـ محول متعدد الخلايا ـ التحكم الطبيعي ـ التحكم الغير خطي

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Introduction general

Recently, fossil fuels have been used to power transportation, allowing people and goods to move freely. According to the US Department of Transportation, there are 250 million vehicles on US roads and about 800 million vehicles worldwide. Electric cars were developed as an alternative to traditional cars that use fossil fuels, in order to overcome environmental issues and move towards energy sustainability, as humanity is under serious threat due to the current state of the environment. As a result of this increase in temperature and the rise in emissions of greenhouse gases, especially carbon dioxide (CO2) emissions, natural climate disasters become more frequent and severe, and some ecosystems are destroyed. Currently, approximately 27% of the world's carbon dioxide emissions are attributed to the transportation industry. As a result, it is a major contributor to global warming. Historically, the use of electric motors in cars began at an early age, but the development of technology and continuous research in the field of electric cars has led to significant progress in recent years.

Electric automobiles have a variety of advantages and disadvantages. Modern electrical systems are used to create, store, and distribute energy in electric cars. The multi-cell transducers are one of these systems' essential components. These transformers translate electrical energy into voltage and current levels that are appropriate for the functioning of electric motors from a power source (often a car battery).

Multi-cell transducers consist of a group of electrical cells connected together, working cooperatively to balance electrical distribution and improve system efficiency. These transformers are characterized by their ability to control voltage and current levels and convert electrical energy with high efficiency. The use of a multi-cell converter is the most important element to reach the goal of this discussion, and from it we say that this converter is the main part of the direct current (DC) electric vehicle motor operating system. The multi-cell inverter converts the electric energy stored in the car battery (DC) into a voltage and current suitable for the operation of the electric motor. In addition, the behavior of the current and voltage of the electric motor is controlled using advanced electronic control systems or strategies.

In this note we used two methods, namely, pulse width modulation (PWM): Pulse width modulation is a technique used to control the level of electrical power that is applied to an electric motor. This system works by changing the on and off period of the electrical signal applied to the motor, by changing the width of the pulses (time of operation of the signal) by a specified percentage. By changing the pulse width, the power and speed of the motor can be adjusted and its efficiency improved. For example, when the motor requires less power, the pulse width is reduced, whereas when more power is required, the pulse width is increased. This system provides precise control over the behavior of the current and voltage going to the electric motor.

Sliding mode method (SMC) is a nonlinear control approach used to achieve stable and accurate performance in electric motor operation. This system is based on creating a sliding surface (mathematical surface) that represents the difference between the actual state of the system and the desired state. This surface is selected so that it has the characteristics that make it slide quickly and stabilize at the desired values. These are two effective ways to control the behavior of electric motor current and voltage in electric vehicles. They each use different technologies to achieve precise control and improve overall engine performance.It is one of the special approaches to robust controller design

Chapter 1

1 VEHICLE ELECTRIC

1.1 Introduction

Modern society heavily relies on transportation powered by fossil fuels in order to move people and things freely. The US Department of Transportation estimates that there are about 800 million cars worldwide and 250 million motor vehicles on the road in the US. China surpassed the United States to become the largest auto producer and auto market in the world in 2009, with output and sales of 13.79 and 13.64 million vehicles, respectively. With continued urbanization, industrialization, and globalization, it is inevitable that the number of personal vehicles will increase significantly on a global scale . The issues raised by this development are clear given how much oil is consumed in transportation.Burning oil-based products has produced emissions that have led to climate change, poor urban air quality, and political upheaval in addition to the fact that the world's oil sources are finite. Personal mobility is largely to blame for problems that have developed with the world's energy system and the environment.

Because of personal transportation, people can go wherever and whenever they want. This freedom of choice, however, causes a tension that calls into question how long people will be able to manage the environment and natural resources sustainably.

Energy supply and use are big global issues. The globe consumes around 85 million barrels of oil per day, despite the fact that there are only 1300 billion barrels of confirmed oil reserves. If consumption stays the same, oil will run out in 42 years. Discoveries of new oil reserves happen more slowly than the rate at which demand is increasing. The oil needed for transportation is utilized to the tune of 60%. The United States consumes almost 25% of all the oil in the globe. It's essential to reduce oil use in the personal transportation sector if we want to attain energy and environmental sustainability.

The second point is that global climate change poses a serious threat to humanity. When fossil fuels are burned, a gas known as carbon dioxide (CO2), also referred to as greenhouse gas emissions or GHG emissions, is created and released into the atmosphere. Extreme weather occurs all around the world, and as a result of too much heat being trapped on the Earth's surface due to an increase in CO2 concentration, global temperatures rise. Potential

long-term implications of global warming include shifting ecosystems and rising sea levels.
One of the main sources of CO_2 emissions is from gasoline and diesel-powered vehicles. Sulfur dioxide and particulate matter (soot) from burning diesel fuel, hydrocarbons or volatile organic compounds (VOCs) from evaporated, unburned fuel, and carbon monoxide (CO) and nitrogen oxides (NO and NO_2, or NO_x) from burning gasoline are additional emissions from conventional fossil fuel-powered vehicles. The health of both people and animals is affected by air pollution, which is a result of these emissions.
Despite the need for the current paradigm in society, it is not long-term viable. Two phases in the global effort to keep human resource use within sustainable limits include using fewer fossil fuels and reducing carbon emissions. Personal transportation should therefore encourage increased autonomy, long-term mobility, societal prosperity, and economic progress in the future. Having vehicles that are powered by electricity from clean, safe, and intelligent energy sources is essential for reaching goals.
Electric vehicles have a variety of advantages and drawbacks. Electricity is more efficient than combustion in a car. According to well-to-wheel study, an electric car can go 108 miles (173 km) on a gallon of gasoline, compared to an ICE car's 33 miles (53 km) on the same amount of fuel. This is true even if the electricity is generated using petroleum. In a more direct comparison, using gasoline for a compact car costs euro 0.10 per mile compared to utilizing electricity, which costs euro 0.12 per kWh at a price of euro 3.30 per gallon. Electricity can be generated using renewable energy sources such as hydroelectricity, wind, sun, and biomass. The current power infrastructure does, however, have additional capacity that is reachable at night, when there is less demand for electricity. The best time to charge electric cars (EVs) is at night when the grid has excess energy capacity [18].
Battery-powered EVs encounter a number of challenges, such as high pricing, a limited driving range, and protracted charging times. Hybrid electric vehicles (HEVs), which power the vehicle with both an ICE and an electric motor, address the cost and range issues of pure electric vehicles without the need for a charging station. HEVs can use a significant amount less fuel than ordinary gasoline-powered automobiles. However, the vehicle continues to run on either gasoline or diesel fuel [34].
In comparison to HEVs, plug-in hybrid electric cars (PHEVs) have a larger battery pack and motor. Charge-depletion (CD) mode operating, which allows PHEVs to be driven for a short distance (20–40 miles) on electricity,

is possible. When the battery energy is exhausted, PHEVs engage in a mode of operation known as charge-sustain (CS) mode operation or extended range operation, which is identical to that of a standard HEV. By using PHEVs with a range of 40 miles of entirely electricity-based propulsion, a substantial proportion of fossil fuel can be replaced as most personal vehicles are used for commuting and 75% of them are only driven 40 miles or less daily. Similar to a HEV, a PHEV uses its onboard electric motor and battery during extended-range driving to optimize the performance of the engine and other vehicle systems for greater fuel efficiency. The PHEV can recover more kinetic energy while braking, further improving fuel efficiency, because of the increased battery power and energy capacity .

1.2 Strengths of Electric Vehicles (EVs):

- Electric vehicles (EVs) have zero exhaust emissions, which lowers air pollution and greenhouse gas emissions. They aid in halting climate change and enhancing local air quality.
- Compared to cars with internal combustion engines, EVs are more energy-efficient. They lose less energy because they transfer a higher proportion of grid energy to power at the wheels.
- Compared to vehicles fuelled by gasoline or diesel, electric vehicles are less expensive to operate. Because there are fewer moving components, maintenance costs are frequently lower for EVs and charging is typically less expensive than refueling with fossil fuels [6].
- A greener energy ecology can be supported by charging EVs using electricity produced by renewable energy sources like solar or wind power, further decreasing their carbon impact.
- Electric motors provide instant torque, resulting in quick acceleration and smooth performance. Electric vehicles often have a high power-to-weight ratio, making them capable of excellent acceleration and top speeds [24].

1.3 Weaknesses of Electric Vehicles (EVs) :

- Compared to conventional gasoline-powered automobiles, many electric cars have a shorter driving range. Even while battery technology is improving, this can still be a problem on lengthy journeys, especially in places with sparse

charging facilities.
- Particularly in some localities or isolated locations, the number of charging stations may be limited. Lack of charging infrastructure could limit long-distance travel and give EV owners range anxiety .
- An electric vehicle requires more time to charge than a conventional vehicle does to refuel with gasoline. It still takes longer than a simple stop at a gas station, even with fast-charging alternatives [22].
- Comparing electric automobiles to their gasoline-powered equivalents, the upfront cost is often higher. Even if the price of EVs is falling, some users may still find it to be prohibitive. The increased initial expenditure can, however, be mitigated by long-term operating cost benefits .
- Battery longevity in electric vehicles is sometimes a worry. Battery capacity may deteriorate over time, necessitating expensive replacement. In addition, EV battery recycling is still under development and requires more work to have a minimal negative environmental impact [7].

1.4 Classifications of electric vehicle:

1.4.1 PHEV Review

PEV stands for "Plug-in Electric Vehicle," which is a type of vehicle that runs on electricity and can be recharged by plugging it into an external power source. There are two main types of PEVs: Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs).
BEVs rely solely on electricity to power the vehicle, using a large battery pack that is charged by plugging the vehicle into a charging station or a standard electrical outlet. BEVs have zero tailpipe emissions and are considered to be one of the cleanest and most environmentally-friendly types of vehicles
PHEVs, on the other hand, have both an electric motor and an internal combustion engine. PHEVs can be charged by plugging them into an external power source, and they can also use gasoline to power the internal combustion engine when the battery is depleted. PHEVs offer the benefits of electric drive while also providing the ability to travel long distances without needing to stop to recharge [5]
PEVs have gained popularity in recent years due to their environmental benefits and cost savings over traditional gasoline-powered vehicles. They also offer a quieter and smoother driving experience compared to internal combustion

engine vehicles. However, they do require access to charging infrastructure, and the range of BEVs can be limited compared to gasoline-powered vehicles, although this is improving as battery technology advances [13] .

1.5 Concept of plug-in hybrid Electric Drive Trains

Plug-in electric drive trains are a type of propulsion system used in plug-in electric vehicles (PEVs). The electric drive train consists of an electric motor, a power inverter, and a battery pack. The electric motor is used to convert electrical energy stored in the battery pack into mechanical energy, which propels the vehicle forward.

In a plug-in hybrid electric vehicle (PHEV), the electric drive train works in conjunction with an internal combustion engine to provide power to the wheels. The battery pack can be recharged by plugging the vehicle into an external power source, allowing the vehicle to operate in electric-only mode for a certain distance before the internal combustion engine is needed.

In a battery electric vehicle (BEV), the electric drive train is the sole source of propulsion, as there is no internal combustion engine. The battery pack can be recharged by plugging the vehicle into an external power source, and the vehicle operates solely on electric power.

The advantage of plug-in electric drive trains is that they are highly efficient and produce zero tailpipe emissions, making them a cleaner alternative to traditional gasoline-powered vehicles. Additionally, they offer a smoother and quieter driving experience compared to internal combustion engine vehicles. However, the range of BEVs can be limited compared to traditional gasoline-powered vehicles, and charging infrastructure can be limited in some areas. As battery technology continues to improve, however, the range of BEVs is expected to increase, making them a more viable option for more people [13] .

1.6 Classification and Architectures of plug-in hybrid Electric Drive Trains

Plug-in electric drive trains can be classified into two main categories: series and parallel hybrid architectures.

Series Hybrid Architecture: In a series hybrid architecture, the internal combustion engine is used solely to generate electricity to power the electric

motor. The electric motor is the primary source of propulsion, and the internal combustion engine acts as a range extender. The battery pack can be recharged by plugging the vehicle into an external power source. Series hybrid architectures are used in some plug-in hybrid electric vehicles (PHEVs) [19].
Parallel Hybrid Architecture: In a parallel hybrid architecture, both the electric motor and the internal combustion engine are connected to the wheels and can provide propulsion. The battery pack can be recharged by plugging the vehicle into an external power source. Parallel hybrid architectures are used in some PHEVs.

In addition to these two main categories, there are also several different types of architectures that are used in plug-in electric drive trains, including:

Power Split Hybrid Architecture: In a power-split hybrid architecture, the electric motor and the internal combustion engine are both connected to the wheels, and power is split between the two sources. The battery pack can be recharged by plugging the vehicle into an external power source. Extended Range Electric Vehicle Architecture: An extended range electric vehicle (EREV) is a type of plug-in hybrid electric vehicle that has an electric motor as its primary source of propulsion but also includes an internal combustion engine that acts as a generator to provide electricity when the battery is depleted.

Battery Electric Vehicle Architecture: In a battery electric vehicle (BEV) architecture, there is no internal combustion engine, and the vehicle is powered solely by an electric motor. The battery pack can be recharged by plugging the vehicle into an external power source [13].

Fuel Cell Electric Vehicle Architecture: A fuel cell electric vehicle (FCEV) is a type of electric vehicle that uses a fuel cell to generate electricity, which is used to power an electric motor. The fuel cell generates electricity by combining hydrogen and oxygen, producing water as a byproduct [15].

1.7 HEV Review

Hybrid cars seamlessly combine the power of petrol engines with the efficiency of electric motors. When parking or driving in the city, the vehicle can automatically switch to electric mode without using fuel, greatly reducing CO2 emissions. While decelerating or braking, the electric motor continues to generate energy and stores it in the car's battery to keep it charged. And when accelerating or cruising at higher speeds, the petrol engine is automatically

switched on for extra power and responsive performance.
Hybrid cars are specially designed to reduce the consumption of fossil fuels and replace them as much as possible with clean energy, in order to reduce the intensity of emissions of polluting gases into the air, while taking into account the preservation of the car's power and smooth driving at the same time.
Basically, the main reason for manufacturing these cars is the desire to reduce fuel consumption as a result of the increase in its prices. Therefore, we can consider that hybrid car are nothing more than a transitional model between cars operating on internal transmission engines and electric cars [22].
And taking into account the current conditions and the ongoing research to develop electric cars, it seems that we are rapidly approaching an effective and practical design for electric cars that compete with fuel.
But if we look realistically, hybrid cars will remain on the market for at least the next twenty years, as it is not possible to replace all normal cars immediately [16].

1.8 Concept of Hybrid Electric Drive Trains

The hybrid car is very similar to regular cars in terms of appearance, as the difference between the two cars is in terms of energy sources. Whereas, electric cars use an electric motor that relies on batteries to obtain energy, and fossil fuel cars burn diesel or gasoline to move the car
Hybrid cars use both engines together. There is an internal motor and an electric one inside the car, where the car takes advantage of the features in both to save fuel.
The main principle in hybrid car engines is to select the optimal source of energy to give you maximum savings and efficiency. When driving at a low speed, the hybrid system of the car automatically stops the fuel engine from working and uses the electric motor as a power source, as the energy needed for movement is at its lowest limits.
As for driving at higher speeds, both engines work together, as the other engine burns fuel to secure the extra energy needed, so that energy waste is almost non-existent or at its minimum limits.

1.9 Classification and Architectures of Hybrid Electric Drive Trains

Although all cars that use electricity and fuel as energy sources are called hybrid cars, these cars do not share the same design or the same way of working. Hybrid cars are classified according to three criteria:

Classification of hybrid cars by type:

1.9.1 Conventional hybrid vehicles (True hybrid):

In fact, this classification did not exist for a long time, as all the hybrid cars that were manufactured at the beginning were classified within this branch, and the traditional hybrid car can be known through the charging method used.
As it depends entirely on the use of surplus energy in the car to charge the battery, especially the car's energy when braking.

1.9.2 Plug-in hybrid vehicles:

This type of car appeared at the end of 2010 with the launch of the Chevrolet Volt car in the market, so that other companies began to offer cars of the same type, as is the case in traditional hybrid cars, the car uses the lost energy to recharge the battery, but the difference lies in the possibility of charging the battery directly from the food network.
Although this method may seem expensive at first, it saves a lot of money, as the price of electricity needed to charge the battery from the network is much lower than the price of fuel needed to drive the car at the same distance, and with the presence of fast battery chargers, you can recharge the battery in a short time.

Features of the rechargeable vehicle:

This type of car is often characterized by larger batteries, which means that it is able to store a larger amount of energy, and thus provides the possibility of driving on energy alone for long distances, which can be translated into more fuel savings.

Classification of hybrid vehicles according to work system:

1.9.3 Series hybrid :

This model is the oldest in the manufacture of hybrid cars, where the internal combustion engine in this type is directly connected to an electric generator that connects electricity to a special charger that recharges the battery, including electricity to controllers that feed the motors connected to the wheels.

Advantages of hybrid vehicles with a series hybrid:

This system offers several advantages: Since the internal combustion engine does not communicate directly with the wheels, which means that you can use it more efficiently and reduce fuel consumption. In addition to the fact that this system eliminates the use of gearboxes, and since the wheels take their energy directly from the electric motors and with being more efficient than the internal combustion engines, this system is considered energy-saving. And we must not forget that the sequential arrangement allows you to turn off the engine and drive using the energy stored in the battery.

Disadvantages of hybrid vehicles with a series hybrid:

On the other hand, this serial connection does not allow the use of the internal combustion engine to drive the wheels directly. As I am, these parts can be heavy in weight and significantly increase the weight of the car. Also, the large number of devices between the internal combustion engine and the electric motor may cause some energy loss.

1.9.4 Parallel hybrids:

On the other hand, this serial connection does not allow the use of the internal combustion engine to drive the wheels directly. As I am, these parts can be heavy in weight and significantly increase the weight of the car. Also, the large number of devices between the internal combustion engine and the electric motor may cause some energy loss.

Advantages of hybrid vehicles with a parallel hybrids:

The direct connection of the internal combustion engine to the wheels reduces energy loss. Enables you to use the internal combustion engine to provide more power to move the car. Since the number of components in this system is less, cars operating on this system are lighter in weight.

Disadvantages of hybrid vehicles with a parallel hybrids:

As internal combustion engines are not practical at all speeds. Also, this system requires the use of a gearbox, unlike the sequential system. In view of the fact that this system requires the connection of two different sources of energy for the gearbox, complex mechanisms must be used to connect them in order to prevent one from obstructing the other.

1.9.5 Parallel/series hybrids:

As the name suggests, these cars use a system that combines the two previous systems, as this system communicates directly with the wheels through the gearbox on the one hand, and on the other hand it communicates with an electric generator that charges the battery or provides electricity directly to the electric motor that is also connected to a gearbox. the speed. In cars operating with this system, there is a special computer that operates the driving conditions and battery status to choose the most appropriate driving mode to obtain the greatest savings. When the battery is full and the road does not require a lot of power, the computer turns off the internal combustion engine and drives using electric power only. Either when the car needs more torque or the percentage of charge in the battery decreases, the computer starts the internal combustion engine automatically.

Classification of hybrid vehicles according to capacity:

Hybrid cars are divided into this classification according to the capacity of the electric motors used in them and the type of batteries present, as some companies reduce this capacity to reduce the price and cost, so they have classified them into:

1.9.6 Mini Hybrids:

These vehicles contain miniature batteries to reduce cost and their role is limited to supporting the internal combustion engine only, as the capacity of the battery and the electric motors do not allow the separation of the internal combustion engine.

1.9.7 Mild Hybrids:

The electrical equipment of this type is larger in size and is mainly used in cars with a bypass system, but it also does not provide the possibility of driving in fully electric mode, and you cannot even use this mode for short distances. The price of these cars is average.

1.9.8 Strong Hybrids:

These vehicles can be serial or sub-system cars or even mixed. This type of driving allows the use of electric mode and the separation of the internal combustion engine completely and for greater distances. It also supports the possibility of automatically disconnecting the internal combustion engine when stopping to save fuel when driving in cities.

Type of vehicle	Features and capabilities
	Start-stop — Regenerative braking — Boost — Electric-only mode — Electric-range(miles)
Micro hybrid	yes ——— possible ——— No ——— No ——— No
Mild hybrid	yes ——— yes ——— yes ——— No ——— No
Full hybrid	yes ——— yes ——— yes —— possible —— possible(¡2)
Plug-in hybrid	yes ——— yes ——— yes ——— yes ——— yes(20-60)
Pure electrie	yes ——— yes ——— yes ——— yes —— yes(80-150)

Table 1: The main features and capabilities of various hybrid electric vehicles

1.10 Features and specifications of the hybrid car:

1.10.1 Auto engine stop:

The most common cause of fuel consumption in normal cars is the continuous stoppage, as the engine consumes fuel when stopping and requires a large amount of fuel, so hybrid cars separate the intake engine when stopping and use the electric motor in the car.

1.10.2 Charging at throttle:

The car gains kinetic energy when it is running on the roads, as the braking principle depends on increasing the friction between the wheels and the road to reduce this energy, and instead of letting this energy be wasted completely, hybrid cars invest it and convert it into electric energy that uses battery charging.

1.10.3 Electrical brake support:

Hybrid cars benefit from the direct connection of electric motors to the wheels and use them to brake and reduce torque.

1.10.4 Advantages of hybrid vehicles:

You save fuel greatly, as some hybrid vehicles enable you to drive twice the distance with the same amount of fuel. It benefits the environment, as it reduces carbon dioxide emissions. Noise reduction, especially in cities, due to its ability to take off electric. The use of electric brakes in braking significantly increases the life of the brakes. It allows manufacturers to use smaller engines to get almost the same performance, which contributes to reducing the cost and weight of the car.

1.10.5 Disadvantages of hybrid vehicles:

These vehicles need expensive equipment to manufacture them, such as batteries and electric motors, in addition to computer monitoring systems for the car. The performance of the hybrid car is still far from that of the traditional car when driving off-road. Prices of hybrid cars are usually higher than the prices of regular cars.

1.11 Electrical energy storage systems :

The EV exclusively employs electrical energy for propulsion, as was just described. The energy density of batteries used to power electric vehicles today is lower than that of fuels. One kilogram of gasoline has an energy content of one kilogram of batteries, on average. This is why the majority of the work done to improve EV performance to a level comparable to internal combustion vehicles is concentrated on the batteries. The primary areas that need improvement are:
Autonomy: A traditional car's full tank can take you roughly 1000 kilometers. A couple hundred kilometers or so is considered the range of an electric car. Naturally, this autonomy restriction slows down the selling of EVs. According to a 2013 survey, more than half of the European people would consider purchasing an EV if the range was greater than 250 km.
Recharging: In addition to the battery's poor autonomy, this presents another challenge. In fact, staying connected to the home network for a number of hours is necessary to recharge the battery. Fast charging stations or other charging options, like the "Better Place" station concept, are being considered. The first option involves quickly changing the battery, while the second one permits a half recharge in 30 minutes. However, there is currently a lack of reliable information regarding how fast charging affects battery life, and these systems call for new infrastructures. According to estimates, urban adaption in France will cost an additional €3,000 per EV.
Cost and profitability: Currently, buying an EV is 25% more expensive than owning a traditional car, and the battery accounts for 30% of the EV's cost. The energy cost of EVs (3.4c€/km14) is also greater than that of contemporary gasoline and diesel vehicles (2.8 and 2.6c€/km), according to "well-to-wheel" analyses performed by Torchio and Al. However, estimates indicate that the trend will reverse by 2030, with EVs costing 4.8 cents per mile compared to 5 and 5.2 cents per mile for diesel and gasoline vehicles, respectively.

1.12 Types of Electrical energy storage systems :

Electric vehicles (EVs) use electrical energy storage systems to power their electric motors. These systems typically consist of a rechargeable battery that stores electrical energy and provides it to the electric motor when needed.

The battery is charged by plugging the EV into a charging station, which provides electrical power to the battery. There are several types of batteries that can be used in EVs, including:

- Lithium-ion batteries: These are currently the most commonly used batteries in EVs. They offer high energy density, long cycle life, and low self-discharge rate.
- Nickel-metal hayride batteries: These were used in earlier generations of EVs, but have been largely replaced by lithium-ion batteries. They have a lower energy density than lithium-ion batteries, but are more stable and less prone to thermal runaway.

- Solid-state batteries: These are a newer type of battery that uses a solid electrolyte instead of a liquid electrolyte. They offer higher energy density and faster charging times than lithium-ion batteries, but are still in the development phase and not yet widely available.

In addition to batteries, some EVs also use super-capacitors for short-term energy storage. super-Capacitors can charge and discharge quickly, making them useful for regenerative braking systems and other high-power applications.

Overall, the choice of energy storage system for an EV depends on factors such as cost, energy density, cycle life, and safety. As battery technology continues to improve, it is likely that we will see new types of batteries and energy storage systems being developed for use in EVs.

1.12.1 Li-ion battery:

Lithium-ion (Li-ion) batteries are currently the most common type of battery used in electric vehicles (EVs). Li-ion batteries work by moving lithium ions between a cathode (positive electrode) and an anode (negative electrode) through an electrolyte. When the battery is charged, lithium ions move from the cathode to the anode, storing energy. When the battery is discharged, lithium ions move from the anode back to the cathode, releasing energy to power the EV.

Operation and technologies:

The operation of Li-ion batteries in EVs is dependent on several technologies:
- Cell chemistry: The performance of Li-ion batteries in EVs is influenced by the chemistry of the cells. The cathode material is typically made of lithium cobalt oxide (LCO), lithium nickel cobalt aluminum oxide (NCA), or lithium manganese oxide (LMO). The anode material is typically made of graphite or silicon.
- Battery management system (BMS): The BMS is responsible for monitoring and controlling the charging and discharging of the battery, as well as preventing overcharging or over-discharging. The BMS also ensures that the battery cells are operating within safe temperature and voltage ranges.
- Thermal management system: Li-ion batteries can generate a significant amount of heat during charging and discharging. A thermal management system is used to regulate the temperature of the battery to ensure safe and efficient operation.
- Charging infrastructure: Charging infrastructure for EVs includes both public and private charging stations. Charging times and charging rates depend on the type of charger used and the capacity of the battery.
- Regenerative braking: Regenerative braking is a technology that allows the battery to be charged during deceleration or braking, improving the efficiency of the EV.

Overall, Li-ion batteries are well-suited for use in EVs due to their high energy density, low self-discharge rate, and long cycle life. However, the performance and lifespan of the battery depend on several factors, including cell chemistry, BMS, thermal management, charging infrastructure, and usage patterns.

1.12.2 Super-capacitor:

Super-capacitors, also known as ultra-capacitors, are energy storage devices that can complement or replace batteries in electric vehicles (EVs). Super-capacitors work by storing electrical charge in an electric field between two conductive plates, typically made of activated carbon. Unlike batteries, which store energy through chemical reactions, super-capacitors store energy electrostatic-ally, allowing them to charge and discharge quickly and efficiently.

Operation and technologies:

The operation of supercapacitors in EVs is dependent on several technologies:

- Electrodes: The electrodes in a supercapacitor are typically made of activated carbon, which provides a high surface area for storing charge. The electrodes can also be coated with a conducting polymer to improve their performance.
- Separator: The separator in a supercapacitor is typically made of a porous material, such as a polymer membrane, which allows ions to move between the electrodes while preventing direct contact.
- Electrolyte: The electrolyte in a supercapacitor is typically an aqueous or organic solution containing ions that facilitate the movement of charge between the electrodes.
- Current collectors: The current collectors in a supercapacitor are typically made of a conductive material, such as aluminum or copper foil, which connects the electrodes to the external circuit.
- Charging and discharging circuit: The charging and discharging circuit in a supercapacitor is responsible for controlling the flow of current between the supercapacitor and the external circuit, as well as monitoring the voltage and current of the supercapacitor.

Supercapacitors have several advantages over batteries for use in EVs. They can charge and discharge quickly, allowing for rapid acceleration and regenerative braking. They also have a long cycle life and can operate in a wide range of temperatures. However, they have a lower energy density than batteries and may not be able to provide sufficient energy for long-range driving.

Overall, the use of supercapacitors in EVs is still in the experimental phase, but they have the potential to improve the efficiency and performance of EVs in the future.

1.13 Association Li-ion battery/supercapacitor:

Series, parallel, and with one or two converters are only a few of the options available for connecting energy storage sources to the grid. Inverters, which are frequently employed in high DC bus voltage applications, can be the converter(s). In the case of a hybrid vehicle, Camara has researched a double-stage inverter architecture for the hybridization of a source (battery or supercapacitor) [6].

1.13.1 Cascade architecture with a DC/DC converter:

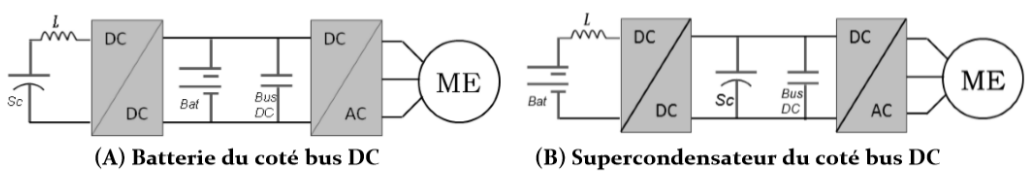

Figure 1: cascade architectures with a DC/DC converter [28]

One of the storage units is physically connected to the DC bus in this arrangement. The battery connection on the side of the DC bus maintains the DC bus voltage. Dixon et al. and other authors on electrified cars have incorporated this architecture in their studies of hybrid energy sources, with a focus on the supercapacitor's potential for energy recovery. Losses and installation costs are decreased with a single converter, and controlling the flow of energy is reasonably easy. The battery may become damaged during power peaks due to a lack of insulation between the inverter and the battery.However, the battery is better protected when the supercapacitor is connected to the DC bus as shown in. However, because the supercapacitor voltage varies so much depending on the SOC, the bus voltage is less stable. Because of this, this arrangement is inappropriate for a continuous power source (like an EV power source), but it may be interesting for starting aid for internal combustion or micro-hybrid vehicles [10],[28].

1.13.2 Cascade architecture with two DC/DC converters :

The battery and the supercapacitor are connected by an extra buck-boost converter in this system. As a result, the battery's voltage can be different from the supercapacitor's. To be able to manage the output current and, consequently, the current limitations, it is advantageous to place the battery on the input side of converter 1. The voltage at converter 2's input can undergo substantial changes due to the supercapacitor's wide range of voltage. As a result, both the supercapacitor and this converter must be larger. This solution's efficiency is low since the two converters must be used before the energy can reach the motor [9].

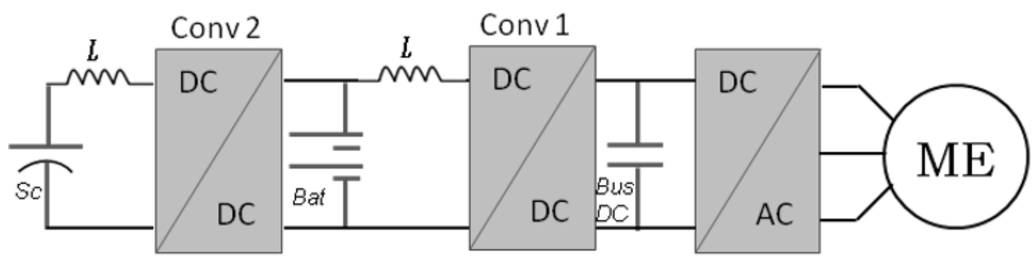

Figure 2: series architecture with two DC/DC converters [28]

The fundamental drawback of serial architectures is their dependability in the case of storage system failure. Furthermore, it is impossible to divide the power between the two sources on an independent basis [28].

1.13.3 Parallel architecture with two DC/DC converters :

The second conceivable active association design makes use of input with two paralleled bidirectional converters. Based on the battery and supercapacitor SOCs, respectively, they are independently voltage and current-controlled. This indicates that, in contrast to an association in series, where the flow passing through the two converters is identical, the power flow that passes converters 1 and 2 is not the same [26],[28].

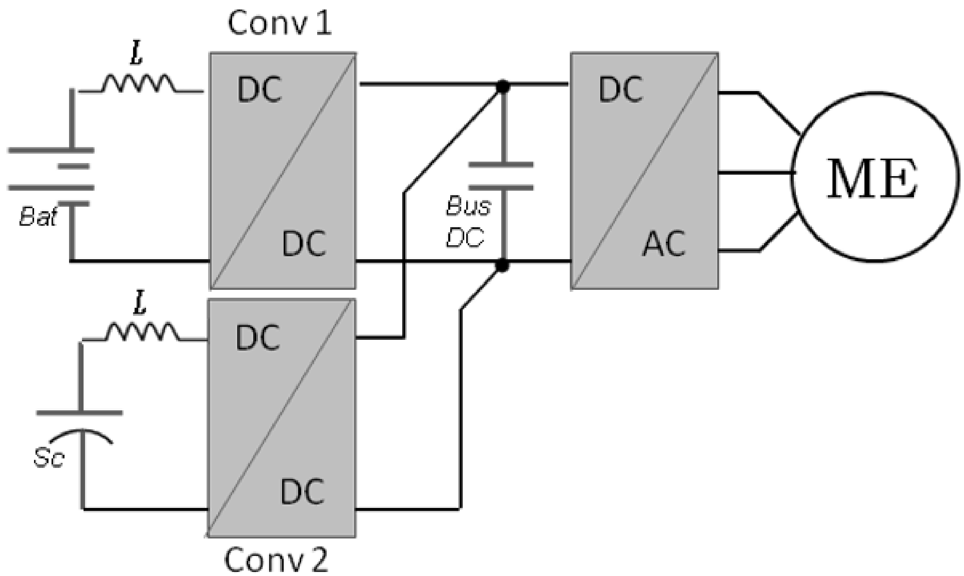

Figure 3: parallel architecture with two DC/DC converters [28]

The parallel active association boosts the overall system's resilience by allowing for operation with just one source in the event that the second fails.

1.14 Top 5 Evs companies in the world :

Electric vehicles (EVs) have grown in popularity in recent years due to their capacity to reduce air pollution and greenhouse gas emissions. Logistics businesses specializing in the automobile sector, such as Royale International, play an important role in the distribution and transportation of these vehicles to the market,these are the famous companies in the field :

- Tesla is a US-based electric vehicle (EV) manufacturer that is largely recognized as the market leader. Elon Musk, a computer millionaire, launched the business in 2003, and it has since gained a reputation for producing innovative and high-quality EVs. The Model S, Model 3, Model X, and Model Y are just a few of the many electric vehicles (EVs) that Tesla now sells. These cars are renowned for their outstanding performance, extensive range, and cutting-edge features like self-driving capabilities. With over 500,000 EVs sold in 2020, Tesla became the market leader in EV sales.

- Chinese EV manufacturer Build Your Dreams (BYD) is currently a significant player in the EV market. The business, which was established in 1995, has grown its operations and created a variety of EVs, including sedans, SUVs, and buses. In addition, BYD is renowned for its cutting-edge solar panels and batteries. Even yet, the business has gradually increased its footprint in other markets while maintaining a strong presence in China.

- The Japanese EV manufacturer Toyota is well known for its electric and hybrid cars. The Prius, a mass-produced hybrid vehicle that went on sale in 1997 and quickly rose to become one of the world's most well-known hybrids, marked the company's entry into the market. Toyota is still innovating today, producing hybrids and electric vehicles like the Mirai fuel cell car and the RAV4 EV, demonstrating their strong commitment to sustainability and their goal of having at least 50% of their global sales be electrified by 2025.

- Despite having a lengthy history in the automotive sector, the corporation just started making a serious effort to produce electronic vehicles recently. The ID.3 hatchback, ID.4 crossover, and ID. BUZZ van are just a few of the EVs it now offers under the ID brand. By 2025, this German EV firm wants to sell 1 million EVs annually, and to achieve this objective, it has made significant investments in EV manufacturing and charging infrastructure.

- General Motors (GM), a well-known American automaker, has recently stepped up its efforts in the EV industry by introducing a wide range of electric vehicles under its recognizable Cadillac, Chevrolet, and GMC brands. The Chevrolet Bolt and the Cadillac Lyriq are a couple of the company's standout products that have won a lot of praise.

1.15 conclusion :

In this chapter, we talk about the basics of electric vehicles and the advantages and disadvantages of each type, such as VE only, HEV, and PHEV. We also refer to the world's best manufacturers and leaders in the development of electric vehicles. We see that just 9% (16.7 million) of the world's sales of tourist cars were electric in 2021, but estimates indicate that this number will increase to 75% (727 million) by 2040. Sales of buses will increase from only 14% to 83%, similar to those of commercial vehicles and motorbikes. Therefore, the sphere of mobility and movement in the future will be dominated by this area and this technology.

There are many problems in electric cars such as charging control problem which takes a lot of time and storage problems for this energy and problems in controlling their distribution between components, There is also a problem of how to convert energy from the power source to the electric motor, so in Chapter II we will try to touch on multi- cellular transformers in preparation for Chapter III, which will be to control these transformers with a certain strategy using a simulator called a MATLAB.

Chapter 2

2 Multilevel converter and their application:

2.1 introduction

In this second chapter, we discuss Key components of modern power systems are electronic power converters. They transform electrical energy from one form to another by regulating the voltage, current, or frequency properties. These converters are extensively employed in many applications, including industrial systems, electric vehicles, and alternative energy sources.
Electrical energy switching can be precisely controlled by using semiconductor devices like transistors, thyristors, and diodes, enabling accurate and efficient conversion.A few benefits of using electronic power converters are improved energy economy, improved power management, precise voltage regulation, and strong dynamic responsiveness.
These converters can take different forms, such as inverters, rectifiers, voltage converters, DC-DC converters and AC-AC converters. Each type of converter has its own specific characteristics and applications.For example, inverters are used to convert DC to AC, while rectifiers do the opposite, converting AC to DC.
Electronic power converters are crucial for maintaining energy quality, regulating voltage, and safeguarding systems from overload and short circuits, as well as for maximizing the use of electrical energy.They aid in raising the overall effectiveness of electrical systems, cutting energy waste, and encouraging more environmentally friendly electricity consumption.
In short, electronic power converters are key devices for converting and controlling electrical energy. They enable efficient and flexible use of electricity in a variety of applications, contributing to the advancement of electrical technologies and the transition to cleaner and more sustainable energy systems.

2.2 operating principle

Based on its unique design and intended use, an electronic power converter functions. When converting electrical power from one form to another, such as from AC to DC or DC to AC, these converters are crucial. The following can be used to explain how an electronic power converter works :

The main goal of rectifiers, or AC-to-DC converters, is to change alternating current (AC) input into direct current (DC) output. This is accomplished by using thyristors or diodes, which only permit current to flow in one direction, essentially preventing the reverse flow during the negative half-cycles of the AC waveform. The result is a pulsing DC waveform at the output.
DC-to-AC converters, or inverters, on the other hand, are made to change direct current (DC) input into alternating current (AC) output. Electronic switches like transistors or insulated gate bipolar transistors (IGBTs) are used by inverters to produce a switching pattern that closely resembles the required AC waveform. By carefully controlling the switching states of these devices, the inverter produces a high-frequency AC output that can be used to power AC loads [21].
As the name implies, DC-to-DC converters are in charge of changing the voltage level of DC power. To control and adjust the DC voltage to the required level, they use power semiconductor devices, such as transistors or IGBTs, in conjunction with inductors and capacitors[21].
The characteristics of the AC power, such as the frequency or voltage level, are altered via AC-to-AC converters. Applications like voltage regulation or frequency conversion are made possible by these converters, which frequently combine rectification and inversion techniques to produce the necessary AC output waveform.
Pulse width modulation (PWM) control techniques are frequently used to adjust the output parameters of electronic power converters. PWM includes quickly and frequently turning on and off power semiconductor components. The average output power can be carefully regulated, enabling exact regulation of the output voltage or current, by varying the width or duration of the switches' on-state[23].
Overall, electronic power converters operate based on various principles such as rectification, inversion, DC-DC conversion, AC-AC conversion, and PWM control. The specific design, configuration, and control methods of the converter depend on its intended application, topology, and desired performance[23].

2.3 types of power converter :

Static converters are electrical circuits that modify the signal spectrum (amplitudes, frequencies, and phases) to adjust the source to the load by using power semiconductors (diodes, thyristors, transistors, etc.) as switches. The term ”power electronics” refers to the research and design of these devices. There are differences among the following converters:

Rectifiers : A converter for alternating and continuous power. The output voltage is not a substitute (the mean value is not zero). In the case of a controlled rectifier, this mean value can be changed. They are primarily used to power DC voltage-operated charges or to recharge batteries (a rectifier is always built into the chargers for your PCs and mobile devices).

choppers : They are DC-DC converters that enable a DC voltage to be changed to adapt it to the load, change the speed of a DC motor, or alter the level of brightness of a lamp. A lot of people cut frequently. It is the analog of the dimmer used in AC mode for DC voltage sources. The term ”buck” (or ”step-down” or ”Buck”) refers to a chopper when the voltage applied at the input is less than the voltage delivered at the output. If not, it is referred to as Booster (also known as Lift or Boost). There are helicopters (Buck-Boost) that can operate both ways.

dimmers : It is an AC-AC converter with a constantly variable efficiency that produces an AC voltage at the same frequency as the input voltage. By changing the supply voltage of reciprocating motors, such as asynchronous or synchronous motors, this converter is primarily used to change the speed of the motors.

inverters : When a DC source (such as batteries) is available, the inverter, a DC-AC converter, is typically used to power loads that require an AC voltage or to inject solar energy into the grid.

Cycloconverters : A converter known as an alternative alternative, produces an AC voltage with a different frequency and effective value from the input voltage. Cyloconverters are devices that change the frequency or effective value of the supply voltage to change the speed of reciprocating motors.

2.4 Overview of multilevel converters topology: :

2.4.1 Introduction :

Power electronics called multilevel converters are used to transform electric power from one form to another. Compared to traditional two-level converters, they are made to create an output voltage waveform that is required while having less harmonic content and better voltage quality. The output voltage is synthesized by multilevel converters employing a variety of voltage levels,

which are commonly created by combining several power semiconductor devices and capacitors.
The general concept of multilevel converters involves connecting several power cells or submodules in series or parallel to generate multiple voltage levels. Each power cell consists of one or more semiconductor switches, such as insulated gate bipolar transistors (IGBTs) or metal-oxide-semiconductor field-effect transistors (MOSFETs), and energy storage components like capacitors. Within this category three basic structures can be distinguished:
1- Diode-Clamped Multilevel Converter (also known as Neutral-Point Clamped Converter).
2- Flying Capacitor Multilevel Converter.
3- Cascaded H-Bridge Multilevel Converter.
The fourth multilevel structure is based on the idea of connecting some two-level converters in sequence. The power supply for each converter in this topology is made up of separate (isolated) voltage sources.

2.4.2 The NPC (Neutral Point Clamped) converter:

The NPC (Neutral Point Clamped) converter topology was proposed by Nabae, Takahashi, and Akagi in 1981 [23]. Several researchers have published articles reporting experimental results obtained with four-, five- and six-level NPC converters, intended for various uses such as static reactive energy compensation (STATCOM) [35], variable speed drives [32]. The NPC converter's architecture is made up of several arms, each of which is made up of a series combination of switching devices (usually IGBTs or MOSFETs) and diodes[21]. The DC bus and the load are connected in parallel by the arms. The neutral point, sometimes referred to as the midway or the clamping point, is connected to the DC bus's center point.
The additional clamping diodes between the neutral point and the converter's upper and lower arms serve as the NPC converter's defining characteristic. These clamping diodes make sure the neutral point voltage stays clamped at a particular level, usually at half the DC bus voltage. The NPC converter produces multi-level voltage output without the need for extra switching devices by clamping the neutral point.
Controlling the arms' switching states allows the NPC converter to produce the desired output voltage waveform. The output voltage can be at one of three levels while it is operating in the three-level mode: positive, zero, or

negative. Different voltage combinations can be achieved at the output by adjusting the upper and lower arms' switching states.
The output voltage waveform can be created by switching the components in the upper and lower arms in a predetermined manner. The switching patterns guarantee that the neutral point voltage is kept clamped while generating the required voltage levels.
The NPC converter has several benefits over conventional two-level converters, including less voltage stress on switching components, a waveform with less harmonic distortion, and increased efficiency. It is frequently utilized in high-power applications that call for precise voltage control, great efficiency, and little harmonic distortion.
However, implementing the NPC topology requires complex switch control to ensure reliable and efficient operation. Pulse Width Modulation (PWM) algorithms are used to control switch switching and generate the desired voltage waveforms.[23]
The NPC creates an output voltage with n+1 levels using a fractional voltage source and a serial combination of n switches1. By connecting 2n–2 clamp diodes to the nodes of the split input voltage, it is possible to ensure that the input voltage is distributed evenly at the terminals of each switch in the blocked state. Additionally, these diodes offer a lower blocking voltage at each switch's terminals [31].

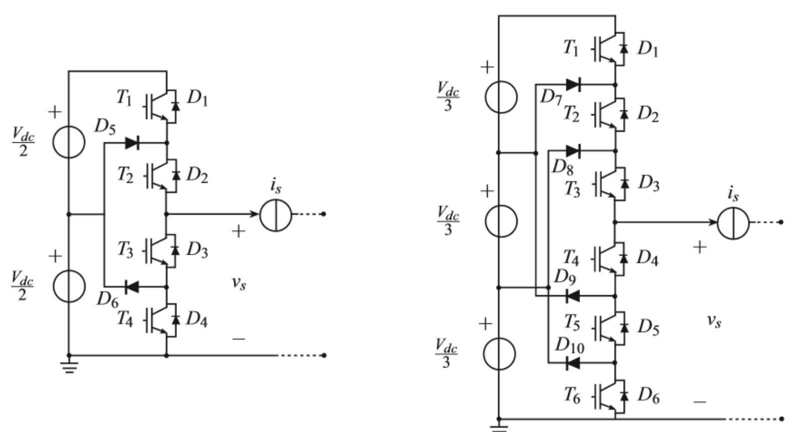

Figure 4: NPC structure at (a) n=4 (three levels) and (b) n=6 (four levels) [31]

For case n=2, the three output voltage levels (0, Vdc/2 and Vdc) can be obtained from the configurations presented in Figure 6 [31]. Figure 7 [30] shows the possible output voltage levels for one phase of the inverter. State 1 means the switch is closed and state 0 means the switch is open.

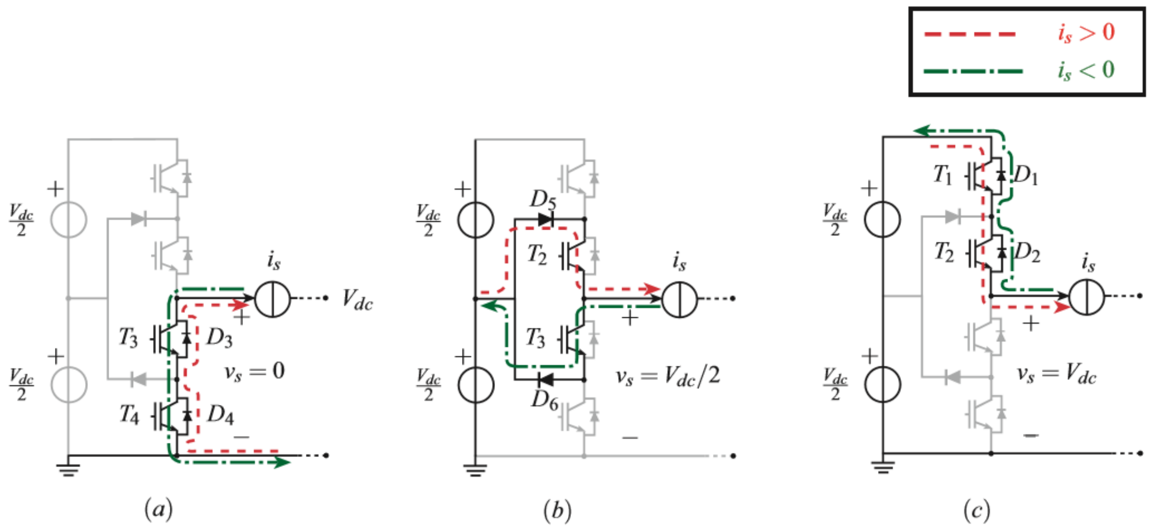

Figure 5: Obtaining different voltage levels with a three-level NPC converter

La tension de sortie (V_{OA})	Etat des interrupteurs			
	S_{a1}	S_{a2}	S_{a3}	S_{a4}
$V_{OA} = -\frac{V_{dc}}{2}$	0	0	1	1
$V_{OA} = 0$	0	1	1	0
$V_{OA} = \frac{V_{dc}}{2}$	1	1	0	0

Figure 6: the possible configurations of the NPC multi-level converter

In summary, the NPC converter topology consists of multiple arms with clamping diodes at the neutral point. By controlling the switching states of the arms, the multi-level voltage output can be achieved, providing benefits such as reduced switching losses, improved efficiency, and lower harmonic distortion in high-power applications.

2.4.3 Flying capacitor :

The flying capacitor topology converter, also known as the multi-level flying capacitor converter, is a power converter topology commonly used in high-voltage and high-power applications. It is designed to achieve multilevel voltage output using a combination of capacitors and switches.

The flying capacitor converter's fundamental idea is to create intermediate voltage levels by connecting capacitors between different voltage levels. The desired output voltage waveform is subsequently created by combining these intermediate voltage levels [27].

Typically, the topology is composed of a number of arms, each of which is made up of a sequence of capacitors and switches. To produce the intermediate voltage levels, the capacitors are charged and discharged. The connections between the capacitors and the load or DC source are managed by the switches.

The switching mechanism used in the flying capacitor converter's functioning makes it possible to redistribute charge among the capacitors. The capacitors are wired in series or parallel to provide the required voltage levels by properly switching the states of the switches.

One of the flying capacitor converter's main benefits is its capacity to produce high-quality output voltage waveforms with minimal harmonic distortion. In comparison to conventional two-level converters, the multilayer voltage output enables smoother voltage waveforms and lower voltage stress on the switches.

The flying capacitor converter, however, also has significant drawbacks. Careful balancing of the capacitors is necessary to guarantee equal voltage distribution and avoid overvoltage situations. The complexity and price of the converter may also grow due to an increase in the number of capacitors and switches.

High-power applications utilizing the flying capacitor converter include electric vehicles, renewable energy systems, and high-voltage DC transmission. In comparison to conventional two-level converters, it has advantages in terms of lowered harmonics, enhanced voltage waveform quality, and increased efficiency.

In summary, the flying capacitor topology converter utilizes capacitors and switches to create intermediate voltage levels, which are combined to generate multilevel voltage output. This topology provides benefits in terms of improved waveform quality and reduced harmonics, making it suitable for high-power and high-voltage applications.

2.4.4 H-Bridge Type Multilevel Converter:

As a multilevel conversion structure, this structure is the first to be mentioned in the literature. In fact, a multilayer voltage waveform is feasible at the output when numerous 3-level structures are cascaded together; in other words, this structure is built on connecting several single-phase inverters in series [2].
A topology used in power electronics for converting electrical energy is the H-Bridge Multilevel Converter arrangement [25]. It consists of a number of interconnected cell arrangements, with a set of power switches in the shape of a H in each cell. An output voltage waveform with several levels can be produced by controlling the switches in a certain way to link the power source to the load. The switches are deliberately turned on and off in a coordinated and sequential manner to produce these voltage levels, which produces an output voltage waveform of high quality with fewer undesirable harmonics. The use of this topology is advantageous in numerous high-voltage and high-power applications, including motor control and renewable energy systems.The waveform and structure of a cascaded H-bridge multilevel converter are shown in Figure 9 [3] .

This first fundamental topology for multilevel converters offers a number of benefits, some of which we can list here:

first fundamental topology for multilevel converters offers a number of benefits, some of which we can list here [1] :

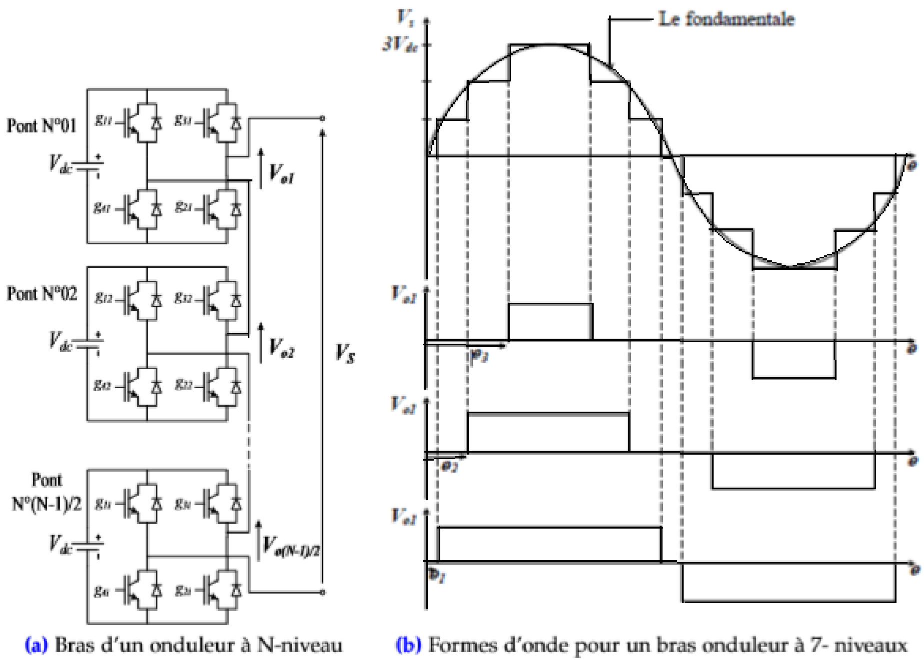

Figure 7: Structure and waveform of a cascaded H-bridge multilevel inverter

-In comparison to conventional two-level converters, the H-bridge converter's multilayer output waveform offers lower harmonic distortion, less voltage ripple, and improved voltage quality. This is advantageous in situations where high-quality power is needed, such as in motor drives or renewable energy systems.
-Compared to two-level converters, the multilayer structure enables lower voltage stress on the power semiconductor devices (such IGBTs or MOSFETs). As a result, converter efficiency is raised along with device reliability and loss reduction.
-By simply adding more H-bridge modules, the H-bridge multilevel converter can be easily expanded to reach greater voltage levels. This qualifies it for high-power applications that call for high voltage levels.
-The H-bridge converter can operate fault-tolerantly because of its modular design. The impact of a single-point failure is reduced since the other H-bridge modules can keep working even if one of them fails.

There are also some disadvantages to this structure [17]:

-In comparison to two-level converters, the H-bridge multilevel converter is more complex and expensive since it needs numerous gate drivers and power semiconductor components. Complex control algorithms for capacitor voltage balance and suitable switching sequences can also be used.

-Compared to two-level converters, the H-bridge converter needs more capacitors, voltage clamping diodes, and power semiconductor devices. The converter system's size, weight, and price may rise as a result.

-The H-bridge converter's voltage balancing can be difficult, especially as the number of levels rises. The voltage imbalances between the capacitor voltages must be regulated to maintain appropriate operation and avoid overvoltage circumstances.

- The multilevel operation of the H-bridge converter involves more switching events compared to two-level converters. This results in increased switching losses, which can affect the overall converter efficiency.
Overall, even though the H-Bridge Multilevel Converter has benefits including better waveform quality and lower switching losses, its larger component count and increased complexity should be considered when designing and implementing systems.

2.5 Parallel Multicell Converter :

Applications for parallel multicellular converters include microprocessors, automotive power networks, and high-power backup inverters. The following are the primary reasons for paralleling switching cells:

- the possibility of reaching inaccessible power levels with single components.
- the use of lower-quality, but more effective, components.
- increasing the number of degrees of freedom to improve the waveforms at the converter's input and output.
- The lower overall cost of the converter due to the usage of smaller-sized components.

The issues that can result from extreme parallelism are the fundamental disadvantage of parallel multicellular converters. These issues are:

- Unbalanced arm currents as a result of the converter's slightest flaw.
- significant current ripples are present in the converter arms.

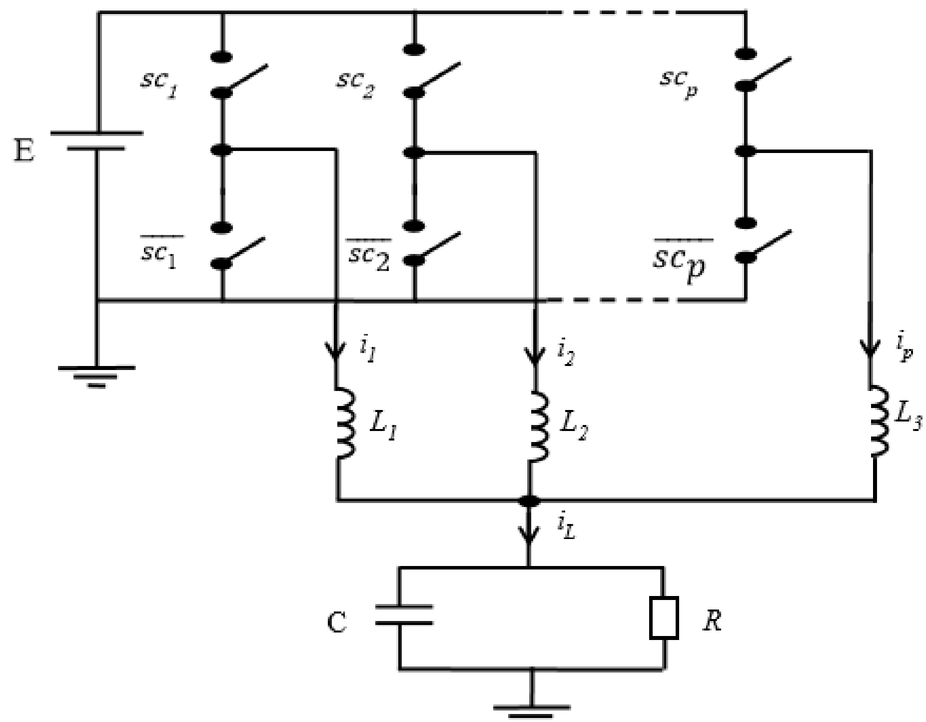

Figure 8: Parallel Multicell Converter

-An association of interconnected switching cells via independent inductances, also known as link inductances, is the foundation of the parallel multicellular converter's (CMP) classical topology (Figure I.2) [16]. Two neighboring cells have out-of-phase control orders of (2/p), and switch cells all have the same cyclic ratio. The switching cells deliver square voltages that are 2 /p out of phase and at levels 0 and +E. Voltages with the same fundamental frequency and harmonic content make up the system of balanced voltages that form the voltage. Each cell has a binding inductance that is the same and is designed to withstand any difference in instantaneous voltage between the cells. This kind of converter's extremely noteworthy modular feature is that they are all powered by the same average current.

2.6 Topological analysis of serial multicell converters :

2.6.1 Introduction

The fundamental idea behind series multicell converters is to combine multiple conversion cells in series to obtain a desired output voltage. Each conversion cell consists of an electronic switch (typically a transistor) and a capacitor. When the cells are connected in series, the overall output voltage is the sum of the voltages across each cell.

The serial multicell converter will be examined in this chapter. First, the working theories, traits, and time waveforms were discovered for a perfect three-cell converter.

We will presume that all of the system's components are perfect for this. As a result, the structure's semiconductors will possess the following qualities:
1. has no on-state resistance.
2. Infinite resistance to off-state.
3. There is no switching time.
The sources of voltage and current will also be presumptive perfect.

There are several possible configurations for series multicell converters, such as equal voltage configuration and unequal voltage configuration. In the equal voltage configuration, all cells have the same nominal voltage, while in the unequal voltage configuration, the cells have different nominal voltages. Each configuration has specific advantages and disadvantages in terms of performance, cost, and complexity.

2.6.2 Principle of operation of a serial multicell converter

To provide a balanced distribution of supply voltage on the various switches during a series connection of semiconductor components, it is necessary.

It is required to make sure that the voltage delivered to these switches is balanced at E/2 if we take into account two switches each capable of withstanding a voltage of E/2 rather than just one. A voltage source can be inserted as indicated in Figure 10 as one solution.

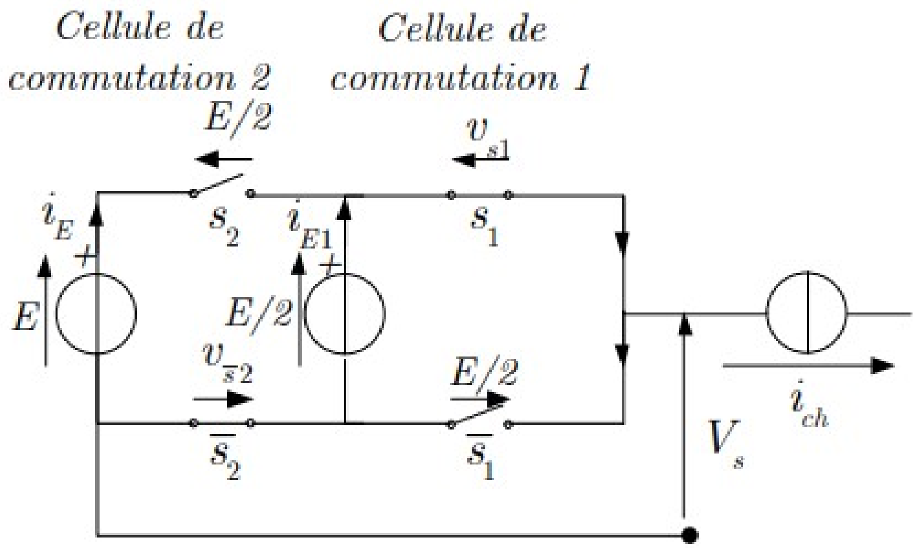

Figure 9: Two Switch Cell Multi-Cell Converter Arm

If the floating voltage source delivers a voltage equal to E/2 then the distribution is balanced.

In effect, $Vcell1 = E/2$, $V_{cell2} = (E - E/2) = E/2$.

It's noteworthy to notice that the stresses placed on the switches of one switching cell have no effect on those placed on the switches of the other cell; as a result, the two cells can be thought of as independent.

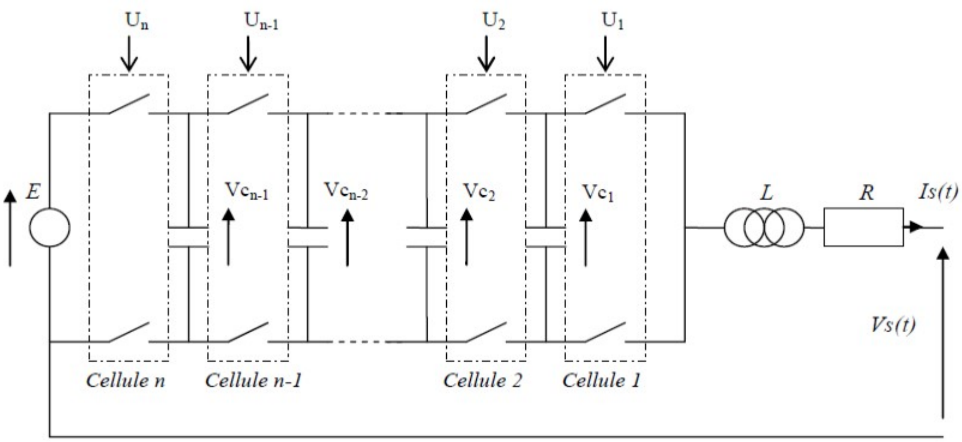

Figure 10: Multi-cell converter with p switching cells

The multicellular structure is shown in Figure 11. It can be adapted to all configurations: chopper or inverter, half-point, or full-bridge assembly. This structure is made up of p-switching cells, "separated" from each other by (p-1) floating capacitors. The voltage across each capacitor naturally balances at a particular percentage of the DC bus voltage when everything is running normally.

The output voltage generated by a p-cell converter can vary over p+1 levels. The state of the converter is determined by p commands, represented by the time functions U_1,.U_2..,U_k,...,U_p

By convention, we define connection functions as follows:

$U_k = 1:$ The top switch of cell K^{th} is on, and the bottom switch is stuck.

$U_k = 0:$ The top switch of cell K^{th} is stuck, and the bottom switch is on.

Assuming that the floating voltages are well balanced at their respective values, the output voltage Vs is simply expressed as a function of the connection functions:

$V_S(t) = (U_1 + U_2 + U_3 + \cdots + U_K + \cdots + U_P) * \frac{E}{P}$

2.6.3 Faults In Multicellular Converters :

Faults can occur in multicellular converters and can encompass various types. Individual cells within the converter can fail, leading to an imbalance in electrical distribution between cells and performance degradation. Capacitors used in the converter may also experience failure, resulting in reduced efficiency and disturbances in current and voltage. Switching devices, such as open circuits or short circuits, can malfunction and affect proper control of current and voltage. Control circuit faults can generate incorrect control signals, negatively impacting performance. Voltage or current overload conditions may arise, potentially causing transformer damage or component failure. Additionally, communication and control system faults between the main unit and individual cells can disrupt communication and hinder proper control. Timely diagnosis and corrective actions are necessary to address these faults. Advanced fault detection and monitoring techniques are employed to prevent or mitigate the occurrence and impact of these faults in multicellular converters.

2.6.4 Conclusion

The series and parallel connections of the switching cells are shown at the top. These relationships have allowed the static converters' input voltage and/or output current to grow. The creation of multilayer converters is one thing that the series connection has made possible.

The NPC converter and the serial multicell converter, often known as the Flying Capacitor converter, are the primary building blocks of this association. The NPC converter eases voltage restrictions at the switches' level, but it is not possible to gain from a rise in apparent switching frequency at the converter's output. However, due to its simplicity of use, this converter is being utilized extensively in the industrial sector. The serial multicell converter (FC type) connects switching cells in series with floating capacitors that have been charged to a small portion of the input voltage. A doubling of the apparent switching frequency at the output also reduces strains at the voltage level of each switch.

2.7 Modeling of multicell converters:

2.7.1 Introduction

In the study of a static converter control, the modeling component is of particular relevance. In fact, both continuous variables (often current and/or voltage) and discontinuous variables (switch states) exist in a static converter, whether it is multicellular or not.

The dynamics of the various modes must be described in the multicell converter modeling. Since the control is based on the idea of Lyapunov stability, this modeling is established in terms of equations of state. It is also established in terms of temporal formulation to validate the state spaces allotted to each mode.

A serial multicell converter has p switches to be controlled to adjust p state quantities which are the floating voltages and the load current. These switches provide 2p-1 degrees of freedom (p duty cycles and p-1 phase shifts). According to the deliberate degrees used for the definition of a control strategy [20].

In this work, two models of the serial multicell converter will be developed [4]:
1- The model with instantaneous values.
2- The mid-value model.

2.7.2 Instant model

The instantaneous model of a multi-cell converter faithfully represents the state of the cells of the converter at any instant. it is based on an analysis of the equations governing the evolution of the state quantities according to the state of the switches (on or off) of the converter.

To establish the instantaneous model of our converter, we take two cells (U_k,$\overline{U_K}$) and (U_{k+1},$\overline{U_{K+1}}$) with their floating capacitor. The evolution of the

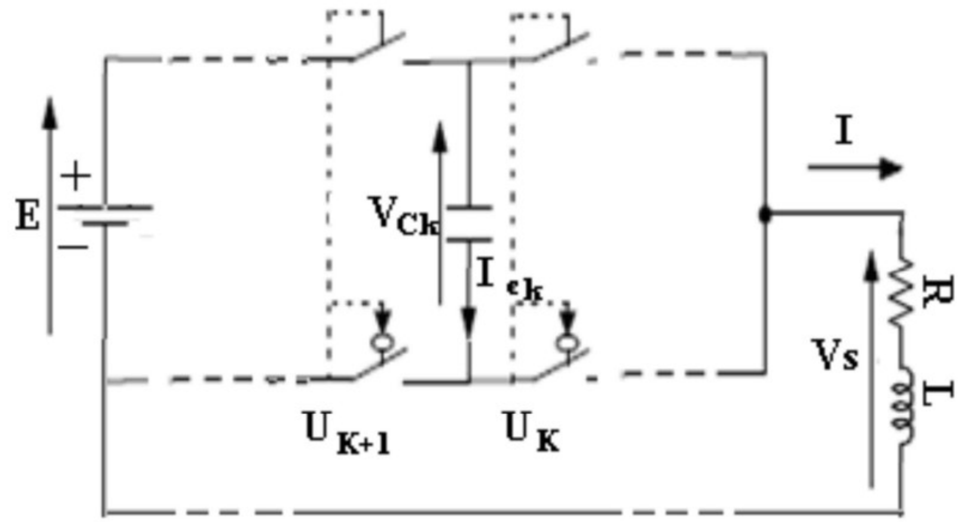

Figure 11: representation of an elementary cell at order k [14]

voltage at the terminals of the capacitor C_K is linked to the evolution of the current I_{ck} , the latter being a function of the state of the adjacent cells (cell k+1 and cell k) and of the charging current I_C .

The charging current depends on the control signals U_k and U_{k+1}

$$I(t)_{ck} = (U_{K+1} - U_K) .I(t)$$

The voltage across capacitor C_k s linked to current I_{ck} by :

$$I(t)_{ck} = C_K \cdot \frac{dV(t)_{cK}}{dt}$$

So it comes: :

$$\frac{dV(t)_{CK}}{dt} = \frac{(U_{K+1} - U_K)}{C_K}.I(t)$$

This equation is generalize to $(p-1)$ floating capacitors. According to the mesh law, the output voltage V_S is the sum of the voltages across the terminals of switches $\overline{U_K}$. These voltages are defined by :

$$V(t)_{U_k} = -\left(V(t)_{k+1} - V(t)_k\right) \cdot U_k$$

Hence, the voltage at the terminals of the load Vs becomes :

$$V_S(t) = \sum_{k=1}^{p} V(t)_{U_K} = \sum_{k=1}^{p} \left(V(t)_{C_K} - V(t)_{C_{K-1}}\right) \cdot U_k$$

With : $V_{C_0} = 0$ and $V_{Cp} = E$

The evolution of the current in the load is given by the following equation:

$$\frac{dI(t)}{dx} = \frac{V_S(t)}{L} - \frac{R}{L}.I(t)$$

By substituting equation (I.7) into equation (I.8) we find:

$$\frac{dI(t)}{dt} = -\frac{V(t)_{C1}}{L}(u_2 - u_1) - \frac{V(t)_{C2}}{L}(u_3 - u_2) - \cdots - \frac{V(t)_{Cp-1}}{L}(u_p - u_{p-1}) - \frac{R}{L} \cdot I(t) + \frac{E}{L} \cdot u_p$$

The instantaneous model presenting the converter (with a load R_L) in the form of an equation of state is defined by:

$$\sum \begin{cases} \frac{dV_{C1}}{dt} = \frac{1}{C_1}(u_2 - u_1) \cdot i_s \\ \vdots \\ \frac{dV_{Cp-1}}{dt} = \frac{1}{C_{p-1}}(u_p - u_{p-1}) \cdot i_s \\ \frac{di_s}{dt} = -\frac{V_{C1}}{L}(u_2 - u_1) - \frac{V_{C2}}{L}(u_3 - u_2) - \cdots - \frac{V_{Cp-1}}{L}(u_p - u_{p-1}) - \frac{R}{L} \cdot i_s + \frac{E}{L} \cdot u_p \end{cases}$$

The instantaneous equation of state of a converter with $\boldsymbol{p}$ cells can then be written in the form :

$$\dot{X} = AX + G(X)U$$

X is the state vector,

$X = \begin{bmatrix} V_C \\ i_S \end{bmatrix}$ and U is the command vector $U = \begin{bmatrix} u_1 \\ \vdots \\ u_P \end{bmatrix}$.

$$Tels\ que : A = \begin{bmatrix} 0 & \cdots & 0 \\ \vdots & 0 & \vdots \\ 0 & \cdots & -\frac{R}{L} \end{bmatrix}, et \quad G(X) = \begin{bmatrix} -\frac{i_s}{c_1} & -\frac{i_s}{c_1} & 0 & \cdots & 0 \\ 0 & -\frac{i_s}{c_2} & \frac{i_s}{c_2} & \cdots & 0 \\ \vdots & 0 & \ddots & \ddots & \vdots \\ 0 & \cdots & 0 & -\frac{i_s}{c_{p-1}} & \frac{i_s}{c_{p-1}} \\ \frac{v_{c1}}{L} & \frac{v_{c2}-v_{c1}}{L} & \cdots & \frac{v_{cp-1}-v_{cp-2}}{L} & \frac{E-v_{cp-1}}{L} \end{bmatrix}$$

As the vector X intervenes in the matrix G, the model is therefore non-linear presenting an input-output coupling. Its major drawback is that the command is discontinuous since, in the ideal case, the command of the switches goes from 0 to 1 in zero time. All amplitude controls (where the state of switches is defined as a function of current and voltage), including sliding mode control, of multicellular converters are based on this model.[10]

2.7.3 Medium model:

By replacing the command orders in the instantaneous model by their average values over a chopping period : $\alpha_i = \int_0^{T_d} u_i dt$, We deduce the average model

$$\langle \dot{X} \rangle = A\langle X \rangle + G(\langle X \rangle)U$$

The replacement of the quantities of the instantaneous model by their average values is valid only if the time constants of the system are much larger than the chopping period. In its general form, the average model of a converter with ***p*** cells is then written:

$$
\begin{cases}
\dot{x}_1 = \frac{1}{C_1}(\alpha_1 - \alpha_2).x_p \\
\dot{x}_2 = \frac{1}{C_2}(\alpha_2 - \alpha_3).x_p \\
\vdots \\
\dot{x}_{p-1} = \frac{1}{C_{p-1}}(\alpha_{p-1} - \alpha_p).x_p \\
\dot{x}_p = -\frac{1}{L}(\alpha_2 - \alpha_1).x_1 - \frac{1}{L}(\alpha_3 - \alpha_2).x_2 - \cdots - \frac{1}{L}(\alpha_p - \alpha_{p-1}).x_{p-1} - \frac{R}{L}.x_p + \frac{E}{L}\alpha_p
\end{cases}
$$

The vector X here represents the average values of the voltages of the capacitors and the average value of the charging current.

This method has the advantage of simplicity and mastery of the switching frequency but has the disadvantage of being based on the average value and therefore favoring slow evolution's. It was the first to be used to define commands for the multicell converter.

We will now apply the snapshot model to a two-cell, three-cell, and five-cell converter.

2.7.4 two cells :

Figure 18 shows the diagram of the 2-cell converter which will be modelled later.

From the equations (18), the behaviour of this converter is described by the following system of equations :

$$
\sum \begin{cases} \frac{dV_C}{dt} = \frac{1}{C}(u_2 - u_1) \cdot i_s \\ \frac{di_s}{dt} = -\frac{V_C}{L}(u_2 - u_1) - \frac{R}{L} \cdot i_s + \frac{E}{L} \cdot u_2 \end{cases}
$$

In state form:

$$\begin{bmatrix} \dot{V}_C \\ \dot{I} \end{bmatrix} = \begin{bmatrix} 0 & \frac{(u_2-u_1)}{C} \\ -\frac{(u_2-u_1)}{L} & -\frac{R}{L} \end{bmatrix} \cdot \begin{bmatrix} VC \\ I \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{E}{L} \cdot u_2 \end{bmatrix}$$

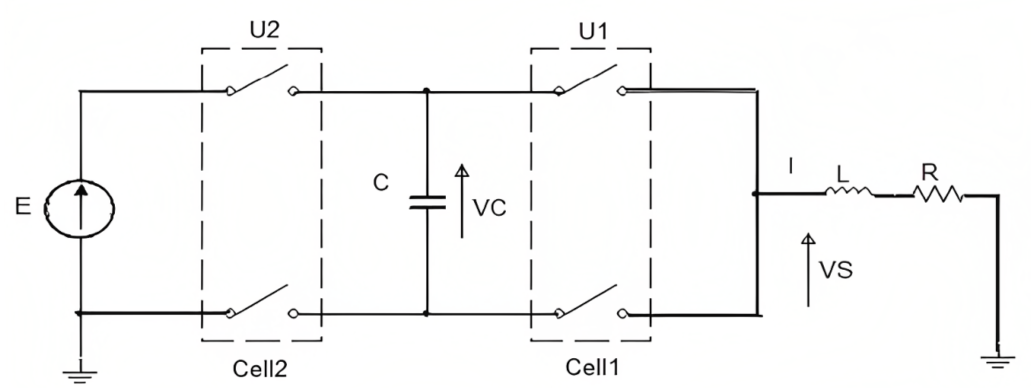

Figure 12: Two-cell converter
[13]

The modeling describes the behavior of the system to better trace a model control strategy (maintain the charging current I and the floating voltage around the values of the following references):

$$I(t) = I_{ref} \quad ; \quad V_{ref} = \frac{E}{2}$$

output voltage V_S across the load becomes:

$$V_S(t) = (u_1 + u_2) \cdot \frac{E}{2}$$

2.7.5 three cells :

The three-cell converter's diagram, which will be simulated later, is shown in Figure 19.

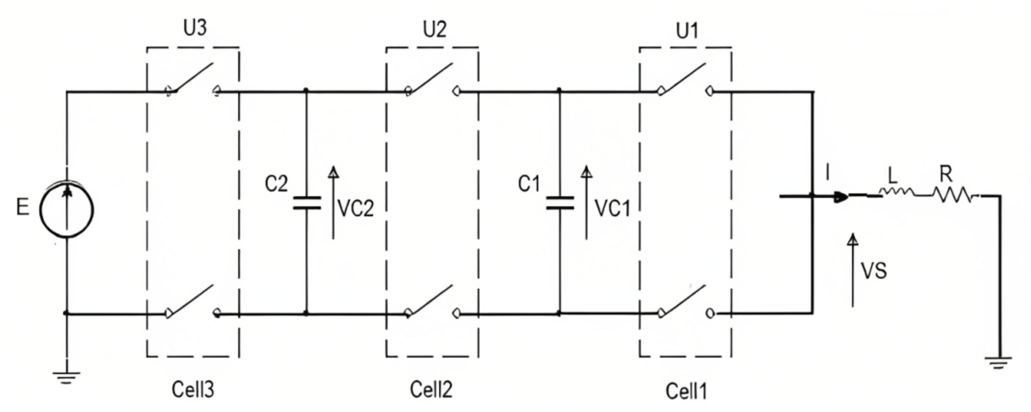

Figure 13: Three-cell converter
[13]

The system derives the behavior of this converter from equations (I.10) of equations following:

$$\sum \begin{cases} \frac{dV_{C1}}{dt} = \frac{1}{C_1}(u_2 - u_1) \cdot i_s \\ \frac{dV_{C2}}{dt} = \frac{1}{C_2}(u_3 - u_2) \cdot i_s \\ \frac{di_s}{dt} = -\frac{V_{C1}}{L}(u_2 - u_1) - \frac{V_{C2}}{L}(u_3 - u_2) - \frac{R}{L} \cdot i_s + \frac{E}{L} \cdot u_3 \end{cases}$$

In the form of a statement:

$$\begin{bmatrix} \dot{V_{C1}} \\ \dot{V_{C2}} \\ \dot{I} \end{bmatrix} = \begin{bmatrix} 0 & 0 & \frac{(u_2-u_1)}{c_1} \\ 0 & 0 & \frac{(u_3-u_2)}{c_2} \\ \frac{-(u_2-u_1)}{L} & \frac{-(u_3-u_2)}{L} & \frac{-R}{L} \end{bmatrix} \cdot \begin{bmatrix} V_{C1} \\ V_{C2} \\ I \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \frac{E}{L} \cdot u_3 \end{bmatrix}$$

Controlling the state variables V_{C1}, V_{C2}, and I always revolves around the following reference values :

$$I(t) = I_{\text{ref}} \quad ; \quad V_{c1 \text{ ref}} = \frac{E}{3};; \quad V_{c2} \text{ ref } = \frac{2.E}{3}$$

The output voltage V_S at the load's terminals changes to:

$$V_S(t) = (u_1 + u_2 + u_3)\frac{E}{3}$$

2.7.6 Five cells :

The diagram of the 5-cell converter, which will be modeled later, is shown in Figure 20 .

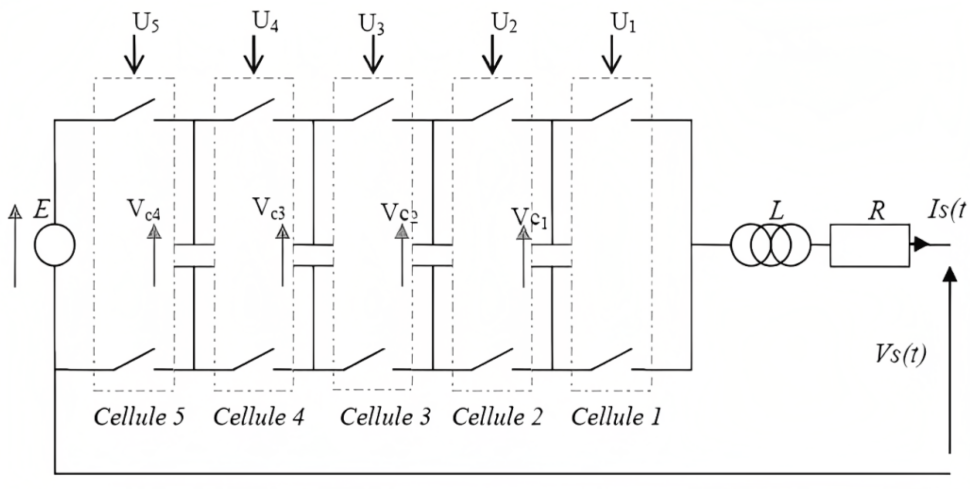

Figure 14: five cell converter
[13]

The equations (I.10) provide a set of equations that describes the behavior of this converter as follows:

$$\Sigma \begin{cases} \frac{dV_{C1}}{dt} = \frac{1}{C_1}(u_2 - u_1).i_s \\ \frac{dV_{C2}}{dt} = \frac{1}{C_2}(u_3 - u_2).i_s \\ \frac{dV_{C3}}{dt} = \frac{1}{C_3}(u_4 - u_3).i_s \\ \frac{dV_{C4}}{dt} = \frac{1}{C_2}(u_5 - u_4).i_s \\ \frac{di_s}{dt} = -\frac{V_{C1}}{L}(u_2 - u_1) - \frac{V_{C2}}{L}(u_3 - u_2) - \frac{V_{C3}}{L}(u_4 - u_3) - \frac{V_{C4}}{L}(u_5 - u_4) - \frac{R}{L}.i_s + \frac{E}{L}.u_5 \end{cases}$$

As a statement:

$$\begin{bmatrix} \dot{V}_{C1} \\ \dot{V}_{C2} \\ \dot{V}_{C3} \\ \dot{V}_{C4} \\ I \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & \frac{1}{C_1}(u_2-u_1) \\ 0 & 0 & 0 & 0 & \frac{1}{C_2}(u_2-u_1) \\ 0 & 0 & 0 & 0 & \frac{1}{C_3}(u_2-u_1) \\ 0 & 0 & 0 & 0 & \frac{1}{C_4}(u_2-u_1) \\ -\frac{1}{L}(u_2-u_1) & -\frac{1}{L}(u_3-u_2) & -\frac{1}{L}(u_4-u_3) & -\frac{1}{L}(u_5-u_4) & -\frac{R}{L} \end{bmatrix} \cdot \begin{bmatrix} V_{C1} \\ V_{C2} \\ V_{C3} \\ V_{C4} \\ I \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \frac{E}{L}.u_5 \end{bmatrix}$$

The hybrid converter model's goal is to regulate load current I and the floating voltages V_{C1}, V_{C2}, V_{C3}, and V_{C4} around the reference values:

$$I = I_{ref} \quad ; \quad V_{c1\text{ ref}} = \frac{E}{5}; \quad V_{c2ref} = \frac{2.E}{5}; V_{c3ref} = \frac{3.E}{5}; V_{c4ref} = \frac{4.E}{5}$$

The output voltage V_s at the load's terminals changes to :

$$V_S(t) = (u_1 + u_2 + u_3 + u_4 + u_5) \cdot \frac{E}{5}$$

2.7.7 Conclusion

At this point we talk about the development of growth from a multicellular converter on the sequence are a template with instantaneous values that adopts the analysis of equations that govern the evolution of the state quantities according to the state of the keys. The medium-value model depends on replacing the instant model quantities with their average values only valid if the system's temporal constant is much larger than the chipping period. It allowed us to study transformer modeling using two, three, and five cells.
In the next pages, we will rely on instantaneous growth only to control the two-cell helicopter and then three cells and finally five cells using a natural strategy called pulse-width modulation control(P W M). This is to optimize the speed of the electric motor in the electric vehicle.

Chapter 3

3 Control and simulation of Multicellular Converters

3.1 DC Motor drive modeling

A model of the DC motor made up of the set of equations presented here can be thought of as a nonlinear dynamic system. With regard to a real motor, the main limitations of this model are :
1-the rough assumption that the magnetic circuit is linear (because the metal components are not entirely smooth and there is some flux dispersion inside the motor, in addition, equation does not hold for high values of i owing to saturation of the metal) .

$$\phi = K_0 N_i,$$

2-the rough assumption that only viscous friction is present in the motor and that all mechanical friction is linear with respect to the motor speed. This is because Coulomb friction is typically experienced in motors.

The electric equations :

DC motor, the magnetic flux is generated by windings located on the stator. In fact, since the magnetic field B originates from the stator coils, not only the rotor coils may rotate with respect to the stator, but also the stator supply may rotate (in an electrical sense) by increasing the number of coils and by a more sophisticated supply, despite the fact that the physical reason why electrical power is transformed into mechanical power is the one described in Section previous.
This handout will offer a straightforward model that may be used for the aforementioned scenarios, provided that the system variables are properly transformed .
We will assume that the motor's stator consists of a single coil with an inductance Le caused by the windings and a resistance Re caused by dispersion in the conductor . Given by is the equation for such an electric circuit :

$$v_e(t) = L_e \frac{\mathrm{d}i_e}{\mathrm{d}t} + R_e i_e$$

Since relation (14) is linear, by transforming in the Laplace domain the signals, it can be written :

$$\frac{i_e(s)}{v_e(s)} = \frac{K_e}{1 + \tau_e s}$$

where $K_e := \frac{1}{R_e}$ is the stator gain and $\tau_e := \frac{L_e}{R_e}$ is the stator time constant.

Although the rotor is assumed to be a single coil with the properties of inductance L_a and resistance R_a , equation , also has to account for the motor's back EMF. Given by is the equation for such an electric circuit.

$$v_a(t) = L_a \frac{\mathrm{d}i_a}{\mathrm{d}t} + R_a i_a + e$$

Again, since relation is linear, by transforming in the Laplace domain the signals, it can be written :

$$\frac{i_a(s)}{v_a(s) - e(s)} = \frac{K_a}{1 + \tau_a s}$$

where $K_a := \frac{1}{R_a}$ is the rotor gain and $\tau_a := \frac{L_a}{R_a}$ is the rotor time constant.

Taking into account the results of the previous section, we look at equations , and we find that the following two equations are derived from the back EMF e and the torque exerted by the motor T_M :

$$\begin{aligned} T_M &= K_\Phi \Phi i_a, \\ e &= K_\Phi \Phi \omega. \end{aligned}$$

Regarding the flux that is present in the motor, the coils on the stator are what produce the flux Φ. Since the flux is proportional to the current ie,

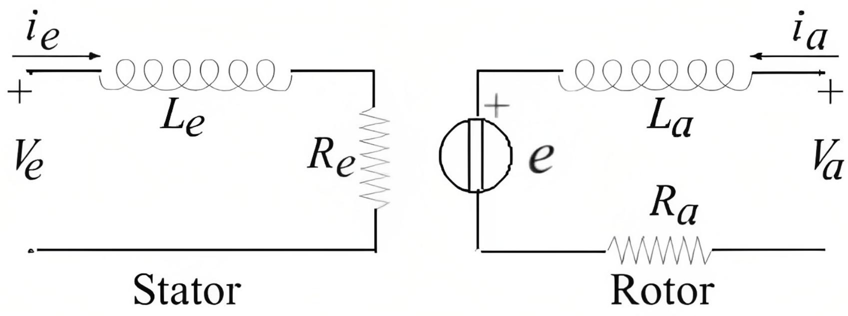

Figure 15: Electrical equivalent scheme of a DC motor

as noted in the preceding Section, it may be expressed as equation :

$$T_M = K i_e i_a,$$
$$e = K i_e \omega,$$

where $K := K_\Phi K_0 N$

The mechanical equations :

Let's now discuss the motor's mechanical representation. The motor produces a torque while being powered by voltages applied to the stator and rotor, as demonstrated in Section 1.2. The mechanical structure, which is affected by this torque, is defined by the rotor's inertia J and the viscous friction coefficient F. Considering that a load torque is applied to the motor in any working circumstance, the following equation may be stated if T_L is the load torque:

$$T_M - T_L = J\frac{\mathrm{d}\omega}{\mathrm{d}t} + F\omega$$

A linear transfer function may be connected to equation , much like in the electrical case and for the mechanical equations :

$$\frac{\omega(s)}{T_M(s) - T_L(s)} = \frac{K_m}{1 + \tau_m s}$$

where $K_m := \frac{1}{F}$ is the mechanical gain and $\tau_m := \frac{J}{F}$ is the mechanical time constant.

3.2 pulse width modulation (PWM) control method :

3.2.1 Introduction

By better matching the control to the structure of the converter and tending toward better power transfer, the control of static converters, which straddles the domains of automatic control and power electronics, strives to improve the performance of converters. the load with energy. The major goals of the control are to as closely as possible match the converter's output amounts to reference quantities while simultaneously controlling them to make them immune to disturbances from the load and the power supply.A control law's effectiveness is assessed in terms of its stability, speed, and precision. The investigation of the converter's dynamic and static behavior, and the subsequent creation of a model of it, are the first steps in the search for an acceptable control law. We will discuss various typical model-based commands in this chapter that may be used to impose the dynamics of the floating voltages and the load current of a serial multicell converter linked to a load R, L.

3.2.2 Concept of pulse width modulation system:

PWM is a method for controlling the average voltage or current given to a load by altering the width of a series of pulses. It is frequently employed in electronics and electrical systems to control the production of electricity, dim lights, control the speed of motors, and carry out a variety of other functions.

3.2.3 principle of operation:

This control is very easy to use and efficient. It also works in open loop and maintains the stability of the voltages at the floating capacitors' terminals. This control method uses fixed frequency pulse width modulation (PWM) [1]. The modulating signal, which might be sinusoidal or continuous (duty cycle) in the case of an inverter or chopper, intersects with a triangle carrier to produce the directives for each cell.These orders need to be offset from one another by an angular distance of $\delta = 2\pi/p$, where p is the number of cells. Each carrier has a range of values from 0 to 1, and the function that can produce these carriers is described by the equation :

$$t_{rk} = \frac{1}{2}\left[\frac{2}{\pi}\,\text{Arcsin}\left[1 + \sin\left(\frac{2\pi}{p}t \cdot f_{dec} + \delta_k - \frac{\pi}{2}\right)\right]\right]$$

The voltages at the floating capacitors' terminals must be balanced at their reference value for the multi-cell converter to operate properly $k.E/p$ and $k\epsilon$ $[1, 2, \ldots 1-p]$. When the duty cycles are the same and the phase shift between the control signals is equal to $2\pi/p$, the floating voltages automatically balance. Let's say that at least one of the floating voltages differs from what is desired.A change in the output voltage's intermediate levels will be the immediate result. In fact, the floating voltages ($(V_{C1}, V_{C2}, \ldots, V_{p-1})$) and the DC bus voltage (E) are combined linearly to create the arm voltage (denoted V_L). The output voltage's line spectrum is likewise compromised in such a situation. A harmonic line among others can be seen at frequency f_{dec}, while the first harmonic family is typically found around $p.\ f_{dec}$.The output current of the converter contains this harmonic component. It will restore balance to each floating voltage at $k.E/p$ by flowing through the floating capacitors. This enables the demonstration of the relationship between balancing and the alternate load current component [3]. There needs to be a causal connection between the output voltage and the flow current for the rebalancing phenomena to take place. In a vacuum, this balancing is not possible. The value of the time constant R, L of the load directing the development of the load current i_L is a necessary condition for the equilibration dynamic in the case of an R, L load. Additionally, a large (respectively low) value of the load inductance L, for a given resistance, results in a sluggish (respectively quick) equilibrium dynamic .

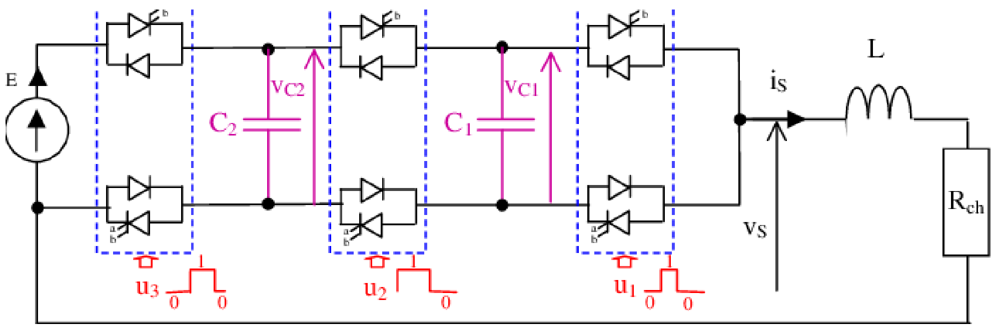

Figure 16: Three cell chopper connected to an R, L load

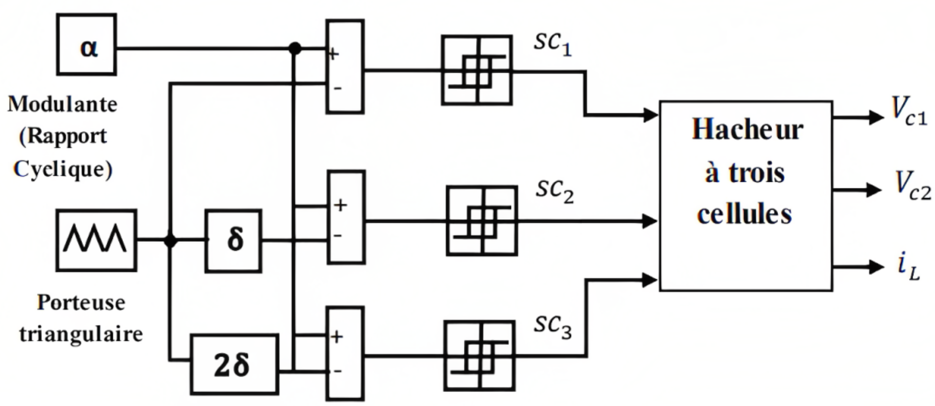

Figure 17: Principle of PWM control applied for a three-cell chopper

3.2.4 Implementation And Results PWM :

The following Images 18 and 19 show the output stream Is and VC tension by time, respectively, We see that there is an increase in the levels of current and tension in both curves, and from here we say that there is a failure in one of the condensates or there are errors at this point and it expresses that there are disturbances and instability and from this analysis we explain the more the pulse width adjustment changes PWM as the current and tension of the engine changes.

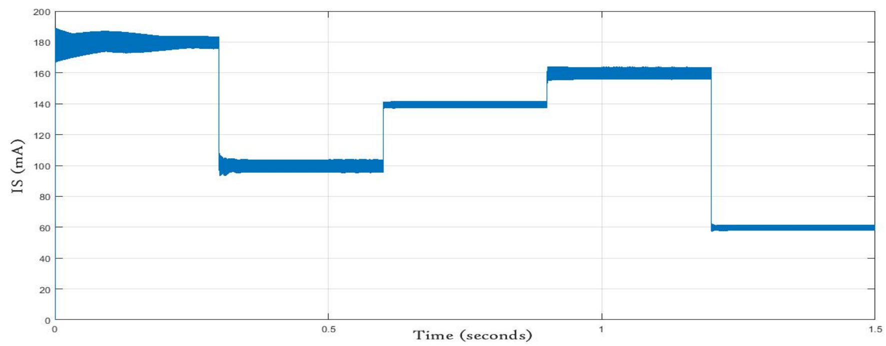

Figure 18: simulation results: IS of PWM

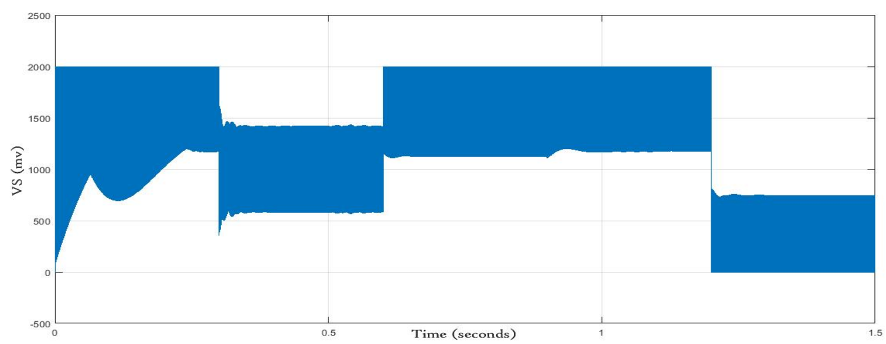

Figure 19: simulation results: VS of PWM

The following A 20 graph of the results of a multicellular converter representing the curves show the difference between the tension value of each cell where it includes 3 different curves when tension crosses 2000 = E on Vc1 = 1500 and 500 = Vc2 it divides the values of the number of each cell and we observe a deviation at the beginning of the transition period [from 0 to 0.3] and then the stability of the system [from 0.3 to 1.5] The graph aims to apply the pulse width modulation method to this multicellular adapter as this method is not the best option for this control.

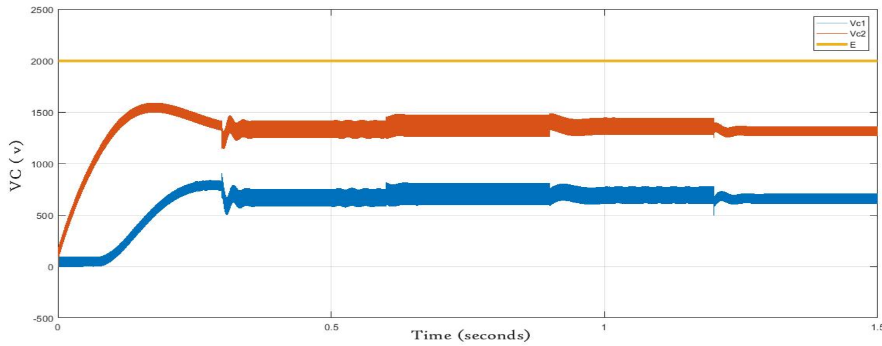

Figure 20: simulation results: VC of PWM

3.2.5 Conclusion

Controls based on the typical model of a multicellular transformer are created in this section. The pulse width modulation (PWM) command is the first one utilized. Although we have observed them introduce sluggish dynamics and significant overshoots in transient and permanent settings, this control ensures a natural balance of the voltages of the floating capacitors in an open loop by following some constraints.
Direct control of a multicellular transformer will be covered in the following part, and it will be compared to the controls discussed in this section.

3.3 Control of non-linear systems

3.4 Sliding Mode control method :

The concept of changing the controller structure with the state of the system in order to obtain a desired response underlies Sliding Mode Control (SMC), a non-linear type control that has been developed for the control of variable structure systems (such as the converter). As a result, the control by sliding mode is of the all-or-nothing type [33].
The position of the control member in this kind of regulation is determined by the system state. The concept is to use a decision boundary known as a sliding surface to split the state space. Upon reaching the sliding surface, the objective is to reach the reference state.

First, it's important to make sure that the sliding surface is attractive in order to accomplish this goal. In other words, regardless of the system's position in the state space, its state must travel in the direction of the sliding surface.

In order to approach the reference, it is also necessary to secure the system's stability and glide around the surface once it has been reached. To do this, you must identify the circumstance in which the system's dynamics slides on the surface in the direction of the desired reference state . [12].

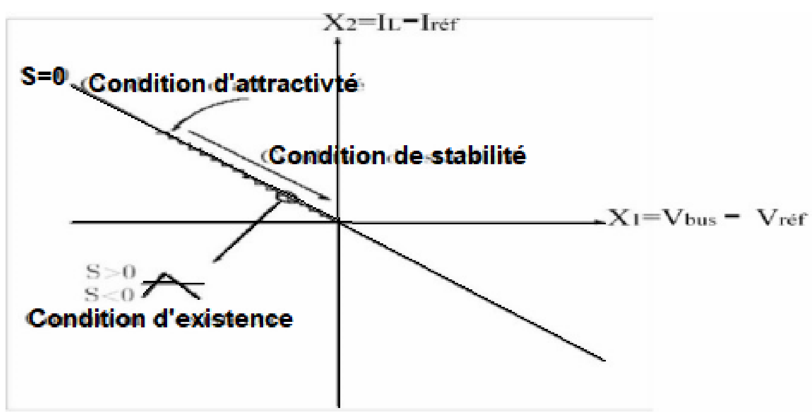

Figure 21: sliding mode surface. [28]

Sliding Mode Control (SMC) is a variable structure control that can switch between two values and change its structure in accordance with the extremely precise switching logic $S(x)$. Sliding mode control works by forcing the system to go to a specific surface known as the sliding surface and to stay there until equilibrium. Two processes are involved in this control: sliding along the surface and convergence toward it . [11].

3.4.1 Control Design by Sliding Mode :

Sliding Mode Control has numerous and significant benefits, including high precision, excellent stability, simplicity, invariance, and resilience. This makes it particularly appropriate for systems with a loose model.

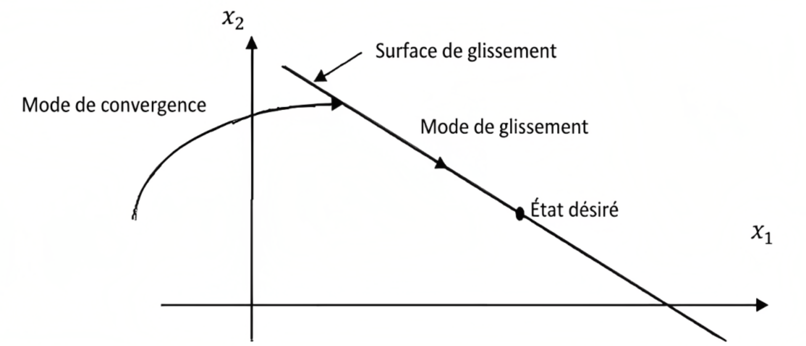

Figure 22: Different Convergence Modes for State Trajectory. [29]

It is frequently desirable to specify the system dynamics while it is in convergence phase. The structure of a controller in this instance consists of two pieces. A first continuous representation of the system dynamics during the sliding mode and second discontinuous representation of the system dynamics during the convergent mode. This second step is critical in nonlinear control since it has the responsibility of removing the impacts of error and disturbance on the model [12].
Three major steps that are very dependent on one another make up this control's design :
1-choice of surface
2-setting up the prerequisites for convergence's existence.
3-Choosing the control law .

Theorem 1 :

Let V(x) be a LYAPUNOV function that is a differentiable function of $\mathrm{R^n}$ in $\mathrm{R^n}$ and satisfies the requirements listed below [52]:

$$\begin{cases} V(0) = 0 \\ V(x) > 0 \quad ; x \neq 0 \\ V(x) \leq 0 \quad ; x \neq 0 \end{cases}$$

x = 0 is a stable equilibrium position when all three of these requirements are satisfied. The position x = 0 is asymptotically stable if the final condition is changed to $\dot{\mathrm{V}}(\mathrm{x}) < 0$ for $x \neq 0$.

The sliding surface $\mathrm{S(x, t)} = 0$ is used as a pseudo-output to determine this function of LYAPUNOV in the case of control via sliding mode.

3.4.2 Objective of the control by sliding mode :

The sliding mode control's goal can be summed up in two key points :
1-Create a $S(x,t)$ surface so that all system trajectories adhere to the tracking, regulation, and stability expected behavior.
2-A $U(x,t)$ control (switching) law must be found that can draw all state trajectories to the sliding surface and maintain them there [8].

3.4.3 Sliding Surface Selection :

The desired dynamic behavior of the system is represented by the $S(x)$ surface. In order to identify the sliding surface that guarantees a variable's convergence to its intended value, SLOTINE recommends a general equation :

$$S(x) = \left(\frac{\partial}{\partial t} + \lambda_X\right)^{r-1} \cdot e(x)$$

Or :
e (x) : Deviation of the variable to be adjusted , $e(x) = x - x_{ref}$.
λ_x : Positive constant that interprets the desired control bandwidth.
r : Relative degree is the same as how many times the output must be derived in order for the command to appear.
$S(x) = 0$: is a linear differential equation whose only solution is $e(x) = 0$.

3.4.4 Condition of existence of the sliding :

The translation of the sliding regime's existence requirement $S(x,t) = 0$ is as follows :

$$\lim_{S \to 0} S.\dot{S} < 0$$

By using the LYAPUNOV stability criterion in the vicinity of the sliding surface and using $V(x) = \frac{1}{2} S^2$ as the potential LYAPUNOV function, these conditions can be inferred from the theorem (1).The LYAPUNOV V function's derivative in this instance equals S.$\dot{S}$.

If S and $\dot{S}$ are opposite signs, the LYAPUNOV conditions outlined in Theorem 1 are examined. It should be highlighted that these latter characteristics turn into adequate conditions to guarantee the attractiveness of the surface if they hold true throughout the state space and not just in a section near the sliding surface [29].

3.4.5 Equivalent control method :

Figure (23) depicts the system's actual (practical) state trajectory as a zigzag curve between u^- and u^+ . It encircles the theoretically ideal or reference state trajectory, S = 0, which is on a line. The displacement of the real trajectory can be divided into two parts: a high-frequency component and a low-frequency component. The low frequency component creates a continuous trajectory that moves down the sliding surface, whereas the high frequency component has a discontinuous trajectory that alternates between u^- and u^+. The state trajectory will then be controlled by the slow switching component, ignoring the frequently filtered quick switching component.The average value that the command quantity takes while rapidly switching between u^- and u^+, as schematically depicted in Figure (23), is what is known as the equivalent command.

The equivalent command makes the switching surface invariant over time $\dot{S} = 0$[17]

Take for example the system governed by the following differential equation:

$$x^{(n)} = f(x,t) + b(x,t)u(t)$$

$x(t)$: the state vector .
$u(t)$: the input control vector.
$f(x)$ and $b(x)$: non linear functions of state and time .

$x_d = [x_d, \dot{x}_d......., x_d^{(n-1)}]$ The initial desired state $xd(0)$ must be in the following conditions for the tracking job to be realizable with a finite control :

$$x_d(0) = x(0)$$

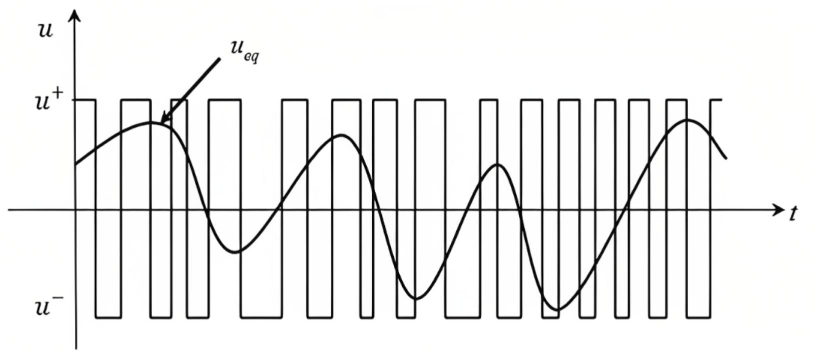

Figure 23: Equivalent command as mean switching value between u- and $u+$. [17]

The trajectory has a direction in running that results in sliding mode along this line (s = 0), as shown by the study of the state plane, as shown below :

$$\dot{x} + cx = 0$$

The sliding mode is defined by the single parameter c and is unaffected by plant dynamics. The equation's order is lower than that of the original system.

The characterization of dynamic movement of the state trajectory to the sliding surface performed by the generalized Lyapunov function, is determined by the surface. One selects the "gains" for each switched control structure such that the Lyapunov function's derivative is negative definite., So it is guaranteed that the movement of the state path to the surface. After the correct design of the surface, a switching controller is developed such that the tangent vectors of the state trajectory point towards the surface such that the state is pushed to and maintained in the sliding surface. Such controllers result in discontinuous closed-loop systems.

Let the tracking error in x be :

$$\tilde{x} = x - x_d$$

the surface of the time varying surface S(t) in the state space where :

$$s(x,t) = \left(\frac{d}{dt} + \lambda\right)^{n-1} \tilde{x}$$

λ strictly positive constant.

if n=2

$$s = \dot{\tilde{x}} + \lambda\tilde{x}$$

Given the initial condition, the issue of tracking x = xd is similar to that of staying on the surface $S(t)$ for all $t > 0$ surely s = 0 expresses a linear differential equation whose unique solution is $\tilde{x} = 0$, given initial conditions. Thus, the issue of monitoring the n-dimensional vector x_d may be simplified to that of maintaining the scalar quantity s at zero. More exactly, the issue of tracking the n-dimensional vector x_d (i.e. the original nth-order tracking problem in x) may in effect be replaced by a 1^{st} order stabilization problem in s. Indeed, the expression of s includes $\tilde{x}$, we only need to distinguish s once for the input u to appear [11].

3.4.6 Implementation And Results sliding mode :

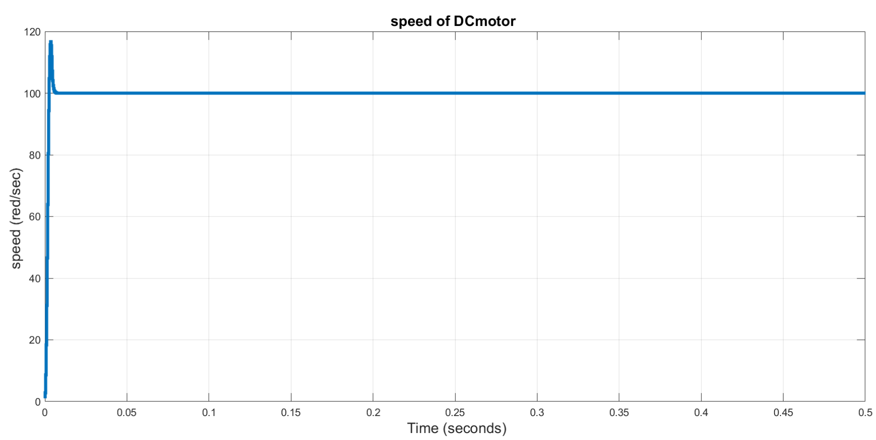

Figure 24: simulation results: Speed of DC motor

The graph shows the speed of the electric motor in the sense of time as we note that there is a slight strong start in the speed of the engine 120 This is estimated to move from a period [0 to 0.02] and then stabilize the system at 100 speed which means that the three-cell transformer has reduced disturbances especially together using the control strategy PWM (pulse width modulation).

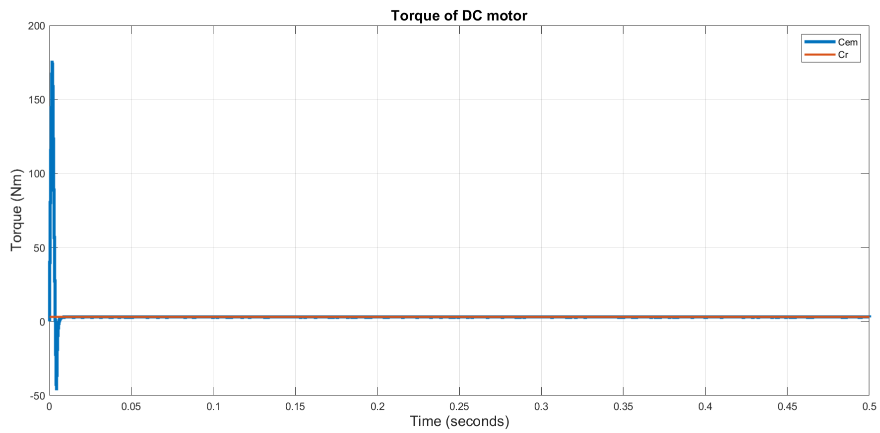

Figure 25: simulation results: TORQUE of DC motor

The graph shows the torque. We notice Cem in the beginning period in the transitional phase that the system is developing and has not stabilized yet [0,0.02], and from [0.02,0.5] we notice Cr in a state of stability from the beginning. In the end, we conclude that Cem applies to Cr, and this means that this sliding mode control behavior method is the best accuracy with precise linear control, and the choice of the model depends on the best accuracy in the result, and it is the best choice for this system.

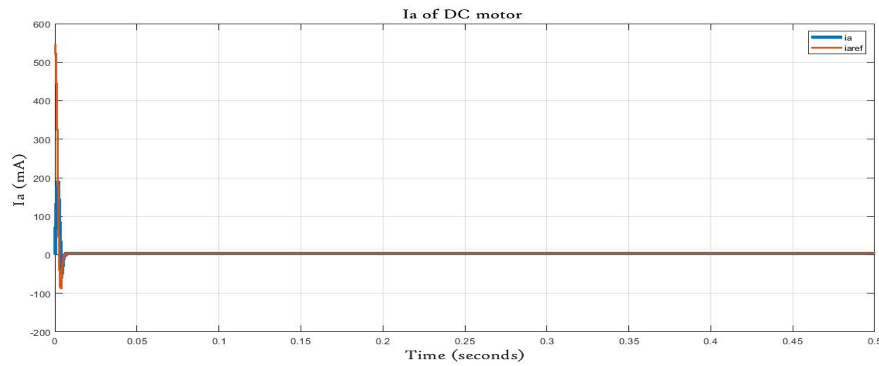

Figure 26: simulation results: Ia of DC motor

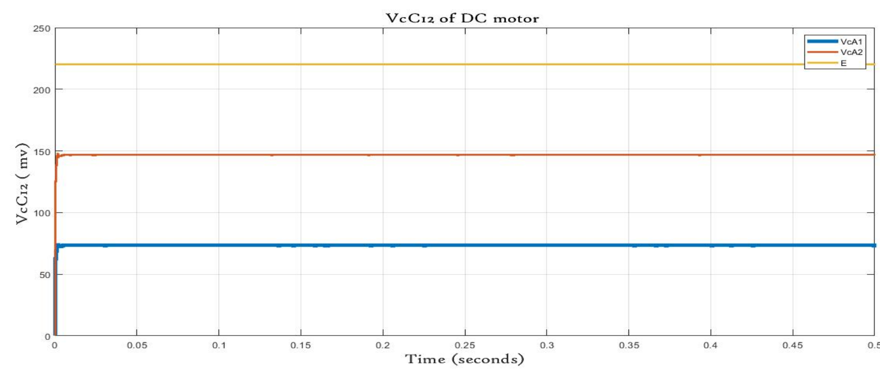

Figure 27: simulation results : VcC12 of DC motor

Figure 26 and Figure 27 show the output current IS and the output tension VcC12 by the meaning of the electric motor respectively; We note that iaref is greater than ia in the transition period [0 to 0.02] and in the period [0.02 to 0.5] we note that iaref applies to ia, i.e. the stability of the system, In the latter, 3 different curves are E, Vc1 and Vc2, and when the E tension crosses the Vc1 and on the Vc2, it is divided by the values of the number of each cell so that the energy is good; And from it, we say that the more cells are transformed, the more they stabilize the system and there are no disturbances or errors..............Through graphic analysis, we explain that one of the best ways to help stabilize and control the system is by sliding mode behavior. Choosing this method or behavior according to the objective or characteristics we want to reach.

General conclusion :

The many multi-cell structures that have been developed due to the development of power electronics, in exchange for calibers and performance, are employed as multi-cell transformers in industry and in many applications connected to power transmission. Since then, a number of architectures with unique characteristics have emerged, including NPC, FC, and H-Bridge.

The work presented in this thesis consists of a study on a chopper with four levels (three cells) which is a series connection of three transformers on two levels.

The first chapter is devoted to electric vehicles and their types, their pros and cons. We touched on energy storage systems such as batteries and super-capacitors and the most important leading companies in this field in the world.

In the second chapter, we presented the DC-AC converters in general by citing these different types of chopper, rectifier dimmers, and inverters.

Then among the converters presented we studied the inverters and their operations by giving type principle and application so we spoke briefly about the chopper at Four levels (three cells).

In the last chapter, the third chapter consists of two control strategies for electric motor speed control, the first is PWM (pulse width modulation) normal strategy and its mathematical model, and the second strategy is slip mode (SMC) and its mathematical model is a three-cell converter. We ended up recording and annotating the simulation results.

We conclude that the sliding mode is a better control strategy not only for height voltage load but for more applications like our work.

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