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A Review of Electric Vehicle Motors and Control Strategies

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Abstract- In the world where environmental protection and energy savings are growing concerns, the automotive industry is experiencing growing demand for automotive electrification. It was from the 2000s that the Electric Vehicle (EV) regained its momentum thanks to technological progress and ecological awareness. EV currently plays an important role in transportation, there are several types on the market such as battery electric vehicle (BEV), hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV) and battery electric vehicle. Fuel cell. Vehicle (FCEV). Recently, all the interest of manufacturers in the automotive field has focused on the all-electric vehicle, thanks to its many advantages and its advantages granted to manufacturers, customers and especially the environment. The latter moves using one or more electric motors powered by a battery. This article will present the motors and control strategies most used by electric vehicle manufacturers and most studied by researchers, citing the principles advantages and disadvantages, and comparing them to be able to conclude what works best and the most sought after in automotive design.

Keywords Electric vehicle (EV), brushless dc motor (BLDC), switched reluctance motor (SRM), finite control set model predictive control (FCS-MPC), model predictive contouring control (MPCC).

1. Introduction

With growing concerns about the cost of energy and our environment, automakers, governments, and even consumers are increasingly interested in electric vehicles (EVs) [1,2]. The size of the electric vehicle market will be huge. Thus, the development of power electronics technology for electric vehicles will accelerate to meet market needs [3]. The drive system, including the motor and its controller, constitutes the heart of electric vehicles. Electric machines are essential components of transmissions [4,5,6], and the control strategies constitute the brain control of electric vehicles . Researchers are therefore working on the development of advanced electric drive systems [7]. Improving the power density and efficiency of traction machines is becoming increasingly popular, leading to creative designs and advancements in drive topologies and the creation of new classes of machines [8,9].To exploit the superior advantages in improving energy ,saving and dynamic performance of electric vehicles, the powertrain will be studied in the rest of the paper [10].

This article will show the types of electric vehicles and their general advantages. Cite the types of motor configurations that currently exist on the market and their advantages, and study the different types of motors used in the design automobile with their control strategies. On the one hand, this study presents the DC motor, permanent magnet brushless motor (PMBL), induction motor (IM), permanent magnet synchronous motor (PMSM) [11], reluctance motor commutated motor (SRM) [12], and the synchronous reluctance motor (SynRM) [13]. On the other hand, the advantages of control strategies will be exposed, such as field oriented control (FOC) [14], model-predictive finite control set (FCS-MPC), direct torque control (DTC) [15], and Fault Tolerant Control (FTC) [16].

The purpose of this paper is to compare motors and control strategies applied to electric vehicles. In which their advantages and disadvantages relative to each other are described, and compared to conclude which one is more efficient, and usable in the field of electric vehicles. The remaining paper is organized as follows: Section 2 is a short comprehensive paragraph, in which the electric vehicle will be discussed in a general way, presenting the main constituents of an EV and their types. Section 3 will cover the types of electrical machines, their advantages and disadvantages, with a comparison between them. Additionally, Section 4 covers the control strategies applied to electric vehicles with their advantages and disadvantages with a comparison between them. Finally, the last section offers a conclusion, discussing the point of view regarding the comparison carried out during this work.

2. The Electric Vehicle Concept

Although it constitutes a promising technology, the thermal engine was preferred to electric traction for economic reasons. However, with the growing awareness of environmental problems, and more particularly in the perspective of an energy transition, the electric vehicle is returning to the public debate, including Battery Electric Vehicle (BEV), Hybrid Electric Vehicle (HEV), Plug-in Hybrid Electric Vehicle (PHEV), Fuel Cell Electric Vehicle (FCEV), Solar Electric Vehicles (SEV), and Extended Range Electric Vehicles (EREV). all these types are going to be discussed in this chapter [14].

2.1. Electric Vehicles Types

2.1.1. Battery electric vehicle

The BEV is a vehicle that operates using the combination of a battery and an electric motor. It draws all its energy from its batteries. Their large capacity battery must be connected to a fixed socket or to a specific socket when they are no longer circulating in order to be recharged. Although these are undoubtedly the least polluting vehicles on the market, their autonomy is still limited. Even if for several years, their autonomy has made it possible to go beyond simple urban use, this technology still needs to evolve to allow drivers to make long journeys without having to recharge along the way [11]. Figure 1 shows the Battery Electric Vehicle.

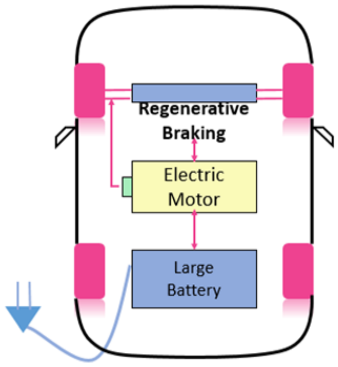

Fig. 1. Battery electric vehicle (BEV).

2.1.2. Hybrid electric vehicle

The Hybrid Electric Vehicle (HEV) as shown in Fig.2 differs from BEV in that it has a conventional Internal Combustion Engine (ICE) for use outside urban areas and a low-speed electric motor (EM) dedicated to urban traffic. The same ICE that powers the alternator powers the batteries when the Internal Combustion (IC) mode is engaged, shutting down the EM. Using both electric and thermal energy sources as efficiently as possible is the primary goal of a hybrid vehicle in order to minimize CO2 emissions and lower energy usage [16].

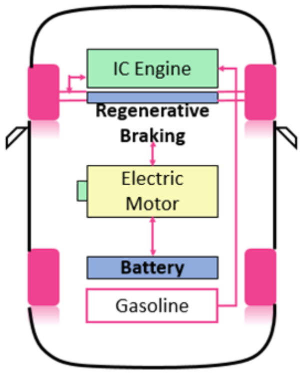

Fig. 2. Hybrid electric vehicle (HEV).

2.1.3. Plug-in hybrid electric vehicle

The PHEV is an update of HEV-level battery charging system that is powered externally. The latter works thanks to the action of batteries which are recharged while the vehicle is driving. Thus, at low speeds, the driver does not use fossil fuel to move. However, once the speed of 50 km/hour is exceeded, it is its thermal engine which takes over the controls to ensure the vehicle's locomotion. The combustion engine operates when the batteries are exhausted and the driver is unable to do so [17]. Figure 3 shows the Plug-in Hybrid Electric Vehicle.

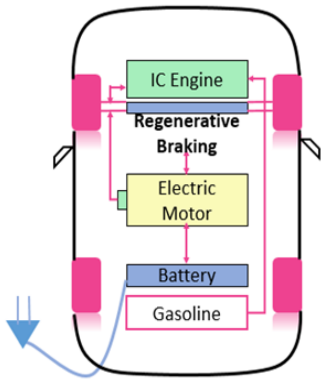

Fig. 3. Plug-in hybrid electric vehicle (PHEV).

2.1.4. Fuel cell electric vehicle

The long-distance FCEV has been introduced. With FCEVs as shown in Fig. 4, a hydrogen tank and a number of fuel cells where the hydrogen undergoes a chemical reaction to produce energy and water vapor replace the traction battery. The surface area of the polymer electrolyte membrane and the quantity and size of the individual fuel cells that make up the fuel cell determine how much power the fuel cell can produce. Due to its ability to provide dependable, efficient, and clean green transportation, FC has grown in importance as a technology in the development of electric vehicles [18].

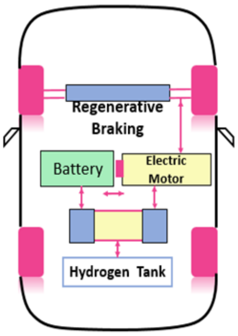

Fig. 4. Fuel cell electric vehicle (FCEV).

2.1.5. Solar electric vehicle

The SEV as shown in Fig.5, is a type of unusual solar vehicle that is primarily or exclusively powered by direct solar energy. Its unique feature is the installation of panels, usually photovoltaic cells (PV), on top of the vehicle. These panels enable each solar radiation that the automobile receives to be converted into electrical energy, which is subsequently stored in a battery, thanks to the photovoltaic effect. These cells are mounted throughout the vehicle [19].

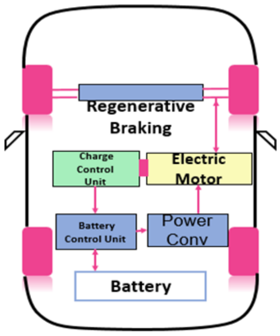

Fig. 5. Solar electric vehicle (SEV).

2.1.6. Extended range electric vehicle

The EREV as shown in Fig.6, is propelled by an electric motor that is powered by huge capacity batteries. These are kept charged by a thermal engine, which is a miniature alternator block. However, because of its steady pace around the maximum rotation speed, which is equivalent to about 1500 revolutions per minute, it can drive 100 kilometers on less than 2 liters of gasoline and has a respectable amount of autonomy [20].

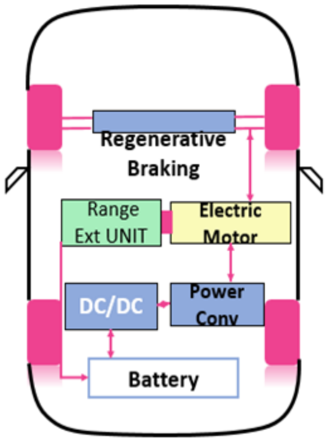

Fig. 6. Extended range electric vehicle (EREV).

2.2. Comparison of Different Electric Vehicle

From a technical point of view, each type of electric vehicle has advantages and disadvantages compared to the others, in table 1 a comparison is made between all the types of electric vehicles discussed previously.

Table 1. Comparing major available EVs: Advantages & disadvantages

Technology	Advantages	Disadvantages	Reference
Battery Electric Vehicle (BEV)	Usage of quieter operation, no emissions, the ability to collect energy from regenerative braking, lower operating costs, cleaner electrical energy.	Limited range, ongoing advancements in battery technology, and the need for better public charging infrastructure.	[4,21]
Hybrid electric vehicles (HEV)	Decreased pollutants and fuel use, as well as the potential to recover energy through regenerative braking.	Increased price, more readily available parts, and more sophisticated construction with two powertrains.	[12,22]
Plug-in Hybrid Electric Vehicle (PHEV)	Substantial possibilities for network connections, lower fuel and emissions, and optimized performance, potential for regenerative braking to yield energy recovery.	They are more costly than standard hybrids, in high demand, require charging stations, and necessitate frequent gas station stops for their owners.	[23]
Fuel Cell Electric Vehicles (FCEV)	Only release water vapor, run silently, and provide performance and autonomy comparable to modern vehicles, Silent, odorless, and most importantly.	The energy required to produce hydrogen is high, and there is a shortage of stations and supplies. Enhancing one's carbon footprint is necessary.	[4,18]
Solar Electric Vehicle (SEV)	Able to use all of their power at any speed, need no operating costs, very little maintenance, and produce no hazardous emissions	Can only run on solar power; they lack the power and speed of regular automobiles, and good solar-powered vehicles are pricey.	[19,24]

An attempt was made to analyze the five electric vehicles existing in the automobile sector. We distinguish that each type has their strong and weak points. Hence we find the strong point of the electric vehicle is zero emissions. But on the other hand there are the disadvantage of autonomy which is still in development, the HEV/PHEV has the advantage of reduced fuel consumption and emissions but we find opposite the cost which is very high. The FCEV offers the advantage of autonomy and performance similar to current vehicles, and the most disturbing drawback is the production of hydrogen consumes a lot of energy and ultimately the strong point of the SEV and the possibility of using all their power at any speed but it does not can only work in the sun.

2.3. All Electric Vehicle Concept

2.3.1. Main components of an all-electric vehicle

On the driver's side, driving an electric vehicle is no more, if not less, complicated than driving a thermal vehicle. All you have to do is press the accelerator pedal to cause it to move forward. From there, a sensor records the driver's request at the accelerator pedal position by an electrical signal sent to a module, called a converter, which supplies the electric wheel traction motor(s) according to the driver's needs. Using other components scattered throughout the vehicle, complementary to the inverter converter. The fundamental parts of an electric vehicle as shown in Fig.7. Our high-voltage batteries serve as storage devices. The charger module is the component that powers the electric vehicle and serves as the interface between the HV batteries and the electrical distribution network. It is also known as the "brain" of the system, allowing the batteries to be charged. The electric motor, which is positioned at the end of the driveline and powers the wheels. It is managed by the vehicle thanks to data it gets from its numerous sensors [25]. Its role is to convert the electrical energy from the batteries into mechanical energy, the 12 volt battery, it supplies the on-board circuit and the electrical consumers, the 400-12 v converter, it recharges the 12 v battery.

2.3.2. Types of motor configurations in all-electric vehicle

The different drive options of electric motors play an important role in power delivery and efficiency. This is why lately we find in automobile construction, electric vehicles which can come in different configurations such as single, double, triple and four motors [3,26]. In some EVs the wheels are directly connected to the motor, which eliminates the transmission. Of which the advantages of the configuration with a single motor are the simplicity in terms of control and the disadvantages translate into the low efficiency and power compared to the other configurations which are more advantageous in acceleration, eligibility and speed. And there as a disadvantage they are more expensive [26]. Which allows us to conclude that the multiplied configuration increases maneuverability and vehicle efficiency. Figure 8 describes the four types of an EV.

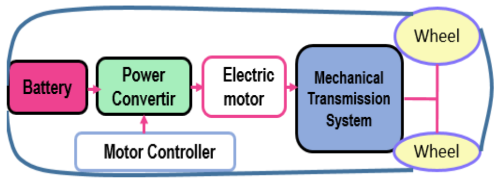

Fig. 7. The main component of an all-electric vehicle.

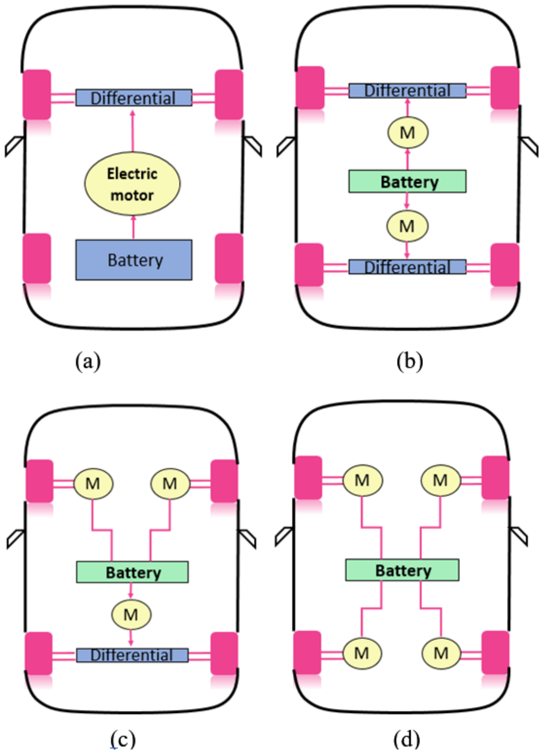

Fig. 8. Types of motor configurations of all-EV: (a) Single motor, (b) Dual motors, (c) Triple motors, (d) Four motors.

3. Electric Motor

There are many ranges of electric motors, and depending on their characteristics. Meet the specific needs of different sectors, such as the automotive sector and specifically EV. Figure 9 shows the detailed diagram of the different types of motors, there are 2 categories, brushed and brushless motors [27], we will detail each type subsequently.

The development of electric vehicles is greatly aided and influenced by electric machines [28]. Because the motor is directly connected to an energy source, the current intensity immediately affects how quickly it rotates. These wheel drives can be based on a variety of motors, including Permanent Magnet Brushless Motor (PMBL), Permanent Magnet Synchronous Motor (PMSM), and DC Motor [24]. In Table 2 we will list the most used electric motors for different brands of electric vehicles.

3.1. Electric Motor Types

There are different types of electric motors used in the production of electric vehicles (EVs). In this chapter, DC motor, permanent magnet brushless motor (PMBM), permanent magnet synchronous motor (PMSM), induction motor (IM), switched reluctance motor (SRM) and motor synchronous reluctance (SynRM) will be presented in the following section with their characteristics, advantages and disadvantages [22].

3.1.1. Direct current motor

The DC motors shows are known for the simplicity of their control, the torque-speed characteristics which can be adapted to the need for traction as well as the simplicity of their speed regulation. Which can be applied in electric vehicles of less than 10 KW [1]. This type of motor has a commutator, which remains in frictional contact with the fixed brushes during the transfer of power to the rotor [29]. Which then requires regular maintenance and a short lifespan. Depending on the field of application, there are different types of electric motors, of which DC motor has several types, which are going to be discussed. This motor is made up of the stator, rotor, collector, and brushes. When a coil-shaped conductor carrying a current is placed in a magnetic field, Laplace forces act on it, producing a torque that causes the coil to rotate on its axis. The motor is an electromechanical converter that enables the bidirectional conversion of energy between an electrical installation traversed by a direct current and a mechanical device according to the source of energy [30]. When the coil has made a half-turn, the polarity must be reversed to reverse the direction of the forces and continue the movement. This is the role of the collector which consists of a metal core with a copper winding, and the stator comprises permanent magnets which generate a magnetic field whose flux passes through the rotor. The advantages of a DC motor are not limited to the preservation of the ecosystem that said the use of its gear also has its drawbacks. The table 3 describes the advantages and drawbacks of dc motor with its types and their control strategies [31].

Table 2. Current electric vehicle motors

DRIVES TYPES	YEAR	DC	SRM	IM	PMSM	PMBLDC	PMBLAC
Audi e-tron GT	2021				×		
Tesla Model Y	2020		×				
Fiat 500e	2020				×		
Tesla Model S	2020			×			
Jaguar I-Pace	2019				×		
Volkswagen iD.3	2019					×	
Audi e-tron S5 quatro	2019				×		
BMW Mini E	2019			×			
Tesla Roadster sport	2018			×			
Renault twizy cargo	2018			×			
Chevrolet Bolt EE	2018						×
Nissan Leaf	2017				×		
Mitsubishi i-MiEVES	2017				×		
Audi A3 e-tron	2014			×			
Reva G_wiz DC	2013	×					
Nidec prototype	2013		×				
BMW i3	2013				×		
Fiat 500e	2013				×		
LandRover	2013		×				
Tesla Model S	2012			×			
Toyota Prius	1997				×		
Three-wheel electric tuk-tuks	-					×	
Some Chinese electric cars	-					×	

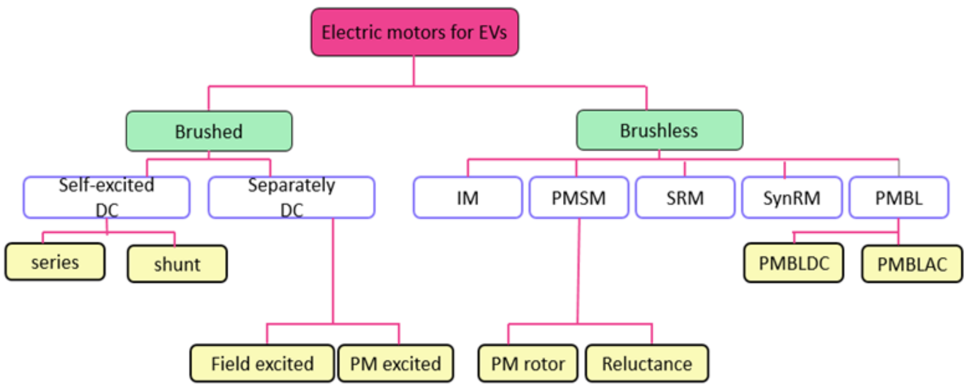

Fig. 9. Different types of electric motors for EV.

Table 3. Advantages and disadvantages, types and control strategies of DC motor

Advantages	- It is robust, it cannot be blocked by an electronic problem[10] - Greater rotor inertia, centrifugal force on the winding. - DC motors provide highly controllable speed. - It is simple and less expensive [16].
Drawbacks	- Loss of efficiency due to power factor, increase in copper losses [16]. - Loss of power at high revs because it is not possible to modify the phase of the control [32] - Due to the presence of brushes there is mechanical noise, mechanical wear, high current coaling, demand for additional space on the shaft, additional moving parts.
Types	- The series motor is characterized by the fact that the stator is connected in series with the rotor. - In the shunt motor, the stator is wired in parallel with the rotor. - In the compound motor part of the stator is connected in series with the rotor and another part is of parallel type.
Control	- PWM - DTC - Integral Controller - PID Controller - Derivative Controller

3.1.2. Permanent magnet brushless DC motor (PMBLDC)

The PMBLDC motors offer the advantage of having a higher torque output for a similar amount of current and voltage when compared to other motors. Due to their higher power and productivity, brushless magnetic DC motors can be used for EV pulse modification to an acceptable amount [33]. One disadvantage of a PMBLDC motor is the expensive cost of its rotor. It is difficult to produce a noticeable torque in the motor due to the magnet's mechanical resistance. Moreover, the reason for the field weakening capability is the presence of a persistent magnetic field. Moving the switching angle forward is the sole technique to extend the working of the constant power area [34]. Table 4 describes the advantages and drawbacks of PMBLDC motor with its types and their control strategies.

Table 4. Advantages and disadvantages, types and control strategies of PMBLDC motor

Advantages	- No brushes mean no speed loss, which expresses the efficiency of the BLDC motor, typically 85-90% [33]. - BLDC motor runs extremely quietly and smoothly due to the absence of brushes [34]. - BLDC motor requires less maintenance.
Drawbacks	- The BLDC motor must be connected to an electronic speed controller to allow current to flow to the electromagnets. - Due to the need for a controller, it may be more expensive. - The BLDC may remain blocked due to an electronic fault. -With angular sensors, risk of breakdown and mechanical constraints to install them.
Types	- Outrunner : The brushless motors whose rotor is around the stator. - Inrunner : The brushless motors have the rotor inside the stator.
Control	- FOC - DTC - MPC. - Intelligent Controller. - Sensorless Controller.

3.1.3. Permanent magnet brushless AC motor (PMBlAC)

A permanent magnet synchronous motor is another term for this type of motor. Its three phase armature windings on the stator and permanent magnet rotor are similar to those of a PMBLDC motor. The armature winding currents of the PMBLAC motor exhibit a sinusoidal waveform, while the current waveform of the PMBLDC motor is rectangular. This is how the two kinds of motors differ from one another. Furthermore, the back EMF of the PMBLAC motor is sinusoidal, whereas the back EMF of the PMBLDC motor is trapezoidal [35]. Similar to PMBLDC motors, PMBLAC motors have many of the same benefits, including high torque and power density, high efficiency, compact design, low weight, and high torque at low speeds. On the other hand, with the same current and voltage, a PMBLAC motor can produce more torque than any other motor [27]. Table 5 describes the advantages and drawbacks of PMBLAC motor with its types and their control strategies.

Table 5. Advantages and disadvantages, types and control strategies of PMBLAC motor

Advantages	- Very high efficiency [16]. -High torque at low speed. - High power density -Weight is low.
Drawbacks	-Very expensive - The control system is expensive - It must be controlled by its own device
Types	- Outrunner : The brushless motors whose rotor is around the stator. - Inrunner : The brushless motors have the rotor inside the stator.
Control	- FOC - DTC - MPC

3.1.4. Permanent magnet synchronous motor (PMSM)

The PMSM is a type of motorization that competes in the automotive industry [25]. It offers high performance at the level of efficiency that goes up to 96.8% at the level of efficiency of the system [36], PMSM reached a level of maximum energy savings thanks to the use of variable speed as well as the optimization of mechanical systems, it has a very high power density [37]. PMSM is composed of a stator, which is composed of several phases/coils and a rotor which is a simple two-pole permanent magnet which can be set in motion if a magnetic force is applied to it. PMSM works with pulses which are obtained by the coils placed on either side of the stator. When the current passes through it, the latter are transformed into a magnet whose direction of the poles depends on the direction of the current, each phase can therefore have more or less downwards, depending on whether you want to push or attract the rotor [38] . Depending on the field of application, there are different types of electric motors, of which PMSM motor has several types, and the advantages of a PMSM motor are not limited to the preservation of the ecosystem that said the use of its gear also has its drawbacks. Let's weigh in table 6, its types, advantages and drawbacks.

Table 6. Advantages and disadvantages, types and control strategies of PMSM motor

Advantages	- High torque [39]. - High power density[40]. - Low inertia [38]. - Better dynamic performance [41,42].
Drawbacks	- The cost is very high [25]. - Low resistance of magnets to temperature. - The electronic part is complicated. - High speed iron loss workout [43].
Types	- -IPMSM : Interior permanent magnet motor. - SPMSM : Surface permanent magnet motor.
Control	- Low-cost ferrite material. - FOC - DTC-SVM - MPC-PTC - SMC - Sensor - Intelligent Controller

3.1.5. Induction motor (IM)

The IM is one of the most commonly used motors in the design of electric vehicles thanks to its great advantage which is simplicity as well as it is silent, durable and reliable. This type of motor is often used in EVs intended for long and high-speed trips [44]. IM relies on the stator to generate a rotating magnetic field on its winding which makes it possible to obtain the electric current necessary in the rotor to produce the torque [45]. It consists of two main parts: the stator and the rotor. The rotor forms what is called a "squirrel cage": It is in fact a set of metal loops, capable of conducting the magnetic field and the electric current [46,35]. When the magnetic field produced by the stator starts rotating, an electric current is induced in the loops of the rotor. This current will inevitably develop its own magnetic field: The rotor magnetic field. This rotor field, induced by the stator, will transform the rotor into an electromagnet [47,48]. According to the Lenz-Faraday law, the magnetic field of the rotor is a phenomenon, which tends to moderate the effects, which give rise, namely the currents in the rotor. The rotor field will therefore also rotate and in such a way as to reduce these currents induced by the stator field. As a result, the rotor begins to accelerate and follow the rotating magnetic field of the stator [49,50]. Depending on the area of application, there are different types of electric motors, of which the IM motor has several types, which will be mentioned in the table. 7 with the advantages of a IM motor and its drawbacks [25,51,52].

Table 7. Advantages and disadvantages, types and control strategies of IM motor

Advantages	- High efficiency [46] - Simplicity and robustness [52]. - Little loss [53]. - Low maintenance [32] - Cheaper.
Drawbacks	- The torque is low [54]. - Difficulty controlling speed [55]. - Very high inrush currents.
Types	- Wound rotor : With slip Rings. - Squirrel cage : Without slip Rings .
Control	- Sensorless control. - FOC - DTC - MPC-PTC

3.1.6. Switched reluctance motor (SRM)

The SRM is a motor that operates through the manipulation of electromagnetic forces, the power is supplied to the stator windings, and the torque is created by the reluctance [51]. SRM is known for its high power, simplicity, as it can eventually create equal torque in both directions so the sequence can often be reversed [56]. The switched reluctance motor can produce torque through the magnetic field that occurs between the stator electromagnets and the corresponding set of salient poles formed on a simple rotor made only of ferromagnetic material [57]. Depending on the field of application, there are different types of electric motors, of which the switched reluctance motor has several types which will be mentioned in the table 8 with its advantages and drawbacks [58].

Table 8. Advantages and disadvantages, types and control strategies of SRM motor

Advantages	- Simplicity and rigidity at the construction level [32]. - Simplicity of control. - Fault tolerance. - Very good efficiency [22].
Drawbacks	- High noise [3]. - High torque ripple [59]. - Vibration.
Types	- Rotary switched reluctance motor. - Linear switched reluctance motor.
Control	- TSF - DTC - DITC - FOC - SMC -MPC

3.2. Comparison of Different Motors for EV

Each motor among the motors studied previously has different characteristics [20,26]. An evaluation is made between them in order to know which one is the most efficient and desirable in the design of electric vehicles, based on very specific criteria such as the simplicity of construction, high power, low cost in terms of maintenance and a good level of maintenance. controllability [1]. In this paper the comparison is focused on the terms of efficiency, power density and cost in table 9 [35,48].

- **Power density**: Is the amount of power (time rate of energy transfer), generated per unit volume of the motor. In very simple terms, the more powerful the motor and the smaller in envelope size, the higher the power density [50,60,61].

- **Efficiency**: Electric motor efficiency is the ratio of shaft output power to electrical input power most electric motors are designed to operate at 50% to 100% of rated load [51,62]. Peak efficiency is typically close to 75% of rated load [48,63].

- **Controllability**: Is defined as the ability of a control system to reach a defined state from a fixed state in a finite time [63,64]. It is considered an important property of the control system because it defines the behavior of the control system [65,66].

- **Reliability**: There is a measure related to reliability, it is the mean time between failures. This is the average time between failures of a machine or component [67,68]. An electric motor is reliable, this means that there is a high probability of operation without failure for a certain period or during its useful life [50,69].

- **Cost**: Among the most important things that await manufacturers of electric vehicles is to provide the consumer, with an electric vehicle that performs better than a gasoline vehicle but at an affordable price [38,53,70].

- **Size**: The power of an electric motor therefore derives from the maximum capacity of energy that it is capable of transforming [69,71]. Motor sizing refers to the process of selecting the correct motor for a given load. Properly sizing a motor is important because if a motor is too small for an application. It may not have sufficient torque to start the load and run it up to the correct speed, in the case of an electric vehicle, the power depends on the size of its engine [26].

- **Speed range**: Speed range means the speed range taken into account for determining the road load. Which is between the maximum speed of the global light vehicle test cycle, for the test vehicle class, and the minimum speed selected by the manufacturer [72,73]. This is an indication of how slowly the drive can operate the motor, before the motor begins to overheat [74].

- **Acoustic noise**: The overall noise level of an electrical machine comes from three main sources: Noise of mechanical origin (bearings, gears, etc.), noise of aerodynamic or hydrodynamic origin (cooling fluids) and noise of origin magnetic [75,76,77].

- **Torque ripple**: Motors produce torque and rotation through the interaction of magnetic fields in the rotor and stator. In an ideal motor - with perfectly machined and assembled mechanical components and electric fields that build and break instantly - the torque output would be perfectly smooth, with no variations [78,79]. But in the real world, there are a variety of factors that make the torque output inconsistent, even if it is only by a small amount. This periodic fluctuation in torque output of a motor under voltage is called torque ripple, it is uneven torque production throughout the rotation of a rotor in an energized motor, caused by variations in electromagnetic fields and their interactions between the rotor and stator [56,80].

- **Technological maturity**: The maturation phase is a crucial stage which makes it possible to make a scientific result reliable on target applications [21]. It is a numerical index characterizing the state of progress of a scientific or technical project or innovation according to a scale of technological maturity [42]. The level of technological maturity is taken into account to decide whether to continue the development of a project or an innovation or to move on to its application phase [16].

- **Maximum torque**: In physics and particularly in mechanics, a couple is a set of forces with a zero resultant, of which, however, the total moment is generally not zero [81]. The term “torque” comes from the fact that the simplest couple is a set of two opposing forces (of the same direction and of the same intensity, but in opposite directions). Torque is to rotational movement what force is to movement translation [82]. Torque is what causes angular acceleration, and rotation in the plane perpendicular to the direction of the torque. Maximum torque is delivered throttle to floor, often between low and mid-range. The torque then fades until maximum speed. The driver can thus perceive the evolution of the torque with the speed [79].

A comparative study is made between the six engines most used in the automotive field, exactly the manufacture of electric vehicles, by choosing 9 criteria such as efficiency, power, cost, etc. The obtained comparative result indicates [1]. The DC motor is the most controllable andtechnological, has high maturity and cost, and has low power density and low efficiency.PMBLDC/PMBLAC motor is the highest in power density, power-to-weight ratio and efficiency, has high controllability and reliability, but its controller cost is very high. PMSM has higher power density and efficiency, and its controllability, reliability, technology and controller cost are high. IM is the highest in controllability, reliability, maturity and technology, has high efficiency and high power-to-weight ratio, low cost. And finally, SRM has higher reliability, high efficiency, maturity, technology and power-to-weight ratio, but its cost is low [44,73].

Table 9. Performance comparison of major electrical motors used in electric vehicle applications

Factors	Electric Motor						References
	DC	PMBLAC	PMBLDC	PMSM	IM	SRM	
Power density	L	H	H	M	M	M	[21]
Efficiency	L	H	H	H	M	M	[53,20]
Controllability	V.H	H	H	V.H	V.H	M	[83]
Reliability	M	H	H	H	V.H	V.H	[26]
Cost	M	H	H	V.H	L	M	[1]
Size	M	S	S	M	M	La	[27]
Speed range	M	L	L	M	M	H	[38]
Acoustic noise	M	L	L	M	L	H	[22]
Torque ripple	L	L	M	M	L	H	[84]
Technology maturity	V.H	H	H	H	V.H	H	[15]
Maximum torque	M	H	H	H	V.H	H	[85]

Where: L = Low, M= Medium, H = High, V.H = Very high, S = Small, and La = Large

4. Control Strategies

Precise and efficient control of electric motors is vital to ensure optimal operation and optimize energy consumption. In this sense, several electric motor control methods have been developed, to meet the specific requirements of various applications. Figure 10 shows the detailed diagram of the different types of electric motor control strategies existing in the market.

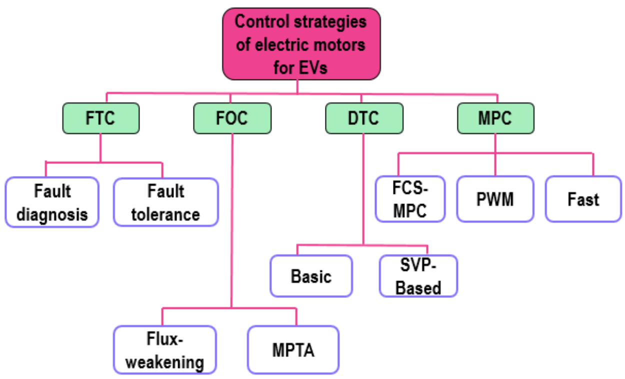

Fig. 10. Different strategies of control for electric motors.

4.1. Control Strategies Types

In this part, the control strategies most used by researchers and the most existing on automobile markets will be presented and compared. We find the following controls, Pulse Width Modulation (PWM), Field Oriented Control (FOC) [3], Direct Torque Control (DTC) [86], Finite Control Set Model Predictive Control (FCS- MPC), Fault Tolerant Control (FTC), Model Contour Predictive Control (MPCC) and Model Direct Torque Predictive Control (MPDTC). The principles, advantages and disadvantages of the controls will be mentioned, with a comparison between them to know the most compliant with the requirements of the EV application.

4.1.1. Pulse width modulation (PWM)

The PWM is a digital signal where the voltage can only take two values. It is often used in variable average value applications such as speed variation and digital-analog conversion [87]. This type of control treats the motor as a digital system, it is known for the simplicity of its production, its main interest is to limit the heating of the electronic components, another interest of PMW is that the voltage applied to the motor is sufficient to overcome frictionand make the engine run [88]. The scheme of PWM is shown in Fig.11.

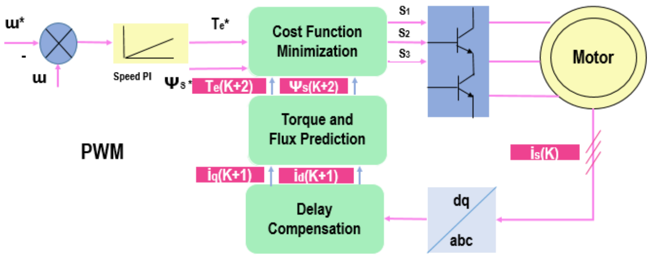

Fig. 11. Structure of Pulse width modulation (PWM).

4.1.2. Field oriented control (FOC)

The FOC is a method of controlling variable frequency variable speed drives. In which the three-phase stator currents of an AC or DC motor are transformed into two orthogonal components which can be considered to be vectors, a vector allows to adjust the magnetic flux and the other the torque, it allows a control of the torque at the stop, it is based on the transient model [36]. This type of control is fast and precise, it offers good dynamic performance combined with fast accelerations, it can also reduce the size of the motor used as it can reduce its electrical consumption and its cost [39]. The application of the FOC scheme can ensure the precise torque output of EVs. The scheme diagrams of FOC is shown in Fig.12.

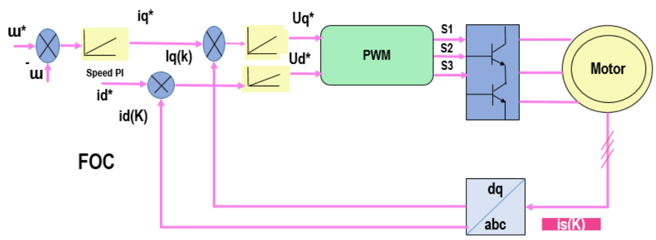

Fig. 12. Structure of field oriented control (FOC).

4.1.3. Direct torque control (DTC)

The DTC is a method of electric speed variation, its contraction is on torque control. It can estimate flux and torque from the measurement of voltages and currents feeding the motor, when it was invented at the start was reserved for asynchronous and synchronous machines [89]. This type of control is known for its robustness and its good performance [90]. It offers dynamic performance, its losses are low because it has a low switching frequency, it is expensive because it requires good quality sensors and a controller powerful to calculate the algorithm [40]. The scheme diagrams of DTC is shown in Fig.13.

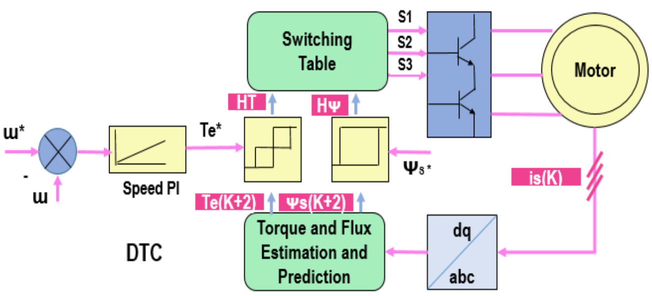

Fig. 13. Structure of direct torque control (DTC).

4.1.4. Finite control set model predictive control (FCS-MPC)

The FCS-MPC controller is suitable for systems that have a discrete output set, it is very suitable for three-arm and two-level inverters because of the finite number of switching states of the latter. The literature proposes several implementations of FCS-MPC [41,91], it has received more attention in research thanks to its good dynamics and high adaptability thus it can simply integrate nonlinearities and constraints. But also it has the disadvantage the value minimum time between two successive switchings is equal to the sampling period [92]. The scheme diagrams of FCS-MPC is shown in Fig.14.

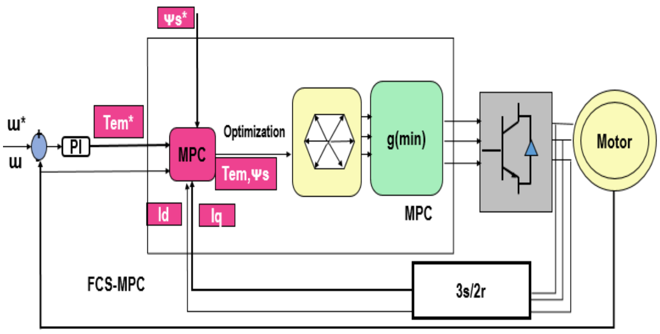

Fig. 14. Structure of FCS-MPC.

4.1.5. Fault tolerant control (FTC)

The FTC is a new methodology developed by researchers for both fault diagnosis and fault tolerant control [84], the main objective of which is to assess the impact of failures on the reliability and system security so that the monitoring of these systems is effective [48]. Indeed, fault diagnosis is essentially based on three tasks: fault detection, fault isolation and fault estimation, after having detected a fault, comes the location step [93]. FTC known by its good dynamics as it can stabilize the system and maintain the desired performance [89]. The scheme diagrams of FTC is shown in Fig.15.

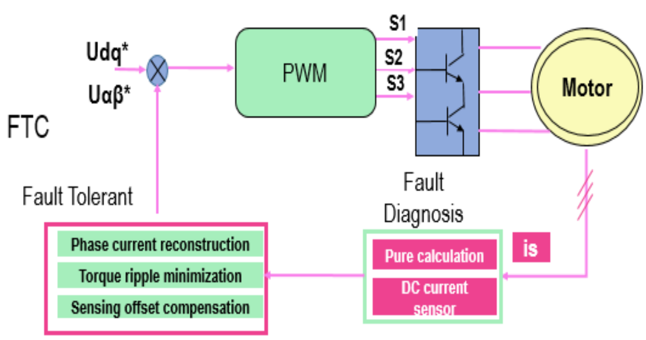

Fig. 15. Structure of fault tolerant control (FTC).

4.1.6. Model predictive contouring control (MPCC)

The MPCC is a method based on minimizing a cost function that trades off the competing goals of travel time, tracking, and accuracy by adjusting the corresponding weights in the cost function. It is used to achieve smooth trajectories and minimize vibrations [94]. This type of control makes it possible to obtain better performance in terms of precision and time. The scheme diagrams of MPCC is shown in Fig.16.

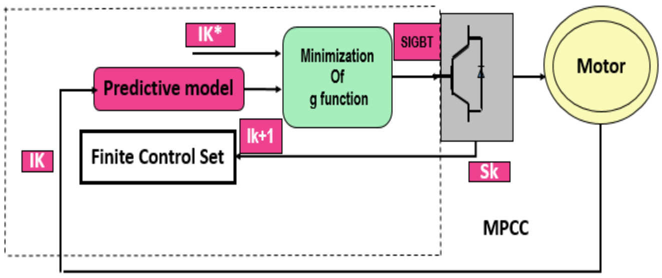

Fig. 16. Structure of model predictive contouring control (MPCC).

4.1.7. Model predictive direct torque control (MPDTC)

The (MPDTC) control is a method of integration of MPC control with DTC control, whose state values are torque and flux, theoretically this approach directly controls the average torque value and it allows the calculation of switching states for have a desirable torque at the end of the control cycle

[95,96]. This method is simple at the programming level, very efficient in the transient state and flexible, thus it protects the power electronic elements from overcurrent, its response speed is fast and its medium and lower switching frequency [97,98], its basic scheme is shown in Fig.17.

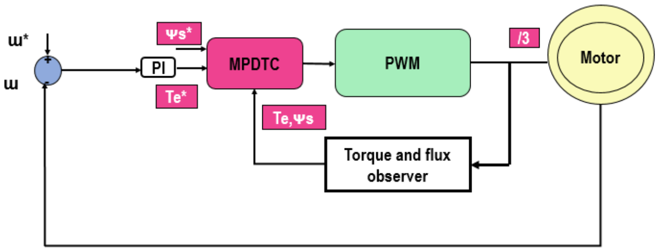

Fig. 17. Structure of model predictive direct torque control (MPDTC).

4.2. Comparison of Different Control Strategies

The Table 10 shows the characteristics of the different control strategies mentioned above, as well as the essential comparison parameters, to conclude the advantages of one over the other and conclude which types meet the requested requirements by manufacturers of electric vehicles [89].

According to the results obtained, there are two types of electric motor control strategies in the application of electric vehicles. There are classic controllers such as FOC, DTC and MPC, whose Field Oriented Control (FOC) helps provide precise phase. In high and medium power situations, it will be better to use DTC strategy, and PWM control was designed for applications in electric motor controllers, it is known for its high flexibility, fast dynamic response and wide speed range. So there are emerging types or new methods, such as FCS-MPC, MPCC and MPDTC, which have identical characteristics such as high performance and high speed [6]. According to the results obtained at the level of a study which carried out between the FOC and DTC control in terms of their performances such as the dynamic response, the rate of torque ripples and stator current, the two approaches offer comparable performance, with the FOC control having a minor edge in steady state and at low speeds. In dynamic mode, the DTC control exhibits a better torque response and is more sensitive to changes in the machine parameters [100].

Table 10. Characteristics of control strategies

Control Strategies	Factors									References
	Dynamic	Robustness	Torque ripple	Speed	Transient response	Current control bandwith	Performance	Switching frequency	Sensitivity to parameters	
PWM	H	L	-	H	F	La	H	L	H	[99]
DTC	H	H	H	H	F	Sm	H	L	L	[89]
FOC	H	L	L	H	S	Sm	M	H	H	[96]
FTC	H	H	-	H	F	-	M	-	-	[93]
FCS-MPC	H	H	-	H	-	-	H	-	-	[89,92]
MPDTC	H	H	-	H	F	-	H	-	-	[96]
MPCC	H	H	L	H	-	-	H	-	-	[96]

Where: L = Low, M= Medium, H = High, S = Slow, and La=Large, Sm= Small.

5. Conclusion

In this paper, the electric vehicle has been closely examined. based on its history, its relative advantages on the one hand with the environment. Including no emissions of greenhouse gases, polluting gases or engine gases when driving, and on the other hand for the consumer where there is no change of air filter, fuel filter, oil gearbox. Its different types were cited, then all the work was projected on the BEV, because recently interest has increased in this type thanks to its many qualities compared to a minimum of disadvantages. The best known problem of which is a range for which all manufacturers are increasing their efforts to find a solution and improve autonomy. In this article, an overview of the different types of electric motors and their different control strategies used in electric vehicle construction is presented. The following points were revealed, on the one hand, studying the principles of motors, DC motor, PMSM. PMBLDC/AC, IM and SRM, SynRM, and comparison between these types of electrical machines. On the other hand, study the control strategies of electrical machines, PWM, FOC, DTC, FCS-MPC, FTC, MPCC and MPDTC, and comparison between these types of control strategies.

In a sense, concluding among the motors used in this study that the PMBLDC motor presents higher performance than other types, in terms of robustness, dynamism and efficiency, and that it is the most used in the sector of the construction of electric cars.

In the other direction, Direct Torque Control presents good performance compared to competitors, in terms of torque response and complexity. The interest of the researchers and our concern in our future work is to find solutions to the disadvantages. Such as the current and torque rate ripples due to the presence of hysteresis comparators, as well as the disadvantage of the switching frequency which is not constant.

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Author Contributions

Zineb Machhour was responsible for conceptualization, resources, investigation, data curation, software development, and preparation of the original draft. Abdelfattah Dani, Mhamed El Mrabet, Zineb Mekrini, and Mohammed Khayat. jointly contributed to the methodology, formal analysis, validation, technical & writing review, and editing. Mohammed Boulaala was responsible for the critical revision & editing, visualization, supervision, and project administration. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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