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Review paper

Review of Electric Vehicle Traction Motors, Control Systems, and Various Implementation Cards

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Abstract— *Utilizing electric vehicles (EVs) in place of conventional vehicles is now necessary to lower carbon dioxide emissions, provide clean energy, and lessen environmental pollution. Numerous researchers are trying to figure out how to make these electric vehicles better in order to address this. Electric motors and batteries are necessary parts of electric cars. As such, the development of these vehicles was associated with the development of these two entities. This review lists all of the sophisticated electric machines, their control schemes, and the embedded systems that are utilized to put these schemes into practice. Due to this review, we determined out, the induction motor and permanent magnet synchronous motor have been demonstrated to be the most efficient and suitable alternative for propulsion drive in electric vehicles. Furthermore, because torque and speed can be controlled simultaneously with minimal noise and ripples, the FOC approach continues to be the ideal control method. This evaluation offers comprehensive information regarding the application of various control measures. Whereas the model- based design technique made it easier for engineers to program, validate, and fine-tune the system's controllers before deploying it in the field, STM32 and DSP320F28379 are the best embedded systems for implementation because of their low cost and compatibility with the SIMULINK environment.*

Keywords—Electric machines, embedded system, model based design, control strategies.

NOMENCLATURE

AC	Alternating current
ADC	Analog to digital conversion
BLDC	Brushless direct current
CPU	Central processing unit
CVT	Continuously variable transmission
DAC	Digital to analog conversion
DC	Direct current
DFOC	Direct field oriented control
DSP	Digital signal processor
DTC	Direct Torque Control
EUSART	Enhanced universal synchronous asynchronous receiver transmitter
EV	Electric vehicle
FOC	Field oriented control
FPGA	Field-programmable gate array
FPU	Floating point unit
G2V	Grid to vehicle
HDL	Hardware description language
HEV	Hybrid electric vehicle
HIL	Hardware In the loop
I2C	Inter integrated circuit
ICE	Internal combustion engine
IFOC	Indirect field oriented control
IM	Induction motor
MB	Mega byte
MBD	Model based design
MIPS	Million instructon per second
MPC	Model predictive control
MPCC	Model predictive current control
MPFC	Model predictive flux control
MPTC	Model predictive torque control
MTPA	Maximum torque per ampere
PID	Proportional integral derivative
PMSM	Permanent magnet synchronous motor
PWM	Pulse width modulation
RAM	Random access memory
SDK	Software development kit
SoC	System on chip
SPI	Serial peripheral interface
SRAM	Static random access memory
SRM	Switched reluctance motor
STM	STMicroelectronic
SynRM	Synchronous reluctance motor
THD	Total harmonic distortion
TMU	Texture mapping unit
VCU	Vehicle control unit
XADC	Xilinx analog to digital converters

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1. INTRODUCTION

Electric vehicle (EV) technology and uses have become widely available as a result of the rapid development of electric machines and power electronics over the past couple of centuries [1].

Standard vehicles are powered by internal combustion engines (ICE). These convert petrol and gas into carbon dioxide, which is the source of pollution. The focus of research is on clean energy, leading to the development of hybrid electric vehicles, which use both internal combustion engines and electric motors to move their wheels [2]. The power source, the auxiliary subsystem, and the electric powertrain subsystem are the three principal subsystems of an electric vehicle [3]. The electronic powertrain subsystem is made up of a power converter, an electronic con- troller, a mechanical transmission, and an electric motor. This paper details the different engines available for electric vehicles. Brushed direct current (DC) motors, brushless direct current (BLDC) motors, synchronous reluc tance motors (SynRM), switch reluctance motors (SRM), induction motors (IMs), and permanent magnet synchronous motors (PMSMs) are the most common types of electric motors used in EV applications. Because of their low cost, great reliability, and established production and control procedures, IMs have been the most common electric motor type for EVs for the last 20 years [4]. However, PMSMs offer higher torque and efficiency than IMs, making them more appealing for EVs [5]. This paper presents three control methodologies for increasing motor EV efficiency: Field Oriented Control (FOC), Direct Torque Control (DTC), and model predictive control (MPC). To regulate transient torque, the Field Oriented control (FOC) approach evolved. This control mimics the behavior of a DC machine by de-coupling the torque and flux of the machine [6]. This decoupling gives a very quick torque response, a wide speed control range, and excellent efficiency over a vast load range. Direct Torque Control (DTC) was introduced in the mid-1980s. TAKAHASHI [7] and DEPENBROCK [8] pioneered this approach. Its operation is based on a direct evaluation of the control pulses given to the voltage inverter switches [9]. However, there are two important drawbacks: the switching frequency is highly changeable, and the ondulations amplitude of the torque and the stator flux are poorly controlled during the speed range of the proposed operation [10]. It should be noted that torque ripples generate more noise and vibrations, causing problems in the spinning shaft [11]. MPC has gained popularity in recent year be- cause to the benefits of its simple principle, great dynamic performance, and ease of implementation [12]. MPC is classified into three types based on the variables under control: model predictive, torque control (MPTC) [13], flux control (MPFC), and current control (MPCC). MPCC, on the other hand, is strongly reliant on the correctness of the machine parameters. If the parameter utilized in the controller varies from the real value, control performance suffers dramatically. As a contribution, this paper offers a few effective embedded systems that facilitate the use of various strategies. Because of software modeling and simulation tools like MathWorks' Simulink, model-based design has evolved into a comprehensive design flow from model generation to implementation, altering and simplifying the way engineers and scientists operate. Once the control model is complete, the Simulink environment can automatically translate it into C and HDL code that will be executed by the control system, saving time and eliminating manual coding errors. This solution simplifies the implementation of the previously mentioned strategies. In this paper, an FPGA embedded system and three microcontrollers (MCUs), PIC18F, STM32, and F28379, will be presented for implement control strategies. they require C and HDL code that is easily generated by the SIMULINK environment. This review is structured in some ways around section 2, which presents electric motors used in electric vehicles and comparison of these drives, what's more, presents the manufacturers who employed them. Section 3 discusses the control mechanisms utilized to operate these motors. Section 4 is for embedded systems that could be used on implementation. Finally In Section 5, the study's conclusion.

2. Electric motors

2.1. Classification of electric motors

Modern automobiles have about 100 different kinds of electric drives [14], however only six possible machines for EV propulsion are considered here (Fig. 1):

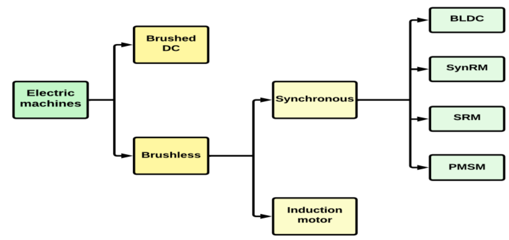

Fig. 1. Types of electric motor.

A) Brushed direct current (DC)

Brushed direct current (DC) is a well-known driving machine for tiny and remote-controlled devices [4]. It is widely regarded as one of the initially developed motors used in EVs due to its appropriate management, strong torque at low speeds, dependability, simple control system, and low cost [15]. It could be a viable choice for an EV powertrain [16]. Given the several faults, such as high maintenance, low efficiency and speed, but primarily bulky construction, as both brushes and commutator require replacing due to frictional aging. Furthermore, the recuperative breaking capacity of a DC motor is severely limited [17]. Lower and medium power range commutation vehicles, on the other hand, remain an important market for DC motors [18]. While the present situation of AC motors, as well as advances in control systems and power electronics , have put DC motors behind their competitors.

B) Brushless DC motors (BLDC)

Brushless DC motors (BLDC) (Fig. 2) can run at high speeds while maintaining excellent heat dissipation and efficiency by adding an internal permanent magnet to the rotor. At a steady power range and over a wide speed range, this motor has produced less efficiency [19]. They are one of the most famous and frequently used motors for various systems as vehicles, and home equipment, due to their small size and low maintenance requirements while attaining great controllability and efficiency [20]. Unlike DC motors, permanent magnets are installed in the rotor of BLDC motors. The inverter converts the direct current (DC) source supply to alternating current (AC) and supplies it to the stator. The stator coils, which are powered by a direct current voltage and regulated by hall sensors, provide power density and outstanding efficiency while producing little noise [21]. This model can be improved further by minimizing iron losses, and ripple using a sensorless design [22]. However, by increasing the windings, the speed range and general effectiveness of these motors can be improved [23].

C) Synchronous reluctance (SynRM)

The synchronous reluctance (SynRM) (Fig. 3) which is rated for high torque, power-to-weight ratio, and speed is extremely interesting in traction motors [24]. The technology has been accessible for more than 100 years, but it was ignored until 1980 due to a lack of high-quality power electronics [25]. The operation of the coil is relatively simple: when the rotor strives to align with the center of the stator, it is driven by magnetic reluctance minimization, also known as reluctance torque [24]. When the rotor and stator poles are aligned, the rotor asserts a minimal reluctance position, resulting in a lower magnetic reluctance. This machine type is ideal for inexpensive EV drive with minimal degradation in performance [26].

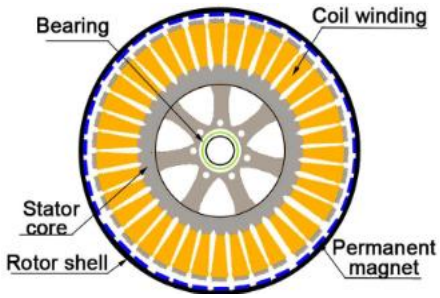

Fig. 2. BLDC motor topology [20].

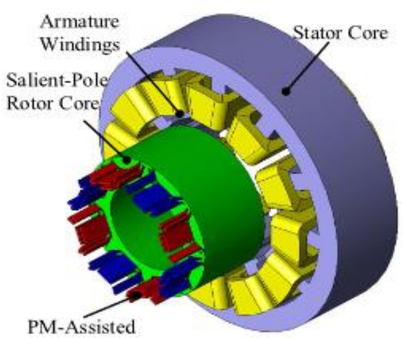

Fig. 3. SynR motor topology [27].

D) Switched reluctance motors (SRM)

The switched reluctance motors (SRM) (Fig. 4) create the possibility to do away with rare-earth metals and save costs by doing away with windings, slip rings, and PMs on the rotor [28]. It has a unique structure. The stator has two prominent poles with concentrated windings sur- rounding these, and the diametrically opposed windings are joined to form the stator phase. The rotor also has salient poles, but it does not have any windings or permanent magnets. As with BLDC motors, the stator phase currents in SR motors are switched on and off synchronously with the rotor position to maintain continuous operation. The closest pair of rotor poles is attracted to the magnetic stator poles when a stator phase is excited. The rotor rotates to the point with the lowest reluctance of the excited stator winding, thus generating machine torque. Because of torque density limits, workable SRM-based EV propulsion systems are few [29]. What's more, they necessitate complicated and expensive converters and controllers [30, 31].

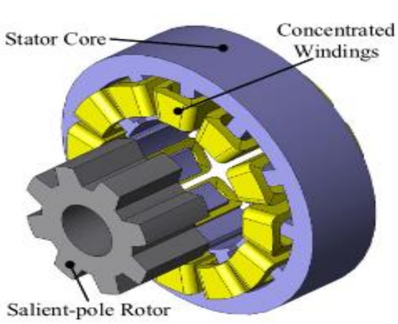

Fig. 4. SR motor topology [27].

E) Induction motor (IM)

The induction motor (IM) uses both kinds of rotor topologies: squirrel- cage and wound-rotor [32]. Squirrel cage induction machines (Fig. 5) are the most often used devices in industry. Induction machine innovation is rather old. Because of their simple yet strong form, they are an excellent choice for traction. Other significant advantages of these machines are high torque, strong dynamic responsiveness, and low overall maintenance requirements [33]. To compete with PM machines in terms of power density and torque density, IMs made with stator windings with bar-wound wires and rotor cage with copper conductors may be viable options [34].

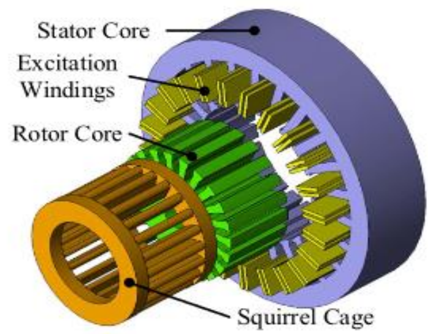

Fig. 5. IM topology [27].

F) Permanent magnet synchronous motor (PMSM)

Permanent magnet synchronous motors (PMSM) (Fig. 6) have permanent magnets in the rotor and three-phase windings in the stator. When an alternating current with a sinusoidal waveform feeds the permanent magnet terminals, the motor is referred to as a PMSM, however when a trapezoidal waveform feeds the terminals, the motor is referred to as a BLDC. Although the hardware architecture of both motor kinds are identical, the software control method differs due to distinct current waveforms [17]. PMSMs can be classified as interior type (IPM) or surface-mounted PMSM (SPM) based on where the permanent magnets are located on or in the rotor [35]. PMSMs have good controllability and torque values in small sizes, weight, and dimension. It has a high power factor as well as a high power density. In applications requiring constant speed, PMSM performs well [36]. PMSMs are becoming more common in electric drive systems for EVs and HEVs because to the rapid development of PM materials [37]. It demonstrates how well PMSMs perform in passenger EVs.

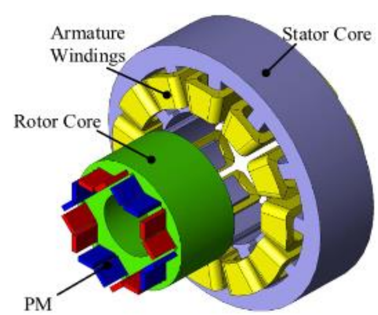

Fig. 6. PMSM topology [27].

2.2. Motors comparison

The requirements of electric vehicles are high torque at the first movement and low power consumption at high speeds. Fig.

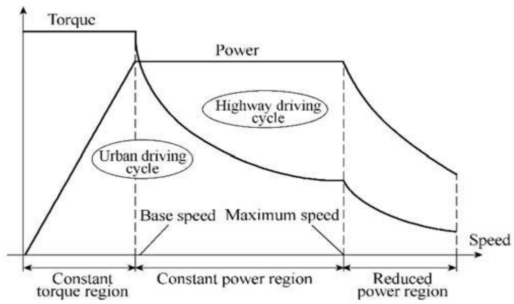

Fig. 7. Characteristics of electric traction motors [23].

Table 1. Electric motor criteria.

Parameters	BLDC	SynRM	SRM	PMSM	IM
Cost	4	3	4	3	5
Size	3	3	2	5	4
Efficiency	3	4	4	5	3
Fault tolerance	2	5	5	4	3
Overload capacity	3	3	2	3	4
Power density	2	4	3	5	3
Speed range	2	4	5	3	3
Torque ripple	5	4	2	4	5
Control simplicity	5	3	3	4	5
Noise level	4	4	2	5	4
Reliability	3	5	5	4	5

7 shows torque-speed- power characteristics of electric traction motors.

The other different selection criteria for any particular engine for the electric propulsion system are summarized in Table 1. Such as cost, size, speed range, efficiency, power density, maximum torque, reliability, and technical maturity [38]. In addition, the five types of motors previously discussed are chosen for comparison. For easy validation and understanding of each parameter, the score is scaled from 1 to 5 from poorest to greatest [24]. The following are included in the scaling: score 1 is for very low grading, score 2 for Low grading, score 3 for Moderate scoring, score 4 for High classification matches, and finally, score 5 for Very high or ultimate evaluation.

Depending on the conditions and the Table 1, each motor becomes more apparent than its peers. Induction motors and permanent magnet synchronous machines, are one step ahead of their competitors.

2.3. Commercial electric vehicles motors

The electric motors utilized in EVs have been thoroughly covered in earlier sections. As a result, each manufacturer selects the appropriate type based on the parameters. Tesla Inc, for example, employed an induction motor until 2015-2016, but has since switched to an in-house synchronous reluctance powertrain or a twin motor arrangement, with one motor at each axle [39, 40]. Other well-known businesses, such as Porsche, Hyundai, and BMW, have been using permanent magnet synchronous motors for over a decade, recognizing their numerous benefits, although Audi and Mercedes choose the more controlled, inexpensive, and quiet induction motors [41, 42]. Due to the specifications discussed in previous sections, brushless motors are not present in practically any car, but they are preferred for electric scooters and motorbikes combined with CVT due to their uniqueness. Permanent magnets have clearly dominated the EV powertrain field, with SynRM being a major rival. As demonstrated in Table 2, this section presents an extensive database regarding commercial electric vehicles in chronological sequence.

Table 2. Commercial electric vehicle historical database.

EV model name	Motor type	Year	Reference
Waveley Electric	DC	1903	[43]
Detroit	DC	1914	[44]
BMW	DC	1972	[45]
BMW	PMSM	1992	[46]
Citroen	DC	1995	[47]
Honda	PMSM	1997	[48]
Ford	IM	1998	[49]
Honda	PMSM	2000	[50]
Toyota	PMSM	2001	[23]
Honda	PMSM	2003	[23]
Renault	IM	2003	[23]
Toyota	PMSM	2004	[23]
Kewet	DC	2007	[23]
Toyota	PMSM	2008	[23]
Tesla	IM	2008	[23]
Mitsubishi	PMSM	2009	[23]
Ford	PMSM	2010	[23]
Nissan	PMSM	2011	[23]
Chevrolet	PMSM	2011	[23]
Skoda	PMSM	2011	[23]
Ford	IM	2012	[23]
Land Rover 110 Defender	SRM	2013	[24]
Tesla Model X	IM	2015	[24]
Mahindra Evertio	IM	2016	[24]
Toyota Prius Hybrid	SynRM	2017	[24]
Chevrolet Bolt	PMSM	2017	[24]
Xpeng G3	PMSM	2019	[24]
Audi E-Tron Q	IM	2019	[24]
Volkswagen E-Up	PMSM	2019	[24]
Jaguat i-Pace	PMSM	2019	[24]
Nissan Leaf	PMSM	2019	[24]
Nio EC6	PMSM	2020	[24]
Kia e-Niro	PMSM	2020	[24]
Mini Cooper SE	PMSM	2020	[24]
Skoda Citigo-e IV	PMSM	2020	[24]
Mercedes Benz EQ	IM	2020	[24]
Hyundai Kona E	PMSM	2020	[24]
Porsche Taycan	PMSM	2020	[24]
Renault Zoe	PMSM	2020	[24]
Tesla Model S	SynRM	2020	[24]
Volvo XC40	PMSM	2021	[24]
Tesla	SynRM	2021	[24]
BMW iX	PMSM	2022	[24]

3. Control strategies for electric machines

Generally, the basic control technique of the electric motor used in EVs is considered sophisticated technology and is further classified into three types (Fig. 8): field-oriented control (FOC), direct torque control (DTC), and model predictive control (MPC).

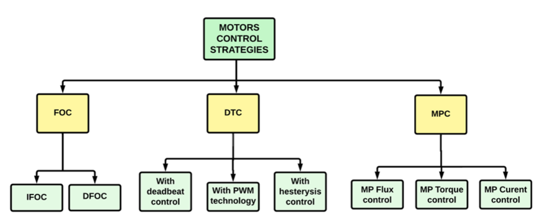

Fig. 8. Different basic electric motor control techniques.

DTC control techniques are described in the application of controllers in EVs and may be commonly utilized in high and medium power conditions [51]. The FOC controller can be used to produce exact phase voltage with a clear decoupling matrix of phase currents into a rotating coordinate frame [27]. With the advancement of the microprocessor, the MPC technique can now

Table 3. FOC-DTC-MPC comparison.

FOC	DTC	MPC
Low THD	High THD	High THD
Small current bandwith	Small current bandwith	High current bandwith
Fixed switching frequency	Low switching frequency	Low switching frequency
Sensitive to parameters	Not sensitive to parameters	Sensitive to parameters
One speed regulator	One speed regulator	One speed regulator
and two others for current	and two hysteresis controllers	and predictive control

be used in drive controllers [52]. MPC is also gaining popularity for EVs due to its extensive speed band and rapid response. Table 3 shows the fundamental distinctions among these three controllers [27].

3.1. Field oriented control (FOC)

FOC was invented by F. Blasehke in 1971 and is commonly used for AC motor control. There are two basic vector control strategies for motor control: direct field oriented control and indirect field oriented control. The flux magnitude and angle feedback signals for direct FOC are calculated directly using current or voltage. This approach is susceptible to parameter fluctuations and performs poorly in the low speed zone. Because of its greater speed range and high-speed functioning via flux field weakening control, the indirect FOC is widely utilized for engine control. The FOC system can ensure that EVs have exact torque output. The operation principle of FOC, as shown in Fig. 9, depends on the application of a suitable coordinate system that permits torque and rotor flux to be regulated independently of one another. The entire FOC controller is a cascade control loop made up of two PI-current controllers and one speed PI controller. The error between the current references, Id* and Iq* , and the real currents, Id and Iq , that is determined by sampling stator current Iabc, is used by PI controllers to determine the regulation voltage references Ud* and Uq* . The other PI controller computes the current reference using the difference between the speed reference and the actual speed. This means that PI controller tuning is complicated and should be adjusted based on varied operating conditions.

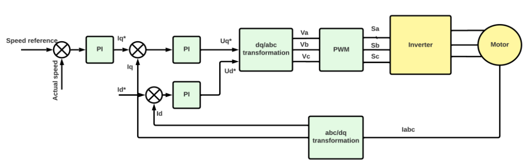

Fig. 9. Fundamental scheme of FOC.

To meet the unique requirements of EVs, there are now a number of modified FOC controllers available, such as -Maximum Torque per Ampere (MTPA) operating with FOC can help improve EV acceleration [53]. The ability to achieve optimum efficiency by adjusting the current vector at specific load situations makes MTPA operation the preferred method for man- aging PM synchronous motor (PMSM) drives [54]. Actually, the key to MTPA is determining the optimal rotor location. -Flux-weakening FOC controllers can improve electric motor speed range, allowing EVs to reach higher top speeds [55, 56].

3.2. Direct torque control (DTC)

Direct Torque Control (DTC) is a control approach for alternating current (AC) speed regulation systems that uses torque as the direct control object. Based on the difference between the setpoint and actual value of the flux and torque coupling, the DTC selects a voltage vector and then modulates the converter to maintain the setpoint Fig. 10. The basic idea of DTC is to use separate hysteresis controllers for electromagnetic torque and stator flux. The torque hysteresis controller has three levels and a bandwidth, while the flux hysteresis controller has two levels and another bandwidth. However, the hysteresis controllers can make DTC's total harmonic distortion (THD) quality worse. Additionally, it has an undesired changeable switching frequency, is difficult to manage, and produces a lot of noise at low speeds [57]. Recently, the literature has provided several improved options. To increase DTC performance, the PWM technology used in FOC is integrated with DTC to eliminate torque ripples. Some controllers retain the hysteresis controller structure while subdividing the switching table to obtain an accurate voltage vector [58]. The deadbeat control idea can be used in conjunction with DTC to achieve faster transient effectiveness and improved steady-state efficiency [59, 60].

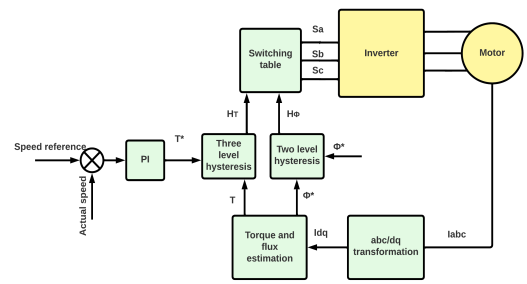

Fig. 10. Fundamental scheme of DTC.

3.3. Model predictive control

In recent years, Model Predictive Control (MPC) has received increasing attention in research. MPC offers the advantages of intuitive implementation and fast dynamic response. It can also easily incorporate nonlinearities and constraints. However, MPC suffers from a higher computational burden compared to other control strategies. With the development of microprocessors, MPC techniques for motor drives are now being explored in the literature. MPC describes a control approach that predicts future system states, taking into account the discontinuous nature of the power converter. In effect, a fixed number of future states, called the prediction horizon, are projected from a current sampling instant. The prediction results are then evaluated using a cost function, which is used as a criterion for determining the correct control action. Fig. 11 shows a basic MPC diagram. In general, there are three alternative control approaches, each with its own set of constraints: model predictive torque control, model predictive current control and model predictive flux control.

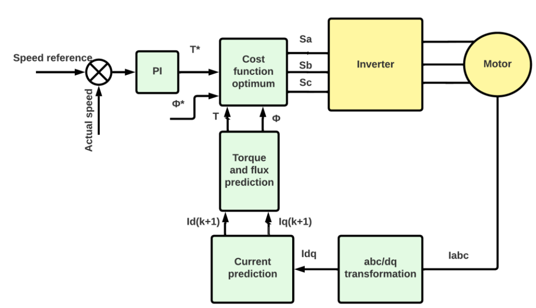

Fig. 11. Fundamental scheme of MPC.

MPC has been deployed on a variety of machines. [61] investigated a nine- phase flux-switching permanent magnet motor using MPCC. Synchronous reluctance motors [62, 63], induction motors [64], switching reluctance motors [65], and PMSM [66] have also been used with MPC. These solutions perform well in terms of control.

4. DIFFERENT CARDS USED FOR MOTOR CONTROL IMPLEMENTATION

Used in many industrial, automotive and commercial applications, electric motors rely on motion controllers to regulate electrical input power to control torque, speed and position. Powerful motor drives are able to increase efficiency and provide faster, more precise control. Advanced motor control systems require more processing power to perform all tasks in real time, as they integrate control algorithms, industrial networks and user interfaces. Modern motor control systems are often implemented using multi-chip ar- chitectures: An FPGA implements high-speed I/O and network protocols, and a microcontroller executes motor control algorithms.

4.1. FPGA

An FPGA is a silicon circuit that can be reprogrammed. We can modify this circuit to include custom hardware features by using pre-built logic blocks and programmable routing resources [67]. Furthermore, FPGAs are totally reconfigurable . The generalization of high-level tools for design, on the other hand, is changing the norms of FPGA programming, thanks to new technologies that enable the conversion of graphical diagrams or even C code to digital hardware circuits (HDL) [68]. Advanced motor-control systems must perform a variety of control, communication, and user inter- face duties, each with its own processing bandwidth and real-time limits. The hardware platform used to construct such a control system must be both robust and scalable, with room for future system upgrades and growth. As demonstrated in Fig. 12, the Zynq All Programmable SoC (system on chip) meets these needs by integrating a high-performance processor with programmable logic. This combination provides higher parallel processing capability, real-time performance, quick computation, and flexible connectivity. The SoC (system on chip) incorporates two Xilinx analog-to-digital converters (XADC) for system or external analog sensor monitoring.

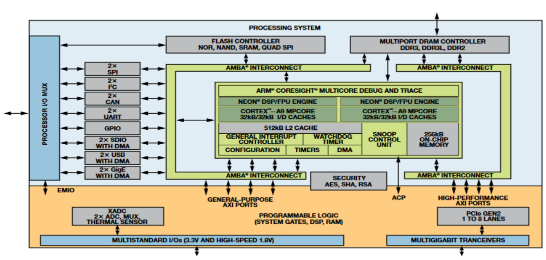

Fig. 12. Xilinx zynq system on chip (SoC) block diagram [69].

Zynq's processing power is based on a NEON coprocessor, a dual-core ARM Cortex-A9 processor, and floating point extensions that accelerate soft- ware execution. The processing system addresses software-implementable tasks such as motion control, supervisory control, system management, user interface and remote maintenance. Embedded Linux or real-time operating systems can be used to take advantage of the system's capabilities. The independent processor can be used without the need to configure the programmable logic. This allows software developers to work in tandem with hardware engineers designing the FPGA fabric [69]. The device has up to 444,000 logic cells and 2,200 DSP slices for huge processing capacity on the programmable logic side. Because the FPGA fabric is scalable, a user can choose from a modest 28,000 logic cell device to a high-end device capable of handling the most difficult signal processing tasks. Five high-speed AMBA-4 AXI interconnects connect the programmable logic to the processing system. This provides more than 3000 pins of effective bandwidth. The programmable logic can support multiple control cores running in parallel for multi-axis machines or multiple control systems, and is suitable for implementing time-critical, processing-intensive applications such as real-time industrial Ethernet protocols.

Many researchers are using FPGA to implement their systems. In [70] a microcontroller was used to send Zigbee sensor data, and an FPGA code design was created by integrating a hardware implementation of virtual processors and associated IP blocks with the software part written in C. And in [71] a comparative study of filters on FPGA and a DSP was implemented.

4.2. Microcontrollers (MCUs)

Microcontrollers are capable of carrying out operations such as sensor reading and control law implementation, but it is crucial to note that these circuits are digital, meaning that they are discretized in how they consider data, as opposed to the real-life environment, which is analog, and everything we encounter is continuous in nature. A microcontroller will employ both digital-to-analog conversion (DAC) to convert binary values to analog output voltages and analog-to-digital conversion (ADC) to convert an input signal to digital data that the microcontroller can use to reconcile this. This paper will present three different populating microcontrollers from three different manufacturers.

A) PIC18F

Microchip Technology's PIC18F microprocessor. This family of micro- controllers features an 8-bit CPU and provides better performance than the PIC16F family. It is wired for the current analysis, and it has some no- table qualities that have been described by many researchers [72, 73]. The PIC18Fxxxx microcontroller family can run at speeds of up to 12 MIPS (12 Million Instructions per Second) and includes a hardware accelerator to im- prove execution time and CPU performance [74]. Furthermore, it can handle a wide range of applications previously designated for digital signal processors (DSP). The PIC18f4550 (Fig. 13) has all of the benefits of the PIC18 microcontroller series, including great performance at a low cost, increased high performance flash memory, hardware accelerators, and serial connectivity modules such as USB. In addition to these advantages, the PIC18F4550 series provides design improvements that make these microcontrollers an obvious choice for many applications requiring excellent execution speed and low power consumption, which is exactly what our real-time embedded solution requires. It consumes little power in Optimal mode and connection applications that benefit from the presence of three serial ports: USB, Inter Integrated Circuit (I2CTM), and Serial Peripheral Interface (SPI). It is useful for embedded control and monitoring applications due to its substantial amount of RAM memory for buffering and Enhanced Flash program memory. The PIC 18F4550 has 256 bytes of data memory, 32K flash program memory, and 2048 bytes of static random access memory (SRAM). Further- more, each port pin sinks and sources 25mA current, making it simple to interact with peripherals. It enables improved power-on reset as well as in-circuit serial programming and debugging. The Analog to Digital Converter (ADC), Enhanced Universal Synchronous Asynchronous Receiver Transmitter (EUSART), Timers, and other interesting peripherals are supported by the PIC 18F4550.

In [75] a project was developed generate various tone using Timer 0 peripheral of Pic18F4550 controller, the [74] was developed an optimized DC/DC conversion system using PID controller and implement it in PIC18F4550 con- troller, and [76] designed a system using PIC18F4550 for temperature monitoring and light intensity control.

B) STM32

STM32 (Fig. 14) is a microcontroller designed by STMicroelectronics, a multinational semiconductor company. STM32 processors are commonly utilized in embedded systems and provide a variety of features and capabilities appropriate for a wide range of applications. It based on the ARM 32-bit Cortex-M7 CPU core with a floating point unit (FPU), has 1MB

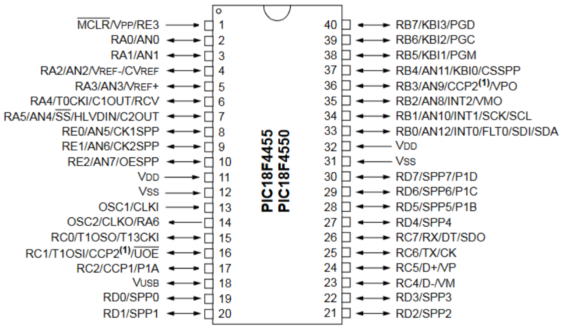

Fig. 13. PIC18F Pin diagram [73].

Flash memory and 320kB SRAM memory, and is equipped with a number of serial interfaces (including I2C, UART, SPI), as well as both 12-bit analog- to-digital converters (ADCs) and 12-bit digital-to-analog converters (DACs) [77, 78].

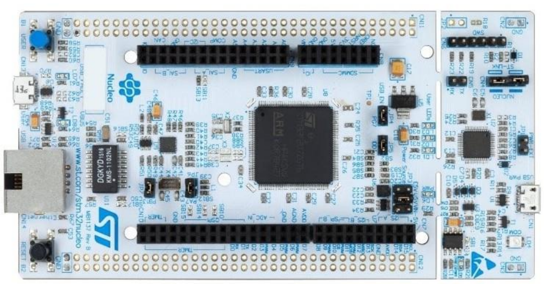

Fig. 14. STM32 board with different layout [77].

In [79], The sweeping robot made up of the HW-201 infrared range mod- ule, the US-100 ultrasonic module, the MPU6050 six-axis sensor module, and the motion module. was created with the STM32F103C8T6 single chip microcomputer as the primary control unit. The [80] employs the STM32F103 core, which is fast, precise, and accurate, and can identify the state of bi- cycles, range the distance between motor vehicles and bicycles, and emit an auditory alarm when the distance is harmful, and in [81], the COSPAS- SARSAR transmitter's baseband signal was generated using a technology based on the STM32L476RG controller.

C) *TMS320F28379D*

The TMS320F2837D (Fig. 15) is a high-performance 32-bit floating- point microcontroller unit (MCU) designed for advanced control applications such as solar inverters, industrial motor drives and digital power, electric cars and transportation, and sensor and signal processing. The Digital Power Software Development Kit (SDK) for C2000 MCUs and the Motor Control Software Development Kit (SDK) for C2000TM MCUs are available to accelerate application development. The F28379D features a revolutionary dual-core C28x architecture that dramatically improves system performance. In addition, the integrated analogue and control peripherals allow designers to unify control structures and eliminate the need for multiprocessors in high-end systems. The dual real-time control subsystems are based on TI's C28x 32-bit floating-point CPUs, which provide 200 MHz of signal processing performance per core. The new TMU accelerator, which enables fast execution of algorithms involving trigonometric operations prevalent in transform and torque loop calculations, and the VCU accelerator, which reduces the time required for complicated mathematical operations typical of encrypted applications, round out the C28x CPUs [82].

In [83] F28379D was used to demonstrate a stand-alone DC microgrid consisted of wind, hybrid photoelectrochemical and

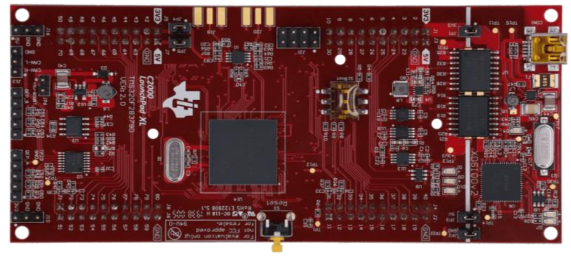

Fig. 15. TMS320F28379 board with different layout [82].

photovoltaic cell, fuel cell, battery, and supercapacitor system, in [84] An adaptive sliding mode controller technique for plug-in hybrid electric vehicles with a UC, a battery, and an integrated G2V charger was presented, and in [85] an HIL testbed using F28379 for microgrid protection considering non-standard curves was presented.

In recent years, model-based design (MBD) has evolved into a complete design flow from model generation to implementation, thanks to soft- ware modelling and simulation tools such as Simulink from The MathWorks. Model-based design is changing the way engineers and scientists work by moving design tasks from the lab and field to the desktop. The entire system can now be modelled, including the plant and the controller, allowing the engineer to fine-tune the controller's behaviour before it is used in the field. This reduces the possibility of damage, speeds up system integration and reduces reliance on equipment availability. Saving time and eliminating manual coding errors, once the control model is complete, the Simulink environment can automatically translate it into C and HDL code that is executed by the control system. To further reduce risk, the system model can be linked to a rapid prototyping environment to observe how the controller performs in real-world situations. Automatic code generation reduces time from concept to execution, reduces coding errors, and ensures consistency with models. Except for the PIC18F, ALL of the cards presented above could use SIMULINK for coding, therefore the three other cards are still the most commonly used as embedded software in the field of EV drives. Furthermore, because FPGAs and their software are so expensive, STM32 and TMS320F28379 are still recommended for EV drive control and other electronic systems.

5. CONCLUSION

The key electric motors used in EVs were compared in this research based on the EV propulsion system requirements. Furthermore, their control strategies are presented, and based on this review, we discovered that:

Electric vehicles frequently use brushed DC motors, BLDC, IM, PMSM, SRM, and SynRM drives. Each type of drive has unique characteristics in terms of cost, efficiency, power density, speed range, torque ripple, and dependability. Because of their dependability and recent developments in power regulation, researchers have discovered that induction motors and PMSM motors are excellent substitutes for electric vehicles.

Various strategies for controlling electric motors are discussed in this re- view in order to improve the motors' efficiency and address certain issues. when the FOC's simultaneous control of speed and torque is still more dependable and effective. Furthermore, compared to DTC method, it produces fewer noises and torque ripples.

The STM32 and DSP320F28379D are preferable to accomplish the implementation due to their high performance and huge memory what's more they enable the propriety of Model Based Design (MBD) that avoid coding error and maintain consistency with model.

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