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An Overview of the Development in Electric Motor Control Methods for Electric Cars

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Abstract : In recent decades, the global energy crisis and environmental contamination have escalated due to rising electricity consumption and the proliferation of fuel-dependent vehicles, which are major contributors to greenhouse gas emissions. Electric Vehicles (EVs) have emerged as a key solution to mitigate these challenges, offering a pathway to reduce both emissions and reliance on fossil fuels. This review examines the evolution and current state of electric motor control technologies, focusing on three primary techniques: Field-Oriented Control (FOC), Direct Torque Control (DTC), and Model Predictive Control (MPC). While FOC remains widely adopted due to its proven efficiency and smooth operation, recent advancements in MPC suggest potential for superior dynamic performance, albeit with increased computational complexity and time requirements. DTC, known for its simple design and rapid response, faces limitations such as torque ripple and variable switching frequency. Our analysis highlights that, although MPC offers promising advantages in control flexibility and accuracy, FOC continues to be the most practical choice for electric vehicle motor control systems due to its balance of performance, reliability, and ease of implementation. This review underscores the need for further research to optimize MPC and DTC techniques to fully realize their potential in EV applications, particularly in enhancing energy efficiency and extending component lifespan.

Key Words : Direct Torque Control, Electric Motor, Field-oriented Control, Motor Control, Model Predictive Control

— Nomenclature —

EV : Electric vehicles
FOC : Field-Oriented Control
DTC : Direct Torque Control
MPC : Model Predictive Control
Gt : Gigatons
DC : Direct current
HEV : Hybrid electric vehicles
PM : Permanent Magnet
PMSM : Permanent Magnet Synchronous Motors
IM : Induction motors
SRM : Switching reluctance motors
PMM : Permanent Magnet Motors
BLDCM : Brushless DC motor
HEM : Hybrid Excitation motor
DCM : Direct Current Motor
IPM : Interior Permanent Magnet
VVVF : Variable voltage-variable frequency
DSP : Digital signal processing

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SVPWM : space vector pulse width modulation
HE-AFPM : Hybrid-excitation axial flux switching permanent magnet motors
PID : Proportional Integral Derivative Controller
IGBT : Insulated-gate bipolar transistor
NMP : Nonlinear model prediction
ABS : Anti-lock braking system
ICEV : Internal Combustion Engine Vehicles

1. Introduction

In recent decades, environmental contamination and energy crises have emerged as critical global challenges. The rapid pace of scientific and technological innovation, coupled with economic growth and increasing global population, has led to a dramatic rise in worldwide electricity consumption. In 2019, global electricity usage was estimated at 23,000 Terawatt hours, with projections indicating an annual increase of 2.5% until 2040, when it is expected to surpass 39,000 Terawatt hours.[1)] This surge in electricity demand has exacerbated the global energy crisis. Simultaneously, the growing demand for automobiles has contributed significantly to environmental degradation. Fuel-dependent vehicles emit large quantities of greenhouse gases, such as carbon dioxide (CO_2) and nitrogen oxides, which have severe negative impacts on both human health and the environment.[2)] Projections suggest that CO_2 emissions will increase by approximately six percent over the next 25 years, reaching a total of 35 Gigatons (Gt).[1)] Between 2004 and 2007, the transportation sector accounted for 23~26% of global greenhouse gas emissions, with 74% of CO_2 pollution attributed to vehicles on public roads(3-4). Even during the pandemic restrictions in 2021, the transportation sector was responsible for nearly 7.7 Gt of CO_2 emissions, representing 37% of global emissions.[5)] Passenger vehicles alone contributed 41% of transportation- related pollution, making them the primary source of greenhouse gases in this sector.[6)] Despite stricter emission standards, such as the Euro 6 norm, which mandates significant reductions in greenhouse gas emissions from conventional vehicles, environmental pollution continues to pose significant health and economic risks.[7,8)] To mitigate long-term damage, the United Nations has set ambitious targets and deadlines for countries to reduce their carbon dioxide emissions.[9,10)] Additionally, the continued reliance on fossil fuels in Internal Combustion Engine Vehicles (ICEVs) risks depleting global reserves of petroleum and coal.[11)]

In response to these challenges, research and development efforts have increasingly focused on Eelectric Vehicles (EVs) due to their potential to reduce greenhouse gas emissions and conserve fossil fuels.[12)] EVs have become a central component in the transition to more sustainable transportation solutions.[11-13)] Advanced EVs incorporate numerous mechanical and electrical design innovations that enhance their performance and efficiency. As electric vehicle technology has progressed, various electrical components have been developed to optimize the motorization of EVs.[9,14)] One of the most critical aspects of EV design is the electric motor control system, which plays a pivotal role in ensuring driving safety, operational efficiency, and overall vehicle comfort. The ongoing development and refinement of these control systems are essential for the continued advancement of EV technology.[11)]

Initially, electric vehicle systems primarily relied on Direct Current (DC) motors due to their simplicity in integration and operation. However, DC motors are no longer sufficient to meet the high efficiency and performance requirements of modern EVs.[11)] Hybrid Electric Vehicles (HEVs) and fully electric vehicles now predominantly use Permanent Magnet (PM) motors with three-phase induction, supported by advancements in power electronics.[1,15)]

The two most common types of electric motors used in EVs are Permanent Magnet Synchronous Motors (PMSMs) and Induction Motors (IMs). These motors often require complex control systems, such as Direct Torque Control (DTC) and vector control, to meet the stringent power and speed specifications of automotive applications.[11] PMSMs are known for their high efficiency and energy concentration, while IMs are valued for their reliability and cost-effectiveness. Both motor types offer excellent control capabilities, making them suitable for EV applications.[16]

This review focuses on three primary electric motor control techniques: Model Predictive Control (MPC), Field-Oriented Control (FOC), and Direct Torque Control (DTC). These methods are widely used in the control of EV motors and represent the state-of-the-art in motor management technology. FOC is the most commonly employed technique due to its well-established efficiency and smooth performance in controlling electric car motors.[17] However, recent research has highlighted the potential of MPC as a superior control strategy, offering advanced dynamic response and control accuracy, although it is more computationally demanding.[11] DTC, traditionally known for its simple design and rapid response, has undergone improvements to address its suitability for EV applications, particularly in reducing torque ripple and enhancing overall performance. This review thoroughly examines the strengths and limitations of FOC, MPC, and DTC, considering the challenges of implementing these techniques on digital processors, such as discretization, fault detection, and normalization. The findings of this review are expected to inform future research and development efforts aimed at optimizing industrial motor controllers for enhanced EV performance.

The subject of this research is the evaluation and comparison of three prominent electric motor control techniques-Field-Oriented Control (FOC), Direct Torque Control (DTC), and Model Predictive Control (MPC)-as they are applied in the context of Electric Vehicles (EVs). The purpose of the study is to assess the effectiveness, efficiency, and suitability of these control methods in enhancing EV motor performance, with a focus on addressing the challenges posed by modern electric vehicle technology, such as the need for higher efficiency, better dynamic response, and reduced environmental impact. The research method involves a comprehensive review of existing literature, analysis of the latest advancements in motor control systems, and a detailed comparison of these techniques based on their performance, implementation complexity, and potential for future development. This review aims to provide insights that will guide future research and innovation in the field of electric motor control, ultimately contributing to the advancement of sustainable transportation technologies.

2. Classification & Features of Electric Vehicle Traction Motor

The primary traction motors found in EVs are Switching Reluctance Motors (SRMs), Permanent

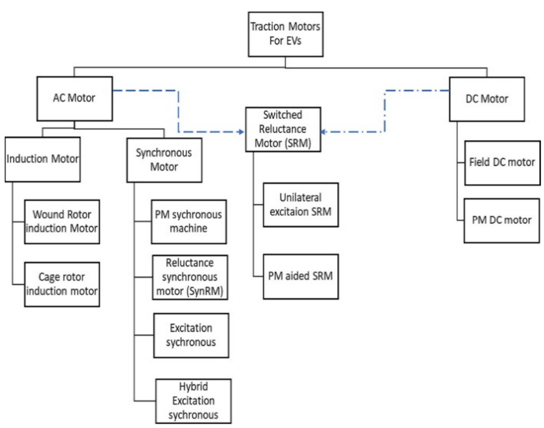

Fig. 1 EV electric motors are classified according to their power source[19]

Magnet Motors (PMMs), IMs and Direct Current Motors (DCMs). PMM is further subdivided into MDC Motor (PM-DCM), PMSM, PM Brushless DC Motor (PM-BLDCM) and PM Hybrid Excitation Motor (PM-HEM).[18] A variety of motor types are available as a workable alternative; they may be broadly categorized as AC, DC, and Switched Reluctance Motors (SRM), as seen in Fig. 1.[19]

2.1 Direct Current Motor

Due to its flexible speed regulation, throughout the end of the eighteenth century, EVs have used DCM as their traction motor. However, DCMs are no longer appropriate for high-speed EVs because to their low efficiency, huge bulk, and poor reliability caused by brushes and commutators. They are exclusively utilized in low-speed EVs, including shuttle buses in picturesque locations and carts for carrying logistical material within factories.[18,20]

2.2 Switch Reluctance Motor

A salient pole structure is used, and silicon steel laminates make up the SRM stator and rotor. The stator only has basic focused windings placed, while the rotor has no windings, PMs, or slip rings. The rotor structure makes it possible for SRMs to operate simply, robustly, affordably, and quickly. Furthermore, the dependable topological structure of the inverter shields it against short-circuit failures.[18-21] Simple control and high efficiency are two benefits of SRMs. However, there are significant barriers to its use in EVs, including torque fluctuation, noise, and vibration.

2.3 Induction Motor

In EVs, squirrel-cage designed IMs are frequently adopted. Their rotors as well as stators are comprised of mounted silicon steel sheets, and their rotor slots have copper or aluminum bars with rings at both ends. 3 phase the coils are installed into the stator's coating stack. IMs are known for their robust, straightforward construction, low cost, excellent dependability, minimal noise, low torque ripple, and lack of maintenance. IMs have a broad constant power range and may be operated at high speeds exceeding 15,000 rpm with ease. But because of their more complicated control circuit and poorer The density of power as well as effectiveness when compared to PMSMs, IMs have a declining global market share.[18,22]

2.4 Permanent Magnet Motor

2.4.1 Permanent Magnet Direct Current Motor

A PM-DCM is created when the magnetic poles and field windings of traditional DCMs are swapped out for PMs. PM-DCMs have better power density and efficiency, but because of the commutator and brush system, these exhibit a shorter lifespan, fluctuate torque, and demand more frequent upkeep. These issues still need to be resolved for EV applications.[23-25]

2.4.2 Permanent Magnet Synchronous Motor

In PMSMs, PMs take the place of the traditional synchronous motor's stimulation winding, whose three-phase winding stator is identical to or comparable to that of an synchronous motor stator or IM. PMSMs are classified as either Interior Permanent Magnet (IPM) or surface-mounted PMSM (SPM) depending on in which the PMs are situated on or in the rotor. Low heat, High reluctance torque, good power factor, high efficiency, a straightforward construction, a compact size, and low noise are characteristics of well-designed IPMs. IPMs have taken center stage in traction motor applications as a result of the advancement of power electronics control strategies. IPMs also exhibit minimal wind friction losses and low wind noise because of their totally enclosed construction, which eliminates the need for maintenance,[23,25] The

Interior Permanent Magnet (IPM) motor control method is optimal due to its high efficiency, superior torque production, and wide operating speed range. IPM motors feature embedded magnets within the rotor, which enhance their power density and thermal management. This design allows for efficient operation across a broad speed range, making IPM motors particularly suitable for Electric Vehicles (EVs) where both low-speed torque and high-speed efficiency are critical.

Recent studies highlight IPM motors' ability to operate effectively in the field-weakening region, which extends their speed range without significant efficiency loss.[38] Additionally, advanced control techniques, such as Field-Oriented Control (FOC), optimize the motor's performance by providing precise torque control and minimizing losses, leading to smoother operation and improved energy efficiency.[39]

Moreover, IPM motors exhibit reduced torque ripple and lower acoustic noise, enhancing the driving experience in EVs.[40] Despite higher initial costs, the long-term benefits of reduced energy consumption and maintenance costs make IPM motors a cost-effective solution for EV applications.[41]

2.4.3 Permanent Magnet Brushless DC Motor

In terms of structure and theory, PM-BLDCM is a unique PMSM; nevertheless, unlike SPM, its stator current waveform is trapezoidal and its windings are regularly focused. The brush-commutator mechanism is not necessary. Nevertheless, during electrical commutation, noise and torque ripple emerge, and exceeding twice the base speed is difficult to reach at maximum speed.[18,21] The development of Permanent Magnet (PM) materials and semiconductor technology has led to the adoption of PMBLDC motors in a number of applications requiring accurate speed and position control.[26]

2.4.4 Permanent Magnet Hybrid Excitation Motor

A PMSM motor could transform into a PM-HEM, or hybrid excited motor, by adding windings for excitation. This results in the motor having PMs and excitation windings in association. This motor has excellent torque-speed characteristics, little flux releases, elevated concentration of flux within the void, and high power density. However, because there are two independent excitations, its topology and control are quite complicated.[25]

The hybrid excitation can be supplemented by permanent magnetic elements to lower the field current and hence lower losses and the associated cooling. Permanent magnets can enhance the machine's compact size. This is particularly crucial in situations when weight and size are crucial, such in wind power and electric cars.[27] Table 1 displays the motors mentioned before and their particular achievements evaluation. For EV traction motors, PMSM, to be more specific, interior embedded type (IPM) is the optimum option.[18,25]

Table 1 Comparing Traction Motors for Electric Vehicles.[18,25]

Index	DCM	IM	IPM	SRM
Efficiency	Low	Medium	High	Low
Speed	Low	High	Medium	High
Performance	Low	Medium	High	Medium
Size	Low	Medium	High	Medium
Control simplicity	High	Medium	Low	Medium
Reliability	Low	Medium	High	High

3. Technologies For Motor Control

The three methods that make up the Variable Voltage-Variable Frequency (VVVF) control technique are as follows: DTC, FOC, and MPC, which basically is an open-loop kind of control founded

Table 2 Comparing Traction Motors for Electric Vehicles[18,25]

Comparison	FOC	DTC	MPC
Speed Estimation	Encoder output	Encoder output	Encoder output
Speed Controller	PI	PI	Cost function definition
Flux-linkage Estimation	N/A	abc-αβ transfor-mation	abc-dq transfor-mation
Flux-linkage Controller	N/A	Hysteresis controller	Cost function definition
Current/ Torque Estimation	abc-dq transfor-mation	Calculation from flux-linkage and currents	abc-dq transfor-mation
Current/ Torque Controller	PI	Hysteresis controller	Cost function definition
Inverter Control	PWM	Look-up table	Cost function definition

on motor designs for stable states. The last two, which are founded on dynamic motormodels, are close-loop varieties. Table 2 displays a differing all three methods of motor control.[12)]

3.1 FOC

Blaschke suggested FOC in the 1970s. In the particular dq0 coordinate system, According to the continuous rotor flux, the stator energy was divided into the torque element and magnetized. As a result, the control of Alternating Current (AC) motors may be compared to the inactive DC motor. FOC may provide a wide speed range, low torque ripple, and smooth beginning, making it ideal for machinery with a high dynamic response in demanding operating environments successfully reduced. An improved uncertainty and disturbance estimator was used to suggest a flux-weakening control technique. To eliminate the ripple of torque at motor cornering speed, a flux weakening adjustment factor is included.[18)] As a result, the robustness in the flux-weakening zone is improved.

The secret to a successful FOC aims to put up

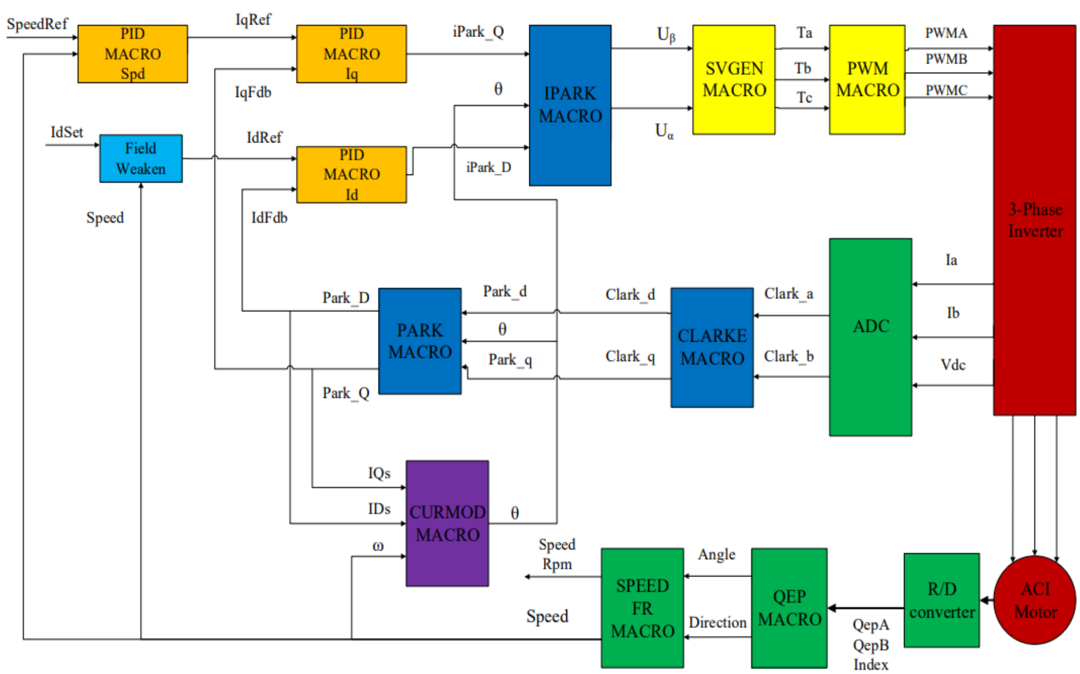

Fig. 2 AC Induction Motor Scheme of FOC[12,29)]

an engine dynamic simulation using two-phase spinning coordinates, which lays the groundwork for strong dynamic responsiveness even.[18,23)]

The motor speed-torque-current visualization is used to suggest a vector control approach.[28)] The vehicle's driving range was increased while Energy requirement and usage of energy were under challenging operating circumstances. The fundamental layout of the FOC for Alternating Current induction motors is seen in Fig. 2. A portion of the function blocks are created by consulting the TI library's modules. These function blocks are easy to employ in other systems since they may be updated and new features added individually. Each of these function blocks is evaluated individually when implementing the algorithm on an electronic controller such as a DSP. Group tests are conducted on the block performances to ensure that all of these functions can cooperate as needed. The Park macro performs the Park transformation, and the iPark macro does the inverse Park transformation in the scheme as Fig. 3 illustrates. SVPWM and the inverse Clark transformation are handled by the SVGEN macro. The Clark transformation is performed by the Clarke macro.[12,29)]

3.2 MPC

MPC has a quick dynamic reaction and a straightforward design. Every sampling instant, it solves an optimum control issue of an open loop in the finite-time domain. This control technique is dependent on the motor model parameters and is thus complex.[12)] Because of its simple implementation, ability to include nonlinear constraints with ease, and quick dynamic response, maximum percentage correction, MPC is thought to be a very good nonlinear controller solution.[30,31)] In contrast to the DTC, the MPC minimizes the error between the anticipated and reference values in order to choose the best voltage vector. Through the use of the

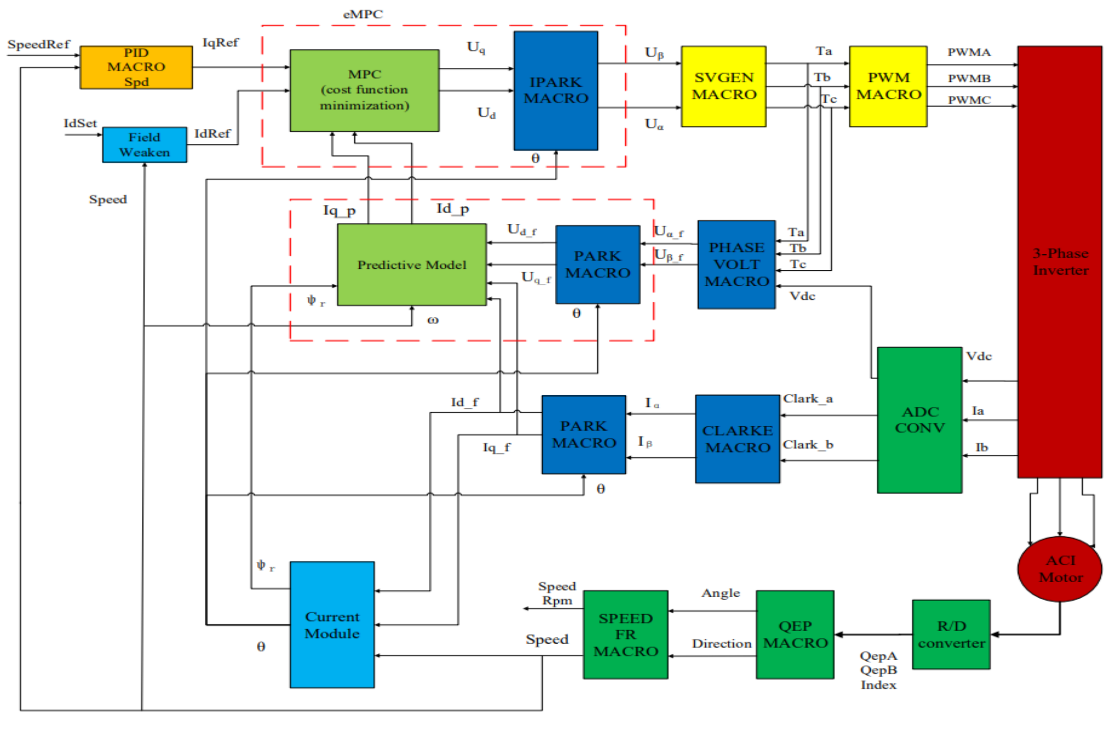

Fig. 3 Design of a digital controller based on MPC[12)]

finite control set MPC in[32] the MPC outperforms the DTC in terms of accuracy and efficiency.

Potential benefits of the MPC include its capacity to save energy and adapt to a range of operational environments. It also offers the concepts and methods for Hybrid-excitation axial flux switching permanent magnet motors (HE-AFPM) motor control.[32] Two key components are required for MPC theory to work: a model of the process that needs to be regulated and an appropriate cost function that has to be minimized. Taking into account the PMSM current-reference tracking issue, MPC use the motor model to calculate ideal voltage inputs for a finite receding horizon period in the future.[30]

The fundamental MPC design for AC induction motors is shown in Fig. 3. In order to compare the efficacy of FOC and MPC, the MPC is utilized in a coordinated rotating frame. The MPC model has two references as inputs: stator current references, I_{dRef} and I_{qRef}. The model outputs are the stator voltages in stationary frames U_{α} and U_{β}. In this design, the red rectangle represents the inverse Park transformation and the Park transformation, which are employed since the state vector is in a rotating frame. In the current module, the flux linkage is computed and the phase voltages are also measured in comparison to Fig. 2.[12]

3.3 DTC

Depenbrock proposed the DTC, which eliminates the existing loop in the FOC system and eliminates the need for a complicated coordinate translation. In a two-phase static coordinate, PWM modulation signals are produced using the two-bit bang bang control. DTC is appropriate for applications needing wide speed regulation and quick dynamic response because of its excellent resilience, low susceptibility to parameter perturbations, and simple construction. However, it also has drawbacks, such as the need for a high sample frequency and ripples in torque and current at low speeds. To lessen these ripples, several researchers combine DTC and space vector pulse width modulation (SVPWM).[33]

It was suggested to use the harmonic voltage elimination (HVEM) and quadratic estimation technique (QEM) to create an enhanced control approach. After obtaining the final voltage vector that suppressed the stator's harmonic current, the quick dynamic response and solid stable performance remained unaltered. It was suggested to implement a unique multi-machine resilient DTC approach based on the Nonlinear Model Prediction (NMP) technique.[34] It was able to accomplish improved driving performance and vehicle stability as well as the four-wheel PMSMs' Anti-lock Braking System (ABS) and Acceleration Slip Regulation (ASR) features.

For an IPM of EV, a Fuzzy Model Predictive DTC (FMP-DTC) technique is suggested.[35] The ideal switch state selection no longer needed adjusting the weighting factor. Accurate speed monitoring, a little torque ripple, and an immediate torque response were attained. A dual-space vector PWM control system served as the foundation for a voltage vector allocation strategy that was put forth.[36]

The two inverters' switching frequencies could be balanced and decreased, and the greatest amount of power-sharing could be achieved, by choosing the most suitable mode. Despite its simplicity, DTC control offers great dynamic and static performance. It is restricted in its ability to raise the inverter switching frequency, though. Further measurements to restrict currents are required because there is no current loop and current protection should be applied immediately. At low speeds, the "dead-time effect" is also noticeable, and a change in stator resistance will cause distortions in stator current and flux linkage.[18] Fig. 4 below shows the overall layout of a typical DTC applied to a doubly fed induction motor.

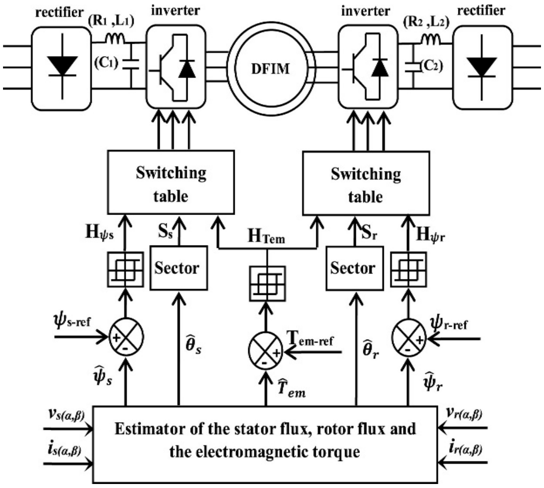

Fig. 4 An overview of the traditional DTC[37]

4. Conclusions

The present status of the FOC, DTC, and MPC development control technologies is comprehensively reviewed. DTC was initially proposed for induction motor drives and then expanded to various types of three-phase AC machines and converters. DTC, unlike FOC, does not need the usage of current control or the SVM block. It determines the most appropriate voltage vector from a specified switching table based on the location of the stator flux and the error signs of torque and stator flux. DTC achieves a very rapid dynamic reaction thanks to its basic construction. The primary disadvantages of DTC are large torque ripples in steady state and variable switching frequency. Furthermore, low speed operation is generally caused by DTC.[38]

Based on these, it appears that MPC is not much superior to the FOC technique for a motor control system. It is important to note that a FOC with this level of performance is the result of extensive PID parameter tweaking, whereas MPC tuning requires less time. The 12 basic vectors FOC has a torque ripple of ±3% within rated power, which is excellent compared to other induction motor vector controllers in use today. Because of its adaptability to various induction motor types, this motor controller has a broad range of applications in electric car technology.[39]

The MPC optimization in studies reviewed, uses 12 voltage vectors, which results in good performance but significant time consumption. A greater control frequency can be used to improve the MPC's performance. On the other hand, it will increase the IGBT switching frequency. A compromise regarding the control frequency must be made in order to extend the IGBT's service life. For the electrical motor management systems of electric automobiles, MPC is a substitute control method for FOC.[41]

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Author contributions

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References

1. V. Boglou, C. Karavas, A. Karlis and K. Arvanitis, 2021, “An Intelligent Decentralized Energy Management Strategy for the Optimal Electric Vehicles’ Charging in Low-Voltage Islanded Microgrids”, International Journal of Energy Research, 46, 2988-3016. (https://doi.org/10.1002/er.7358)
2. Z. Li, A. Khajepour and J. Song, 2019, “A Comprehensive Review of the Key Technologies for Pure Electric Vehicles”, Energy, 182, 824-839. (https://doi.org/10.1016/j.energy.2019.06.077)
3. A. Karki, S. Phuyal, D. Tuladhar, S. Basnet and B. P. Shrestha, 2020, “Status of Pure Electric Vehicle Power Train Technology and Future Prospects”, Applied System Innovation, 3(35), 1-12. (https://doi.org/10.3390/asi3030035)
4. L. Chapman, 2007, “Transport and Climate Change: A Review”, Journal of Transport Geography, 15, 354-367. (https://doi.org/10.1016/j.jtrangeo.2006.11.008)
5. IEA,“Transport”, Available online: https://www.iea.org/topics/transport (accessed on 20 November 2022).
6. I. Tiseo, 2020, “Breakdown of CO_2 Emissions in the Transportation Sector Worldwide, by Subsector”, Available online: https://www. statista.com/statistics/1185535/transport-carbon-dioxide-emissions-breakdown / (accessed on 2 May 2022).
7. V. Rievaj, J. Gaňa and F. Synák, 2019, “Comparison of Emissions Depending on the Type of Vehicle Engine”, Logistics and Sustainable Transport, 10, 45-74. (https://doi.org/10.2478/jlst-2019-0005)
8. F. Synák, M. Kučera and T. Skrúcaný, 2020,“Accessing the Energy Efficiency of an Electric Car”, Communications - Scientific Letters of the University of Zilina, 23, 1-13. (https://doi.org/10.26552/com.C.2021.1.A1-A13)
9. U. R. Chinthakunta, K. K. Prabhakar, A. K. Singh and P. Kumar, 2019, “Direct Torque Control Induction Motor Drive Performance Evaluation Based on Torque Error Status Selection Methods”, IET Electrical Systems in Transportation, 9(3), 113-127. (https://doi.org/10.1049/iet-est.2018.5005)
10. D. Ranawat and M. P. R. Prasad, 2018, “A Review on Electric Vehicles with Perspective of Battery Management System”, In Proceedings of the 3rd International Conference on Electrical, Electronics, Communication, Computer Technologies and Optimization Techniques (ICEEECCOT), 14-15 (DOI:10.1109/ICEEECCOT43722.2018.9001321)
11. M. L. D. Klerk and A. K. Saha, 2021, “A Comprehensive Review of Advanced Traction Motor Control Techniques Suitable for Electric Vehicle Applications”, IEEE, 9, 125080-125108. (https://doi.org/10.1109/ACCESS.2021.3110736)
12. X. Men, Y. Guo, G. Wu, S. Chen and C. Shi, 2022, “Implementation of an Improved Motor Control for Electric Vehicles”, Energies, 15(4833), 1-12. (https://doi.org/10.3390/en15134833)
13. J. J. Makrygiorgou and A. T. Alexandridis, 2019, “Power Electronic Control Design for Stable EV Motor and Battery Operation During a Route”, Energies, 12(1990), 1-17. (https://doi.org/10.3390/en12101990)
14. K. K. Prabhakar, C. U. Reddy, P. Kumar and A. K. Singh, 2020, “A New Reference Flux Linkage Selection Technique for Efficiency Improvement of Direct Torque Controlled IM Drive”, IEEE Journal of Emerging and Selected Topics in Power Electronics, 8(4), 3751-3762. (https://doi.org/10.1109/JESTPE.2020.2979235)
15. L. Shao, A. E. H. Karci, D. Tavernini, A. Sorniotti and M. Cheng, 2020, “Design Approaches

and Control Strategies for Energy-Efficient Electric Machines for Electric Vehicles-A Review", IEEE Access, 8, 116900-116913. (https://doi.org/10.1109/JESTPE.2020.2979235)

16. X. Men, G. Wu, Y. Guo, C. Shi and J. Zhu, 2017, "Implementation of a Motor Control System for Electric Bus Based on DSP", In Proceedings of the 2017 20th International Conference on Electrical Machines and Systems (ICEMS), 1-6. (https://doi.org/10.1109/ICEMS.2017.8056504)
17. X. Men, G. Wu, Y. Guo, Z. Zhu and J. Gao, 2019, "Development of an Advanced Motor Control System for Electric Vehicles", SAE Technical Papers, SAE International, Detroit, MI, USA. (https://doi.org/10.4271/2019-01-0597)
18. W. Cai, X. Wu, M. Zhou, Y. Liang and Y. Wang, 2021, "Review and Development of Electric Motor Systems and Electric Powertrains for New Energy Vehicles", Automotive Innovation, 4, 127-138. (https://doi.org/10.1007/s42154-021-00139-z)
19. M. Gobbi, A. Sattar, R. Palazzetti and G. Mastinu, 2024, "Traction Motors for Electric Vehicles: Maximization of Mechanical Efficiency-A Review", Applied Energy, 357, 129854. (https://doi.org/10.1016/j.apenergy.2023.122496)
20. S. Wang and C. Deng, 2006, "Research on Electric Motor Technologies for Electric Vehicles", Micro Motor (Servo Technology in Chinese), 39, 83-85.
21. Z. Yang, F. Shang, I. P. Brown and M. Krishnamurthy, 2015, "Comparative Study of Interior Permanent Magnet, Induction, and Switched Reluctance Motor Drives for EV and HEV Applications", IEEE Transactions on Transportation Electrification, 3, 245-254. (https://doi.org/10.1109/TTE.2015.2470092)
22. P. Uglielmi, 2012, "Comparison of Induction and PM Synchronous Motor Drives for EV Application Including Design Examples", IEEE Transactions on Industry Applications, 48, 2322-2332. (https://doi.org/10.1109/TIA.2012.2227092)
23. X. Zhu, M. Jiang, Z. Xiang, L. Quan, W. Hua and M. Cheng, 2020, "Design and Optimization of a Flux-Modulated Permanent Magnet Motor Based on an Airgap-Harmonic- Orientated Design Methodology", IEEE Transactions on Industrial Electronics, 67, 5337-5348. (https://doi.org/10.1109/TIE.2019.2934063)
24. D. Rimpas, S. D. Kaminaris, D. D. Piromalis, G. Vokas, K. G. Arvanitis and C. S. Karavas, 2023, "Comparative Review of Motor Technologies for Electric Vehicles Powered by a Hybrid Energy Storage System Based on Multi-Criteria Analysis", Energies, 16(6), 2555, 1-25. (https://doi.org/10.3390/en16062555)
25. M. Zeraoulia, M. E. H. Benbouzid and D. Diallo, 2006, "Electric Motor Drive Selection Issues for HEV Propulsion Systems: A Comparative Study", IEEE Transactions on Vehicular Technology, 55, 1756-1764. (https://doi.org/10.1109/TVT.2006.878719)
26. T. H. Panchal, A. N. Patel and R. M. Patel, 2022, "Reduction of Cogging Torque of Radial Flux Permanent Magnet Brushless DC Motor by Magnet Shifting Technique", Electrical Engineering and Electromechanics, 1-8. (https://doi.org/10.20998/2074-272X.2022.3.03)
27. G. Mörée and M. Leijon, 2022, "Overview of Hybrid Excitation in Electrical Machines", Energies, 15(5671), 1-20. (https://doi.org/10.3390/en15197254)
28. L. Gu, H. L. Zhang and Z. Wang, 2019, "An Improved UDE-Based Flux-Weakening Control Strategy for IPMSM", Energies, 12(4077), 1-17. (https://doi.org/10.3390/en12214077)
29. A. Favato, P.G. Carlet, F. Toso, R. Torchio and

S. Bolognani, 2021, "Integral Model Predictive Current Control for Synchronous Motor Drives", IEEE Transactions on Power Electronics, 36(11), 13293-13303. (https://doi.org/10.1109/TPEL.2021.3081827)

30. Y. Zhang, J. Jin and L. Huang, 2021, "Model-Free Predictive Current Control of PMSM Drives Based on Extended State Observer Using Ultra-Local Model", IEEE Transactions on Industrial Electronics, 68, 993-1003. (https://doi.org/10.1109/TIE.2020.2970660)
31. J. Gao, C. Gong, W. Li and J. Liu, 2020, "Novel Compensation Strategy for Calculation Delay of Finite Control Set Model Predictive Current Control in PMSM", IEEE Transactions on Industrial Electronics, 67, 5816-5819. (https://doi.org/10.1109/TIE.2019.2934060)
32. G. Li, J. Hu, Y. Li and J. G. Zhu, 2018, "An Improved Model Predictive Direct Torque Control Strategy for Reducing Harmonic Currents and Torque Ripples of Five Phase Permanent Magnet Synchronous Motors", IEEE Transactions on Industrial Electronics, 66, 5820-5829. (https://doi.org/10.1109/TIE.2018.2870359)
33. M. H. Sekour, K. Hartani and A. Merah, 2017, "Electric Vehicle Longitudinal Stability Control Based on a New Multimachine Nonlinear Model Predictive Direct Torque Control", Journal of Advanced Transportation, 2017, 1-19. (https://doi.org/10.1155/2017/7192024)
34. J. J. Justo, F. Mwasilu, E. Kim, J. Kim, H. H. Choi and J. Jung, 2017, "Fuzzy Model Predictive Direct Torque Control of IPMSMs for Electric Vehicle Applications", IEEE/ASME Transactions on Mechatronics, 22, 1542-1553. (https://doi.org/10.1109/TMECH.2017.2665670)
35. Y. Jia, N. Xu, L. Chu, L. Zhang, D. Zhao, Y. Li and Z. Yang, 2018, "Power Flow Control Strategy Based on the Voltage Vector Distribution for a Dual Power Electric Vehicle with an Open-End Winding Motor Drive System", IEEE Access, 6, 54910-54926. (https://doi.org/10.1109/ACCESS.2018.2872697)
36. N. E. Ouanjli, S. Motahhir, A. Derouich, A. E. Ghzizal, A. Chebabhi and M. Taoussi, 2019, "Improved DTC Strategy of Doubly Fed Induction Motor Using Fuzzy Logic Controller", Energy Reports, 5, 271-279. (https://doi.org/10.1016/j.egyr.2019.02.001)
37. J. Goss, M. Popescu, D. Staton, R. Wrobel, J. Yon and P. Mellor, 2014, "A Comparison between Maximum Torque/Ampere and Maximum Efficiency Control Strategies in IPM Synchronous Machines", 2014 IEEE Energy Conversion Congress and Exposition (ECCE), 2403-2410. (https://doi.org/10.1109/ECCE.2014.6953560)
38. G. Pellegrino, E. Armando and P. Guglielmi, 2007, "Field Oriented Control of IPM Drives for Optimal Constant Power Operation", 2007 European Conference on Power Electronics and Applications, 1-10. (https://doi.org/10.1109/EPE.2007.4417644)
39. S. Hwang, H. Lee, and Y. Jeung, 2006, "Influence of Magnetic Force upon Noise of IPM Motor Used in Compressor", 2006 IEEE International Magnetics Conference (INTERMAG), 315-315. (https://doi.org/10.1109/INTMAG.2006.375897)
40. J. Massiani, 2015, "Cost-Benefit Analysis of Policies for the Development of Electric Vehicles in Germany: Methods and Results", Transport Policy, 38, 19-26. (https://doi.org/10.1016/j.tranpol.2014.10.005)