A Comprehensive Review of Low-Cost FOC Implementation

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Abstract - As the global transition towards green energy and sustainability mobility accelerates, the demand of the high performance cost effective and high efficiency EV traction control system demand is high. The Field oriented control widely used and which provides smoother performance and higher efficiency makes them ideal for the EVs, implementing FOC in low cost vehicles, makes challenge as the FOC requires high precision sensors. This paper provides a review of the EV traction, various motor types (PMSM, BLDC, IM), and the electronic switching topologies used in controllers. Finally, it also identifies research gaps in position estimation and current reconstruction, proposing a software-based framework for future development.on the low cost stm32 platform.

Key Words: FOC, STM32, Electric Vehicles, Single-Shunt Reconstruction, Hall-Sensor Interpolation, PMSM, BLDC

1.INTRODUCTION

The Automobile industry is now shifting toward green energy as replacing the petrol and diesel engines to the electrical vehicles (EV's). The sale of these vehicles increased rapidly, specifically in two and three wheelers. To ensure the smoother performance as the traditional vehicle the controller should operative effectively

Earlier, most of the controllers used six-step commutation. It is simple but performance is not that much smoother. Today, higher efficiency and better performance is the need of the industry. This results the FOC control techniques is becoming very famous where FOC provides independent control of motor torque and flux which make performance smoother

However, FOC usually requires costly sensors such as high-resolution encoders and three current sensors for accurate phase current sensing. This leads to increasing system costs. So there is a need for development of smart algorithms using the lower cost hardware to achieve similar performance keeping cost low.

2.ELECTRIC VEHICLE ARCHITECTURE

An EV Power train is the replacement of the traditional mechanical powertrain system into the electrical. The efficiency of the vehicle is dependent on the how controller drives not only the battery pack itself

2.1 Main Power Flow

The Ev Traction system mainly includes battery pack, motor Motor controller, VCU , wiring harness and the safety sensors.

The Motor Controller converts the DC voltage into the Three phase AC voltage for the motor operation while keeping the control on the torque and speed.

2.2 Regenerative Braking

A best advantage of the EV traction system is the ability to recover the energy. During the deceleration the algorithm can shift the motor into the forth quadrant mode operation. Which makes the motor behave like the generator and the inverter redirect the generated current back into the battery pack. This process is called regenerative braking.

These can extend the overall range of the vehicle by 10-15% with ideal loading condition.

3.TRACTION MOTOR TOPOLOGIES

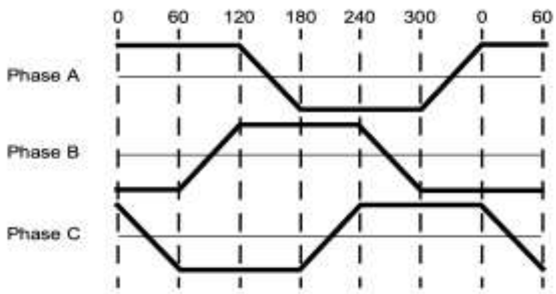
The selection of correct motor reduces the complexity of control method

3.1 Induction and Reluctance Motors

Induction motors are mainly known for their ruggedness and lack of rare earth magnets which makes them environmentally sustainable. Nowadays the switched reluctance motor is also becoming an interesting research topic. But controlling them is more complex, as they exhibit high acoustic noise. To operate them smoothly requires complex torque sharing functions.

3.2 Brushless DC Motors (BLDC)

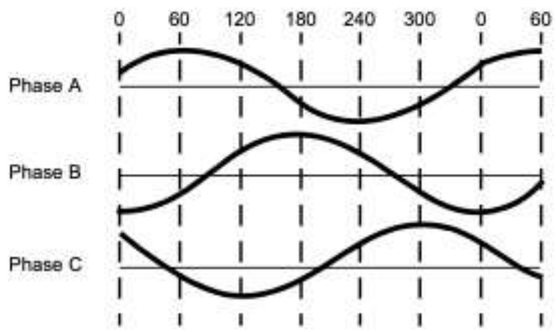
These motors are commonly used in the low cost ebikes, they are similar to the PMSM motors in terms of construction. These motors are designed with trapezoidal Back-EMF, and controlled with hall sensor feedback. Due to the trapezoidal Back-EMF control of these motor quite difficult it produces the high torque ripples which is common problem in low cost Evs



3.3 Permanent Magnet Synchronous Motors

The PMSM motor has the permanent magnets on the rotor. These motors are very efficient in performance and they are able to operate near to the 95% efficiency. These motors are designed with sinusoidal Back-EMF.

As the magnets are placed,the magnetic flux is already present in the rotor so only the stator we current we have to control to generate the required torque. To achieve the proper control of the motor rotor position information is required properly



4. CONTROLLER TOPOLOGY AND SWITCHING

The hardware component between the motor controller and the motor is the three-phase Voltage Source Inverter.

4.1 Two-Level Inverter Topology

The Basic inverters have six power mosfets for low voltage applications , and IGBTs for the higher. They were arranged in such a manner that they formed three legs. While switching them the controller ensures that the high side and low side switch should never be on to prevent the short circuit during the switching. This method is also called a six step control switching where only two switches are operated.

The table shows the switching sequence based on the hall sensor position.

Hall State	AH	AL	BH	BL	CH	CL
100	0	0	1	0	0	1
110	0	1	1	0	0	0
010	0	1	0	0	0	0
011	0	0	0	1	1	0
001	1	0	0	1	1	0
101	1	0	0	0	0	1

4.2 Space Vector PWM (SVPWM)

This technique uses switching of three pairs of switches, and forms eight vector states of switching (six Active two null). This method allows the 15.5% better utilization of input DC voltage which results in a rotary controller that can rotate the motor to higher speed on the same battery voltage.

The controller generates pulse-width modulation signals for the three-phase motor voltage signals. By using SVM, the process of generating the pulse width for each of the three phases reduces to few simple equations where

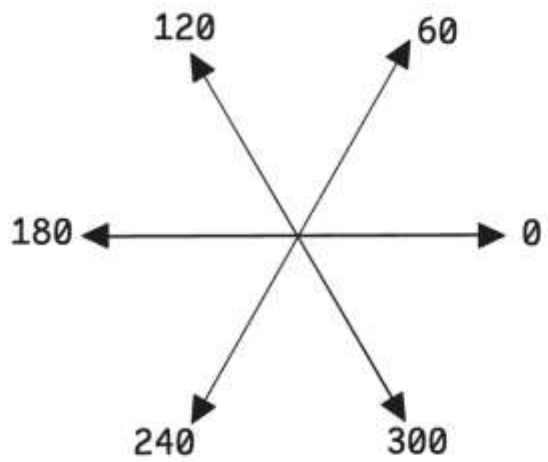


Fig :The Basic Space Vectors

Table shows On/Off States and Corresponding Outputs of Inverter

a	b	c	Va	Vb	Vc	Vab	Vbc	Vca
0	0	0	0	0	0	0	0	0
1	0	0	2/3	-1/3	-1/3	1	0	-1
1	1	0	1/3	1/3	-2/3	0	1	-1
0	1	0	-1/3	2/3	-1/3	-1	1	0
0		1	-2/3	1/3	1/3	-1	0	1
0	0	1	-1/3	-1/3	2/3	0	-1	1
1	0	1	1/3	-2/3	1/3	1	-1	0
1	1	1	0	0	0	0	0	0

5. LIMITATIONS AND RESEARCH GAPS

Based on the survey there are three primary limitations which makes it difficult to use FOC in low-cost systems.

5.1 The Hall-Sensor Quantization Problem

The low EV motor uses Three hall sensors which provides a fixed resolution of each 60° step. The FOC requires the electrical angle of 0.1° resolution for the Frame transformations. The use of hall signals creates a staircase waveform of angles which results in noise and inefficiency.

5.2 Single-Shunt Observability Gaps

For the cost reduction the controller designer uses a single shunt in input DC link instead of three phase current sensing. During the low speed operation or operating at higher modulation the time window for the current sampling becomes very small which creates a dead zone while current sampling and controller does not get the correct motor current.

5.3 Computational Constraints on STM32

The controller operates over the Higher (20khz) switching frequency, and executing the transformation and the PI loops and the SVPWM logic into a small microsecond window make the system more complex. The effective use of hardware peripherals such as DMA, Intruppt triggers is required to prevent the MCU from the sticking/ hand condition

6. CONCLUSION AND PROPOSED SOLUTION

This Papers highlight the gap in software technologies being used to bridge the observer based softwares the proposed frame work should includes

Micro-PLL interpolation : This ensures that the 60° Hall signals transform into the continuous angle.

An Adaptive SVPWM which dynamically shift the PWM pulses to insure the sufficient time window to capture the current properly

Hybrid Observer technique which can prevent the dead zone of the current sensing during the high modulation or low speed operation.

While FOC is technically demanding, the transition from expensive sensors to sophisticated software algorithms is the key to the next generation of affordable EVs. By utilizing the advanced peripherals of the STM32 platform, it is possible to achieve high-performance motor control that matches the smoothness of luxury EVs at a fraction of the cost.

The FOC is the need of low cost EV's for the better performance and efficiency, to achieve these while transition of the expensive sensors to the the sophisticated algorithms that can be done by utilizing the advance peripherals of the STM32 Platforms which can help to achieve the smoothness of luxury EV's at much lower costs.

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