EV Propulsion with torque estimation on permanent magnet synchronous motor PMSM and Induction machine IM

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***Abstract*—Electric vehicles (EV) have gained significant attention to address this demand due to increased fuel economy and reduced cost/mile features. They can be engineered to work over a wide torque speed range whereas delivering greater torque and power density.Mostly with rising electrification of transportation, a thorough grasp of the parameters utilized in motor selection is becoming increasingly crucial for electric vehicles.The energy conservation in modern urban electrical drives originate with the controlled generating of electromagnetic torque propelling electric vehicles , particularly comprises the electrical motors as well as its current control and load torque.This study proposes a new comparative among the permanent magnet synchronous motor (PMSM) and Induction machine (IM) based on flux linkage estimators for Direct Torque controlled (DTC) to maintain varying estimations observers such as construct a sliding-mode observer(SMO) for nonlinear systems and extended Kalman filter (EKF) for load torque and rotor speed observation.**

***Index Terms*—EV propulsion,Permanent magnet synchronous motor(PMSM),Induction machine (IM) driver,Sliding mode Observer (SMO) Extended Kalman filter(EKF),flux linkage ,(DTC),(FOC).**

I. INTRODUCTION

THE propulsion system of an electric vehicle is usually based on a torque-controlled electrical drive.In recent years, the use of highly dynamic electrical drives in a wide range of applications has rapidly expanded. Due to their advantages of high efficiency, high power density, and dependability, AC machines, particularly permanent magnet synchronous machines (PMSMs). These highly dynamic electrical drives must provide precise and quick torque control while still being as efficient as feasible. In the literature, there are several techniques of controlling torque.Several of these techniques require a torque feedback signal, which may have been provided via estimation based on stator flux calculation integration through a simple and direct technology integration and to improves phase delay. and also have integration with a limited feedback.It can be also estimated based on observers.Permanent magnet synchronous motors (PMSMs) are commonly applied in electrical drives in a wide range of applications. Implementing nonlinear control techniques can improve the performance of adjustable speed drives with PMSMs. Feedback linearization, for instance, has proven to be a particularly useful control law for motor machines[1].

The robustness and wide distribution of IM drives having made them popular. In addition, field-oriented vector control of IMs is recognized as an industry standard. Furthermore, in the event of an inverter failure, IMs are dynamically de-excited, which would be a feature that automotive manufacturers appreciate for safety.In order to manage the torque and flux levels of AC machines, rotor flux field oriented control has become the de facto industry standard. The primary principle of DTC is to choose stator voltage vectors directly based on the variations in torque and stator flux linkage between practical and reference values in a stationary reference frame.The currents or fluxes in the rotor are difficult to measure. As a result, an observer is required to estimate the unknown states, as well as to offer improved estimates of known current states that have been tainted by noise in certain cases.The created sliding-mode observer is based on, which is employed in chemical process control on next section of the article. Time-varying gains for the switching functions are employed by the observer to maintain the dynamic modes of these estimated states invariant independent of the states position. Furthermore,shows how to construct a sliding-mode observer for nonlinear systems in a systematic way. For state estimation in an induction machine, the extended Kalman filter (EKF) is extensively utilized [2]. In addition, the EKF has been utilized to calculate rotor resistance and rotor speed.To determine the rotor location, the researchers suggested an expanded electromotive force model. Furthermore, because the extended Kalman filter (EKF) technique can conduct state estimation for nonlinear systems, it was used in [3] to predict rotor speed and location. The EKF approach, on the other hand, is based on the linear error propagation with Gaussian random noises assumption, which degrades estimating performance in practice [4].

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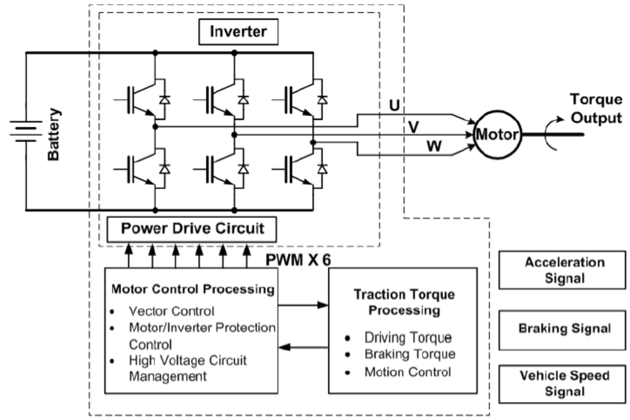

Fig. 1. Components of a typical electric vehicle propulsion system.

II. Electric vehicle propulsion (EVP)

The electric motor, power converter, and electronic controller make up the motor drive, which is the basis of the EV propulsion system.DC motors have long been used in electric propulsion because of their torque-speed characteristics, which are ideally suited to traction requirements, and their ease of speed control. Recent technological advancements have ushered in a new era for commutator less nonlinear control motors, bringing with them the advantages of high efficiency, high power density, low operating cost, increased dependability, and reduced maintenance compared to DC motors. Because they are sturdy, extremely reliable, and maintenance-free, induction motors (IMs) and permanent magnet synchronous motors (PMSMs) are generally recognized commutator-less motors for EV propulsion.For car propulsion, several forms of electric machine technologies have been researched.

The propulsion system, which provides the frictional force effort to drive a vehicle, is a critical subsystem in an EV. As shown in Fig. 1, an EV's propulsion system is composed of an energy storage system, a power converter, a propulsion motor, and related controls. The battery is the most extensively utilized form of energy storage, and the battery charger is an essential component of any electric vehicle system. The existing technology and potential developments for EV propulsion are covered in this study. These technological developments also can be apply to hybrid and plug-in hybrid automobiles.

A. The Principle Of Electric Motor

To supply traction power to the wheels, an electric motor transforms the energy supplied by the battery into mechanical energy. The features of the propulsion system and the ratings of the power devices in the power converter are determined by the motor with the controller. Ruggedness, high torque to inertia ratio, high torque density, wide speed range, low noise, little or no maintenance, compact size, ease of control, and low cost are the major criteria for propulsion motors.

For car propulsion, several forms of electric machine technologies have been researched. Induction machines (IM), permanent magnet synchronous motors (PMSM), switching reluctance, and axial gap machines are examples of these. The majority of commonly produced electric vehicles are powered by either IM or PMSM.

B. Specification of Electric Vehicle Propulsion

For initial stage, electric vehicles require a constant-torque working zone at low speeds, as well as an uphill to steady speed range at higher vehicle speeds. On flat, the maximum speed of the vehicle is determined by its continuous power at maximum speed.

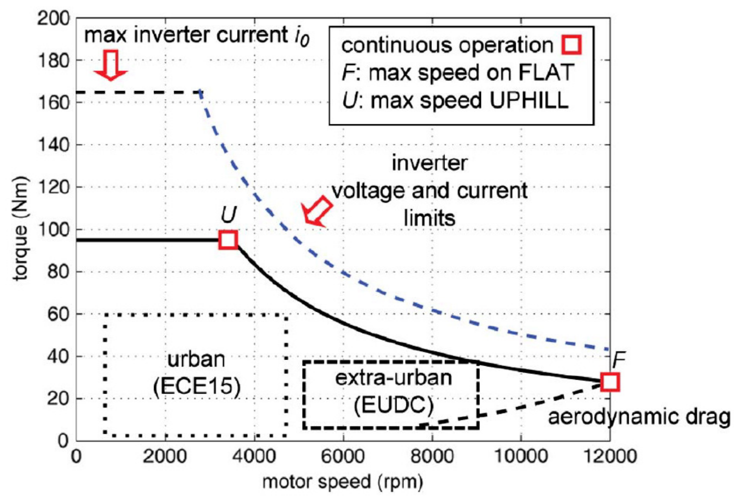

Fig. 2. Sample target description of torque for an electric vehicles.

III. Induction machine (IM)

A. Cage induction motors

Since of their efficiency, robustness, minimal maintenance, cheap cost, and ability to operate in harsh situations, cage induction motors are largely regarded as the most promising alternative for electric propulsion in hybrid EVs and electric vehicles. They're particularly well-suited to the demands of industrial and traction-drive applications. Among the numerous commutator-less motor drives, induction motor drive is the most mature technology today [5-6].

B. Induction motor characteristics.

Flux weakening allows for extended speed range functioning with steady power beyond base speed. However, the existence of breakdown torque restricts its ability to operate at constant power for long periods of time. The breakdown torque is attained at the critical speed. Furthermore, induction motor efficiency may suffer at high speeds, in addition to the fact that induction motor efficiency is fundamentally lower than permanent magnet motor efficiency owing to the lack of rotor winding and rotor resistance losses [6].

In general, induction motor drives were facing a number of drawbacks that pushed them out from the race of EVs

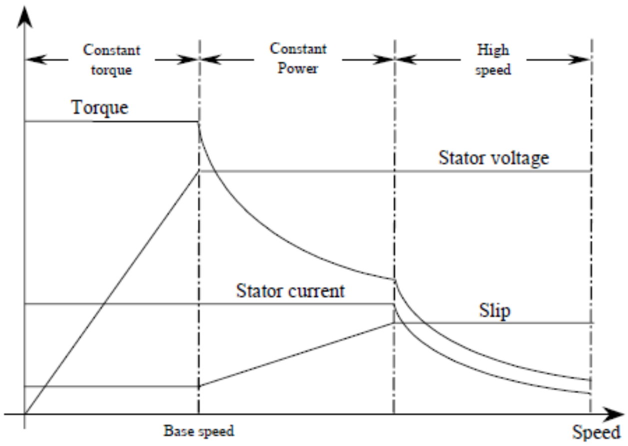

Fig. 3. Induction motor characteristics.

electric propulsion. These drawbacks are mainly: high loss, low efficiency, low power factor, and low inverter usage factor, which is more serious for high speed and large power motor. Fortunately, these drawbacks are taken into consideration according to the available literature. Some researches propose to take into account these problems in the design step of the induction motor used for HEVs [7-8].

C. Improving induction motor

To improve induction motor drives efficiency a new generation of control techniques has been proposed. Some of the proposed techniques are particularly devoted to HEV and EV applications, which constitute a progress compared to the study made in [9].

D. Motor in the Rotor Field-Oriented Frame

The dq reference frame, synchronous to the rotor flux, is considered. In this frame, the stator flux vector components, at steady state, become

$$\begin{cases} \lambda_{sd} = L_s \cdot i_{sd} \\ \lambda_{sq} = \sigma \cdot L_s \cdot i_{sq} \end{cases} \quad (1)$$

where Ls is the stator self-inductance, σ is the total leakage factor (2), and σ Ls is the stator transient inductance

$$\sigma = 1 - \frac{L_M^2}{L_s \cdot L_r} \quad (2)$$

The steady-state expressions of stator voltage and torque are

$$\bar{v}_{sdq} = R_s \cdot \bar{i}_{sdq} + j\omega \cdot \bar{\lambda}_{sdq} \quad (3)$$

$$T = \frac{3}{2} \cdot p \cdot \left(\bar{\lambda}_{sdq} \wedge \bar{i}_{sdq}\right) \quad (4)$$

$$\omega_{sl} = \tau_r^{-1} \cdot \left(\frac{i_{sq}}{i_{sd}}\right) \quad (5)$$

where ω the synchronous electrical speed. Last, the slip speed at steady state is where $\tau_r = L_r/R_r$ is the rotor time constant and R_r is the rotor resistance reported to the stator. Independently of the control technique (rotor-field-oriented, stator-field-oriented, direct torque control), the magnetic model (1) can be used in association to (3),(5) for describing the torque and power curves as a function of rotor speed, at given voltage and current limits [15]10, [16]11.

E. Power Curves at Constant Current

The stator current and flux linkage vectors, as well as the other motors discussed in the next sections, will now be written as flux linkage and current, with no subscript. The IM drive's vector trajectories, associated with a specific current amplitude and limiting voltage, as well as the accompanying power versus speed curves, are qualitatively analyzed. For the continuous currenti_1 and the maximum current i_0, the vector diagrams and power curves are duplicated. This may not be indicative of the drive's real control trajectory, but power curves at various voltages and current restrictions will be useful in comparing the features of the various drives now and in the future.

F. Sliding-mode observer

The model is provided in this paper [25],and similarly to sliding-mode control design, the basic sliding mode observer design procedure consists of performing the following two steps. First, design the manifold (the intersection of the sliding-mode surfaces) $s(y,t) \in R^p$ such that the estimation error trajectories restricted to $s(y,t)$ have the desired stable dynamics. Secondly, the observer gain is determined to drive the estimation error trajectories to $s(y,t)$ and maintain it on the set, once intercepted, for all subsequent time.The construction of the sliding-mode flux observer is now introduced. It is assumed that the only output measured variables are the stator currents and the rotor speed.

The presented sliding-mode observer offers a systematic method to nonlinear system observer design. The following are some of the benefits of this observer: simple and less restricted design; no need for expensive computations; accomplishment of desired dynamic performance through observer pole allocation; and the sliding-mode approach results in the observer's convergence and resilience.

G. The Kalman filter-standard and extended

The Kalman filter is a recursive state estimator that may be used with noisy measurement data and process noise in multi-input, multi-output systems. It gives optimum estimations of system states by combining the plant's inputs and output data with a state space model of the system.

The state estimations are based on a performance criterion that minimizes the mean-squared error, which is defined as the difference between the actual and estimated states [21, 22]. The discrete-time forms of the induction motor model must be employed to use the machine model with a discrete-time Kalman filter. It can only estimate four states in this conventional form. the stator $d-q$ currents and the rotor $d-q$ fluxes.The EKF is the direct extension of the standard Kalman algorithm to the nonlinear system case can be recognized in [22].

IV. Permanent magnet synchronous motor(PMSM)

The necessity for the PMSM to function at the region where torque is required is being pushed by propulsion arrangements, which in many cases is a challenging situation owing to excessive wetness, humidity, vibration, or temperature. Traditional rotor angle sensors are frequently incompatible with these propulsion systems owing to reliability problems or physical limits. As a result, there has been a lot of interest in developing a sensor-free drive, in which the PMSM stator serves as the rotor position observer.
Many approaches to sensor less PMSM operation have been reported in literature. The approaches can be categorized as open loop flux estimators, third harmonic voltage-based estimators, back emf waveform detectors, saliency-based position estimators, and model-based observers. The flux linkage estimation method [12], [13] integrates the difference between phase voltage and stator resistance voltage to estimate the angle of the flux linkage space vector, which is used to produce the appropriate stator current references.

A. Field Oriented Control FOC

Comparable to the IM, the FOC approach [14] may be used to obtain decoupled control of torque and flux magnitudes in the PMSM, simulating a DC motor. This is accomplished via the $d-q$ transformation, which separates the d and q components of the stator current, which are responsible for flux and torque creation, respectively. Because of the permanent magnet's constant flux, there is no need to create flux with the isd current, and this current may be reduced to a zero value, lowering the stator current and increasing the efficiency of the FOC strategy's drive control scheme, as illustrated in Fig. 4.

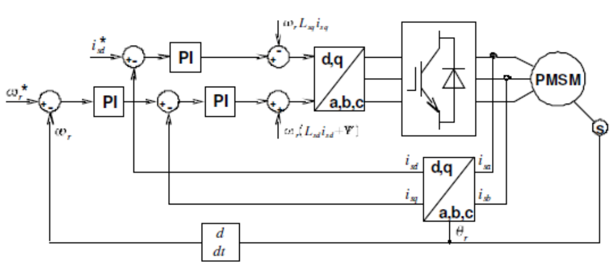

Fig. 4. FOC control scheme for PMSM.

The control system is divided into three different loops: the d loop, which controls the flux; and the q loops, which control the speed and torque. The d loop performs the control of i_{sd} with a current PI regulator. The reference value for this loop can be set to 0. The q loops are connected in cascade. The inner loop controls the torque by means of controlling i_{sd} with a current PI regulator. The fact that the torque can be controlled by means of i_{sd} ,and it is valid for Surface Mounted (SM) PMSM:

$$\Gamma_e = \frac{3}{2} P \Psi i_{sq} \tag{6}$$

The speed PI regulator in the outer loop acts as a reference for this inner loop. The PMSM Fig(4) voltage equations reveal that the d and q axes are not completely independent, containing coupling terms that are dependent on the current on the opposite axis. In order to obtain completely independent control, it is critical to eliminate the impact of these coupling components at the output of the current PI regulator. Decoupling enables the control system to be linearized and have more dynamics.

B. Direct Torque Control DTC

Equation can be used to describe the DTC principle (8). Torque may be regulated by adjusting the relative angle between the stator flux and the PM flux vectors, taking into account the modulus of the stator flux constant. Stator flux can be adjusted by means of the stator voltage according to the stator voltage equation in stator fixed coordinates:

$$\overset{r}{u}_s = R_s \overset{r}{i}_s + \frac{d\psi_s^r}{dt} \tag{7}$$

If the voltage drop in the stator resistance is neglected the variation of the stator flux is directly proportional to the stator voltage applied:

$$\overset{r}{u}_s ; \frac{d \overset{r}{\psi}_s}{dt} \quad \Delta_{\psi}^{r} ; \overset{r}{u}_s \, \Delta t \tag{8}$$

As a result, torque may be regulated by changing the stator flux position fast using the stator voltage delivered to the motor. Acting on the radial (x) and tangential (y) components of the stator flux vector, respectively, achieves the necessary decoupled control of the stator flux modulus and torque. These two components will be determined by the components of the stator voltage vector applied in the same directions, according to (8). The tangential component of the stator voltage has an effect on the relative angle between the PM flux and the stator flux vectors, which controls torque variation (6). The amplitude of the stator flow vector will be affected by the radial component.

The DTC for the PMSM control system is established once all of the considerations are made, as illustrated in Fig. 5. The magnitudes of the stator flux modulus and torque correspond to two independent loops, as can be shown. The calculated stator flux modulus and torque reference values are compared, and the error values are divided into two and three-level hysteresis blocks, respectively. In [15], the hysteresis block for torque error has just two levels, and zero vectors are never used. The traditional [16] approach can be

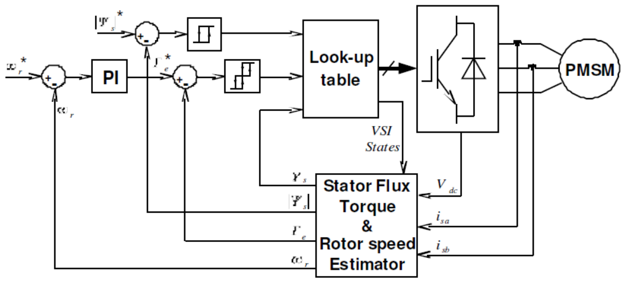

Fig. 5. DTC control scheme for PMSM.

utilized to reduce the torque ripple caused by this decision. Stator flux and torque mistakes are typically confined within their respective hysteresis bands.

C. Essential Torque Equation for PMSM

This estimator uses $T_e = \frac{3}{2}P\left(\varphi_d i_q - \varphi_q i_d\right)$ to calculate the estimated torque and assumes a constant value for the flux linkage of the permanent magnet. Although this may not be true after the motor runs for some time, nevertheless,essential torque equation provides a good reference for the estimation of the torque. Another advantage is that it can be implemented easily. Two inputs are necessary: the current and position of the rotor. Parkâs transformation is used to convert the stator currents from the abc frame to the dq frame [17]. The flux linkages are calculated as follow:

$$\begin{aligned} \varphi_d &= L_d i_d + \varphi_f \\ \varphi_q &= L_q i_q \end{aligned} \tag{9}$$

D. Flux estimation with Compensation Scheme (FCS)

This is a mechanical part ,which it is the torque that can be calculated by using this equation $T_e = \frac{3}{2}P\left(\varphi_d i_q - \varphi_q i_d\right)$. This method allows more flexibility in the estimation of the flux linkage which may varies with time. In addition, FCS can also be implemented easily. However, due to integration, errors like drift and offset may be brought into the estimation of the torque. Three inputs are necessary for the estimation of the torque. They are the current, voltage and position of the rotor. The current and voltage are transformed from the abc frame to $\alpha\beta$ frame. The speed is estimated through the differentiation of the rotor position using $\frac{d\theta}{dt} = \omega_r$. The only assumed constant variable is the stator resistance, R_s.
It can be concluded that the PMSM's lower inductance as compared to the IM results in bigger torque ripples owing to the faster current fluctuation when DTC is used. To compensate for this issue, a shorter sample period must be employed to bring the torque ripple down to an acceptable level.

E. Stator Flux Linkage Estimation Methods

As it is impossible to measure the stator flux linkage, it has to be estimated. In this theory equation (10) can be used for this estimation when stator voltages and currents are measured. The use of a pure open-loop integration however has its disadvantages, as discussed further on.

$$\underline{\Psi}_s = \int_0^t \left(\underline{V}_s - R_s \underline{I}_s\right) dt + \underline{\Psi}_{s|t=0} \tag{10}$$

In this literature review can show different methods are proposed, a short overview is given in [18] and [19]. Most can be divided either in the class of voltage model based methods or the current model based methods. The first are based on the voltage model of the machine, given by equation (10) and offer as distinct advantages the independence on the rotor position and the fact that only one parameter (the stator resistance R_s needs to be known. However the value of Rs has to be adapted online or the detrimental effects of the incorrect value of R_s need to be eliminated.

F. Effects of errors in flux estimations

In [20] a short discussion on this subject is given for the specific case of an LPF as stator flux estimator in a switching table based DTC. The authors conclude that three effects occur. Firstly, due to the attenuation by the filter the controller will try to increase the actual flux above the reference value. Secondly the phase shift can result in the selection of the wrong sector and thus the wrong voltage vector, leading to a reduced magnitude of the actual flux at sector crossings. Thirdly, also due to the phase shift, sixth harmonic torque ripples are introduced in steady state. In a more general situation we can make the distinction between two distinct pathways through which the errors in the flux estimation will deteriorate the torque and flux control. A first path way is where the errors in the flux estimation result in incorrect values for the controlled variables. The estimated stator flux magnitude follows directly from the estimated Ψ_α and Ψ_β, but also the estimated torque value is determined by the stator flux estimation:

$$T = \frac{3}{2}N_p\left(\Psi_\alpha I_\beta - \Psi_\beta I_\alpha\right) \tag{11}$$

G. Measures of quality for the flux estimation

To discuss and compare the quality of the stator flux linkage estimation different situations have to be considered. In steady state (or situations about steady state) deviations in magnitude and phase of the estimated flux components Ψ_α and Ψ_β should be considered. However in transient operation not only the deviations in magnitude and phase are important, but certainly the reaction speed for the estimation is of great importance. As is clear from the previous discussion, the most relevant variables to compare however are the stator flux linkage vector magnitude and especially the angle θ_Ψ. One could note that the true test for the quality of the flux estimators lies in the quality of the obtained torque control. While this is true, comparing results for the stator flux estimation is useful in studying the intrinsic capabilities of estimators; showing how erroneous working conditions and instability arise rather than merely demonstrating them.

H. Sliding Mode Observation (SMO)

The design of the SMO estimator follows [21] which uses the gain scheduled SMO in designing the torque estimator.by Using the electrical dynamics of a PMSM .The details for proving the stability and convergence of the SMO scheme can be found in [21]. Three inputs are necessary for the torque estimation. They are current, voltage and the rotor position. Parkâs transformation is also used to convert the stator currents and voltages from the abc frame to the dq frame. Speed is estimated using $\frac{d\theta}{dt} = \omega_r$.

I. Extended Kalman Filter

The modeling and experiment observations from the EKF observer are presented in this paper[22], which show that the observer can achieve more precise rotor position and speed than the traditional approach, and that adjusting for observed load toque may improve speed performance significantly. For the servo system, the control system with the EKF observer has been found to be particularly well matched and effective. A feedforward adjustment can be produced once the EKF has identified the load torque. The measured load torque is used to correct the reference torque at the output of the time(s) speed PI regulator. This change can improve speed control performance greatly, especially when load torque varies fast.

V. CHALLENGES

This discussion provides a comparison with the EKF in order to demonstrate the benefits of the suggested estimate technique. In terms of computing, the suggested estimate methodology uses expansions to construct the covariance matrix rather than the linearized system matrix, which is crucial in response to the EKF method's linear error propagation assumption. It has a favorable impact on estimating performance in nonlinear systems like AC motor drives. Furthermore, the EKF approach is used to estimate system states or unknown parameters with Gaussian noises, but the sliding modes observer can deal with a variety of distributed random noises in practical cases.
The methods vector control for PMSM drives was compared between DTC and FOC as can be seen on Fig.6 During transients and steady-state, both approaches enable decoupled torque and flux control. Both control techniques have been reported, as well as their principles of functioning.

	DTC	FOC
Dynamic response for torque	Quicker	Slower
Steady-state behaviour for torque, stator flux and currents	High ripple and distortion	Low ripple and distortion
Parameter sensitivity	• For a sensorless estimator: R_s • For a non-sensorless estimator: L_{sd}, L_{sq} and Ψ	Decoupling depends on L_{sd}, L_{sq} and Ψ
Requirement of rotor position	No	Yes
Current control	No	Yes
PWM modulator	No	Yes
Coordinate transformation	No	Yes
Switching frequency	Variable, depending on the operating point and during transients	Constant
Audible noise	Spread spectrum, high noise especially at low speed	Low noise at a fixed frequency
Control tuning	Hysteresis bands	PI gains
Complexity and processing requirements	Lower	Higher

Fig. 6. A list of the variances between FOC and DTC on PMSM

A. Complexity

To determine the complexity of the torque estimator, the parameters that have to be tuned, in order for the estimator to work properly, has to be known. As shown earlier, SMO has the most number of tuning parameters (the most complex), followed by ETE On PMSM .In this particular example Of SMO has the great performance, follow by and ETE.

For sliding-mode observer on IM has been described that behaves like a reduced order observer. The sliding-mode observer is compared to the Kalman filter and the synchronous frame EKF. When compared to the Kalman filter EKF, the sliding-mode observer OF IM is the best option since the estimate results are comparable to the EKF. It's a lot easier to set up, the dynamic performance can be tweaked, and you don't need to know anything about noise statistics.

B. Future Research

In the near future the propulsion motors without permanent magnets will receive greater attention. Although nonrare-earth-based motors such as induction machine, switching reluctance, and PMSM and others motors will continue to be deployed to have long rang and speed .The dependability of the propulsion system would be improved if the speed/position sensors were eliminated.And since the sliding-mode observer OF IM and PMSM is great choice to be used ,so i could give recommend to you based on references to work on sliding mode observer to estimate the torque.

C. Difficulties

We present a basic guideline for the applicability of various torque estimators for various applications with varying cost constraints in this article. As a result, their capacity to diminish output torque ripples is determined. The tweaking of the settings is one of the work's challenges. The SMO and MRAS estimator may not be tuned properly and this may results in poorer performance in some aspects. Further work includes verifying the simulated results with a real PMSM and improving the method for tuning the parameters of the SMO and even MRAS torque estimator.so as future studied to give some recommended to work on varying observers for instance,EKF,UKF or even some particles filters instead of MRAS or sliding mode observer which they more accurate estimations.

VI. Conclusion

Two possible motors for traction used in EVs are evaluated and compared.The development of EV propulsion system technologies will be focusing on vehicle range, which is based on motors, and vehicle cost, and even battery pack life, which is not taken into account in this comparison. This lecture review is primarily a feasibility and comparative study, which examines whether the torque of an induction machine and Permanent magnet synchronous motor can be estimated in a suitable way using observers.The lower inductance of the PMSM compared to the IM results in higher torque

References	Published Date	Number of citations	Descriptions of Objectives	Gaps
H. W. Zhong L., Rahman M.F. and L. K.W., “Analysis of direct torque control in permanent magnet synchronous motor drives,” IEEE Transon Power Elec., vol. 12, DOI 10.1109/63.575680, no. 3, pp. 528–536, May. 1997.	May. 1997	1362	Describes an investigation of direct torque control (DTC) for permanent magnet synchronous motor (PMSM) drives.	The fast torque response can be obtained by adjusting the rotating speed of the stator flux linkage as fast as possible. The differences in the DTC technique for the induction motor and PMSM have been investigated.
Chen and M. W. Dunnigan., “Comparative study of a sliding-mode observer and Kalman filters for full state estimation in an induction machine ”IEEE Proceedings-Electric Power Applications, vol. 3, DOI10.1109/ECCE.2009.5316508, no. 149.1, pp. 53–64, Jun. 2002.	Jul/ 2002	112	Compares a sliding-mode observer with EKF for full state estimation in an induction machine. The design method for the sliding-mode observer is presented and shown to possess invariant dynamic modes	A sliding-mode observer, which behaves like a reduced order observer, has been presented. A comparison of the sliding-mode observer with the Kalman filter, and the synchronous frame EKF, has been performed.
L. T. M. F. Rahman, M. E. Haque and L. Zhong, “Problems associated with the direct torque control of an interior permanent-magnet synchronous motor drive and their remedies,”IEEE Trans. Ind. Electron., Vol. 51, DOI 10.1109/TIE.2004.831728, no. 4, p. 799-809, Aug. 2004.	Aug. 2004	218	Investigates problems associated with the implementation of a direct torque control (DTC) strategy for an interior permanent-magnet synchronous motor drive.	The offsets in the sensor outputs of the dc-link voltage and stator current, the stator resistance variation, and requirement of initial rotor position were investigated
S.-H. Kim and S.-K. Sul, “Maximum torque control of an induction machine in the field weakening region ,”IEEE Trans. Ind. Appl, vol. 31,DOI 10.1109/IAS.1993.298955, no. 4, pp. 371–379, Aug. 1995	Aug.1995	321	A new approach to the induction machine control that ensures the production of maximum torque per ampere over the entire field weakening region is presented	The optimal current condition for yielding the maximum torque is different. while the output torque capability depends on the leakage factor of the machine.
D.-H. Cho, H.-K. Jung, and C.-G. Lee, “Induction motor design for electric vehicle using a niching genetic algorithm ,”IEEE Transactions on Industry Applications, vol. 37, DOI 10.1109/28.936389, no. 4, pp.994–999, 2001.	Jul/2001	102	Optimal design of an induction motor for an electric vehicle using a niching method adopting restricted competition selection is proposed.	The proposed method overcomes some difficulties of multi objective optimization. Moreover, it can reflect the designer's experience, view and judgment effectively.
E. A. Zedong, Zheng, “A rotor speed and load torque observer for pmsm based on extended Kalman filter.”IEEE International Conference on Industrial Technology, vol. 1, DOI 10.1109/ICIT.2006.372295, no. 1,p. 7, Jun. 2006.	Dec. 2006	51	proposed a state observer based on (EKF) for the rotor speed and load torque observation of permanent magnet synchronous motor (PMSM). This observer can be used to estimate the precise rotor position	It can overcome the defects of low precision and differential noise in the general speed calculation method. The sate observer can also observe the load torque and precise rotor position.
N. R. N. Idris and A. H. M. Yatim, “An improved stator flux estimation in steady state operation for direct torque control of induction machines,” IEEE Trans. Ind. Applicant, vol. 38, DOI 10.1109/TAC.1987.1104616, no. 1, p. 110ˆa116, Jan./Feb 2002.	Feb/2002	287	An improved stator flux estimation technique based on a voltage model with some form of low-pass (LP) filtering. This method is proposed to compensate for this error which results in a significant improvement in the steady-state drive performance.	The effect of using an LP filter in place of a pure integrator in the voltage-model-based stator flux estimation to the steady-state performance of the DTC of an induction motor drive system.

ripples due to the quicker current variation when DTC is employed. To compensate for this problem, a shorter sample duration is required to reduce the torque ripple to an acceptable level.Overall it is clear that the EKF, if correctly designed and implemented, can yield the best results. Still the dependence on L_s and Ψ_f should be addressed, as the saturation in the machine otherwise the EKF function so trouble and previous literature papers have not mentioned this issue.

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