DTC-based Performance Analysis of a Permanent Magnet Synchronous Motor

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***Abstract* - This paper proposes Direct Torque Control (DTC) technique for torque and speed controlling of permanent magnet synchronous motor (PMSM). Initially DC motors were used for motor applications where torque and speed need to be controlled. Constriction and control becomes complex due to the presence of commutator and brushes. Then Induction motors were used in Electric Vehicle applications. But nonlinear characteristics of induction motor is major drawback as a result control becomes complex. Now a days PMSM is used due to its high power density, ease of control and more efficient. In the proposed work speed and torque are controlled using DTC for PMSM. It improves the performance of motor system.**

Keywords: Direct Torque Control, PMSM, Speed, Torque

I. INTRODUCTION

The Permanent Magnet Synchronous Motor (PMSM) finds numerous applications including Electric Vehicles. The PMSM has procured an offer in the mechanization business because of its little size, extraordinary proficiency, and speedy response. To expand the unwavering quality and cost of present PMSM drives, high-level control methods have been created. The PMSM is the same as an injury rotor simultaneous machine, with the exemption that it needs damper windings and utilization of an extremely durable magnet rather than a field twisting for excitation. By eliminating the field loop, dc supply, and slip rings, the engine's misfortune and intricacy are diminished. The two elite exhibition control methods for PMSM drives are vector control (VC) and direct force control (DTC). The functioning standards of these control frameworks contrast, however, their objectives are something similar. Both need to drive the engine to follow the speed and force references precisely paying little heed to machine and load boundary vacillations. The immediate force control method is demonstrated to be a reasonable control system for PMSM drives. The ongoing regulator is eliminated, and the dependence on engine boundaries is diminished. Initially, a numerical model of PMSM was laid out in this exploration. Then, utilizing MATLAB/SIMULINK, a reenactment model of PMSM DTC was made [1].

Very long-lasting magnet simultaneous engines (PMSM) are becoming more frequent because to increased qualities such as a high pressure ratio, higher reaction thickness, high power factor, low noise, reduced volume and size, longer life, and expanded unique execution.. Due to its unequalled advantages, PMSMs are widely used with the current-controlled voltage source inverter (VSI) for modern and foothold applications. PMSM employs two sophisticated execution speed control approaches in near circle speed management. Vector control, sometimes referred to as field-arranged control, and direct force control are two of them. Although these two control calculations were developed for nonconcurrent engine drives, they can also be used to govern PMSMs. The DTC decides on the optimal force. This procedure is not generally utilized because of its underlying execution and slow speed of activity. Field arranged control (FOC) is currently utilized for PMSM as a result of its brilliant unique exhibition. For divided control of PMSM drives, stator current is parted into transition creating (d-pivot current) and force-producing (q-hub current) parts in FOC [2].

After vector control, Direct Torque Control (DTC) is another control system. It leaves the vector control idea of decoupling and on second thought controls the transition linkage and engine force straightforwardly through the stator motion linkage. Accordingly, the framework's dynamic reaction is incredibly speedy This control procedure, then again, can't meet the framework's force and motion linkage prerequisites simultaneously, bringing about enormous swings in transition linkage and force, as well as the issue of heartbeat current and voltage. higher exchanging frequencies, as well as clamor from switches Because of its imminent advantages, like low current waveform contortion, high DC voltage use, simple to-computerized execution, reliable inverter exchanging recurrence, actually diminishing throb of the engine force and motion linkage, etc, it is turning out to be more famous. the Space Vector Pulse Width Modulation (SVPWM) control methodology has been generally utilized in the field of engine speed control. The proposed DTC-SVPWM framework has less transition linkage and force swells than the DTC-SVPWM framework while keeping up with similar force responsiveness. The power circuit's intricacy doesn't ascend simultaneously [3].

The result shows that the system offers benefits like quick response and high exceptional execution. The proposed DTC-SVPWM framework has less change linkage and power development than the DTC-SVPWM structure while remaining mindful of similar power responsiveness. The power circuit's diverse plan doesn't climb meanwhile [3].flux control. The inverter states are straightforwardly constrained by Direct Torque Control (DTC) in light of the deviations between the reference and assessed force and motion values. To keep force and motion inside the limits of two hysteresis groups, it picks one of six voltage vectors given by a Voltage Source Inverter.

DTC has the accompanying attributes:

• responsiveness to dynamic force
• heartiness
• easy to comprehend [4].

Super durable magnet coordinated engines (PMSM) are generally utilized in elite execution drives, for example, modern robots and mechanical devices for their benefits of high power thickness, high force, free upkeep, etc. As of late, the attractive and warm capacities of the PM have been impressively expanded by utilizing the high-coercive PM materials. In the most recent couple of years, an extremely durable magnet coordinated engine (PMSM) thusly is procured in increasingly more far-going applications, on account of its properties like little volume, lightweight, high productivity, little idleness, rotor without heat issue, and so forth[5].

Today, the super durable magnet simultaneous engine (PMSM) is gaining popularity and has mostly replaced the traditional DC brush and enlistment engines, making it increasingly appealing for modern applications. The constant advancement of force gadgets and microelectronics has swamped the control subtleties of Permanent Magnet Synchronous Motors. Takahashi and Noguchi proposed the instantaneous force control (DTC) control approach for acceptance engines in the 1980s, and it is already being used on numerous engines in many applications. L. Zhong and M. Rahman used DTC in PMSM engine drives in the 1990s, and it was viewed as easier than other control strategies[6].

For close-by circle speed management, the Permanent Magnet Synchronous Motor gives two undeniable level execution speed control methods. field set up for power control and direction These two control methods are designed for non-standard motor drives, although they can also be used to control PMSMs[7].

At first whilst they may be added Takahashi and Noguchi gave no call to their new manage rule. Later on via way of means of Takahasi and Ohmori the manage gadget changed into named the short electricity manage (DTC). then brock referred to as his manage method Direct Self Control, DSC. Tienen et al inspected the supercurrent usage of the DTC. Starting there forward, the quantity of papers at the DTC has grown immensely on exceptional portions of the DTC for nonconcurrent motors. There has been an thrilling to use the DTC [8]. This [9] paper critiques on exceptional manage strategies used for induction motor for electric powered car applications. The DTC manage technique is used for PMSM to develop the engine's pressure qualities, which has stood out as of late. The exemplary DTC most likely contains out a bang manage method [10].

In modern applications, servo engines should have consistent force, while foothold applications should have both steady force and consistent power. PMSM drives are utilized in an airplane and car applications where high dependability is required as a result of these characteristics[11].

The DTC chooses a suitable voltage from a specified changing table to achieve the necessary force. Regardless, due to its hidden execution and sluggish performance, this procedure is no longer used. FOC is eventually involved because of their fantastic one-of-a-kind show for PMSM.[12].For managing PMSM drives, stator current is divided into movement delivering (d-center current) and power making (q-center point current) components in FOC[13].

The extremely durable magnet coordinated is the subject of this paper. By and by, the DTC approach is utilized to reproduce, which depends on the SVPWM. The outcome shows that the framework offers benefits like fast reaction and high unique execution[14].The control complexities of PMSM have been overcome by the continuous advancement of power electronics and microelectronics [15]

II. METHODOLOGY

A. MATHEMATICAL MODELING OF PMSM

No immersion, sinusoidal electromotive power, zero steady, and variable misfortunes are expected in the PMSM numerical model. In the concurrently spinning reference outline (d-q reference outline), the stator voltage criteria for a PMSM are as follows:.

$$V_{sd} = i_{sd} R_s + L\frac{d_{isd}}{dt} - L_s w_e\, i_{sq} \quad (1)$$

$$V_{sq} = i_{sq} R_s + L_s \frac{di_{sq}}{dt} + L_s W_e\, i_{sd} + ?_m W_e \quad (2)$$

The voltage components of the direct(d) and quadrature(q) axis stators are, respectively. and are current d-q axis stator components What are the Rs and Ls of the stator per phase resistance and inductance? Between permanent magnets, there is a flux link.

The PMSM produces the following torque:

$$T_e = \frac{3}{2} \text{ x } \frac{p}{2}\, ?_m\, i_{sq} = K_t i_{sq} \quad (3)$$

Where:

P = It's the scale parameter..

Kt = torque constant.

The advanced force is adjusted by the heap force, speeding up force, and damping force of the framework, and this mechanical condition is as per the following:

$$\text{Te } \_T_l = \text{J} \frac{dwm}{dt} + B_w \text{m} \quad (4)$$

Where:

Te = electromotive force

TL= Torque at Load

J = inertial moment

B = Coefficient of Damping

wm = speed of the mechanical rotor in rad/sec

B. PMSM DRIVE SYSTEM DESCRIPTION

The below figure1 represents the block diagram of field-oriented controlled PMSM drive with the help of control of flux weakening.

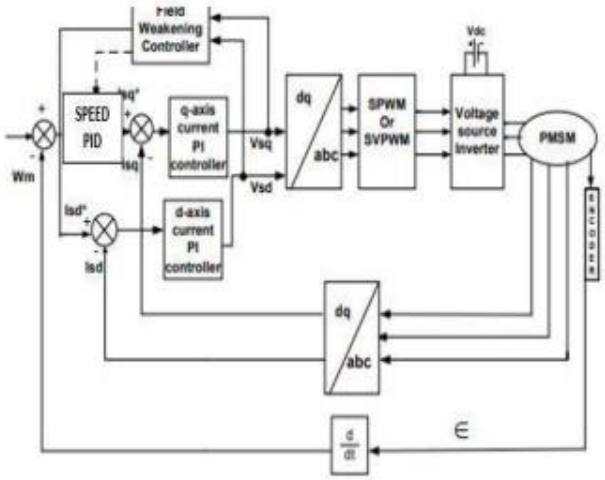

Fig1. Block diagram of field-oriented controlled PMS

This block chart contains a speed controller PID controller, space vector PWM (SVPWM), and PMSM, and supply is given to the structure by 3phase VSI. Here in this structure consistent power and predictable power zone are worked.
As this is a closed circle system depending on the continuous circle the time consisted of the structure is arranged with the goal that the inward current circle answers speedier than the external current circle.

c. DIRECT TORQUE CONTROL FOR PMSM

The maximum massive ac pressure manipulate techniques through then are vector manipulate and direct strength manipulate. As the call implies, direct strength manipulate employs six or 8 voltage area vectors to manipulate electromagnetic strength and regulate connection in a clean and unbiased manner. The voltage vector aircraft is split into 8 sections to alter the stator alternate linkage and abundance.

1. METHOD OF ESTIMATING STATOR FLUX

By using following equation stator flux can be estimated

$$\lambda_S = \int (V_s - R_s i_s)dt \qquad (5)$$

The criteria described above can be utilised to determine the extent of the change's overflow and the location where it occurs. If the obstruction term is excluded from the stator movement evaluation, the difference in the stator progress linkage is solely determined by the applied voltage vector, as shown in Fig2. By applying the stator voltage vector, Vs, the stator movement linkage, s position, and plentifulness can be modified for a brief length of time, referred to as the inspecting time, Ts=t. The position of the stator movement linkage vector, s, has an impact on the power. During the reviewing stretch (or trading range), one of the six voltage vectors is used. DTC's motivation is to keep movement plentiful within a pre-defined range.

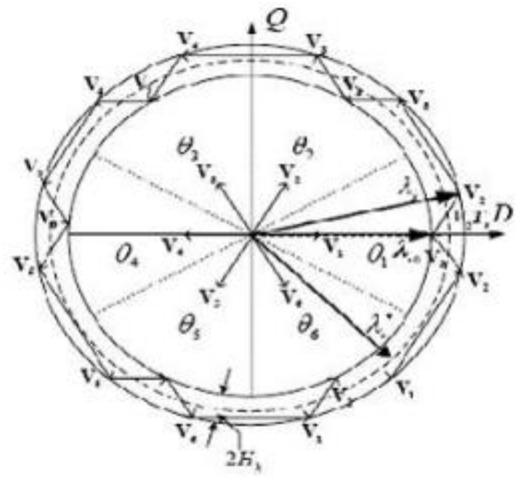

Fig2. Incremental stator flux linkage space vectorrepresentation in the DQ-plane.

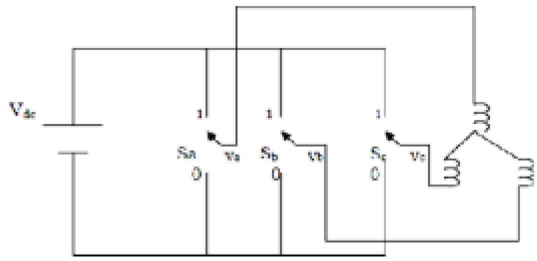

Fig3 VSI connected to the R-L load

2. TORQUE ESTIMATION METHOD

Apply the following equations to derive electromagnetic torque using a stator connecting flux components and observed stator currents:

$$T_e = \frac{3p}{4}(?_d\, i_q - ?_q\, i_d) \qquad (6)$$

The going with hysteresis controller takes a gander at the significance of stator movement and electromagnetic power to their reference values. Hysteresis controls are used to preserve the energy and stator extrade interior a specific reach. The outcome of those controllers is given to a buying and selling table, what choices a voltage vector giving the correct energy thinking about the region of stator linkage development in a specific region. The spherical stator motion vector heading is indifferent into six even bundles given the non-0 voltage vectors the usage of records from the energy and development hysteresis yields, in addition to stator movement vector region, as proven in Fig4.

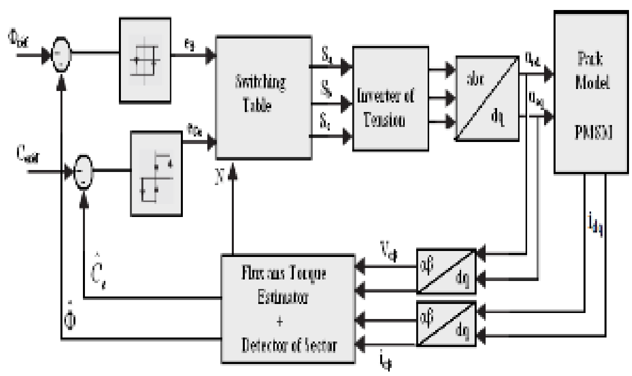

FIG4: Diagram of DTC

The progress hysteresis comparator yield is inferred as, and the movement linkage region is depicted as. The power hysteresis comparator has two values: 0 indicates that the certified power regard is above the reference and outside a significant distance, and 1 shows that the true power regard is below the reference and outside beyond what many would consider possible. The change hysteresis comparator is a two-regarded comparator, with =1 indicating that the movement linkage's certified worth is below the reference and far beyond what many would consider possible, and =0 indicating that the movement linkage's certified worth is above the reference and far beyond what many would consider possible.

III. SIMULATION AND RESULT

Engine models such as vigour, unmatched execution, high power component, vital and unpretentious control, and low maintenance requirements have sparked a new type of engine fueled by dependable magnets. In MATLAB, a model for the show analysis of synchronous motors with DTC was created.

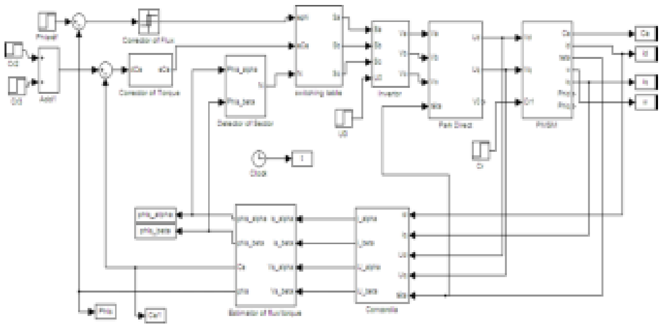

Fig5: Simulation Module Of PMSM

DTC is standard for convincing control in regards to the power and progress without changing past what many would think about conceivable and weight. . . In DTC, the inverter voltage vector can also be used to control the change and power. To achieve the development and power objectives, two free hysteresis regulators are used. In the reenactments that were performed. Certain stator changes and power references are shown to be specifically connected with the features investigated from afar, and hysteresis comparisons are discarded. The genuine voltage vector and the stator improvement space vector are wrapped up using the inevitable results of the change and power comparators.

The DTC methods for a two-level controlled solid area for an absolutely Synchronous Motor is devised and rehashed in the MATLAB/SIMULINK environment. The reenactment results were dissected, and it was discovered that the power came from a source beyond what many would imagine conceivable: a huge amount of wave content. The DTC method is appropriately carried out with a three-level inverter to reduce the wave content. The three levels in the stage voltage of a three-level inverter allow for a decrease in the symphonious substance in stator voltages and streams, as well as an increase in power and progress. Another technique called DTC-Space Vector Modulation can be used to reduce the symphonious substance in the short power control approach for PMSM using a three-level inverter. In a Real-Time setting, the quick Torque Controller Technique of PMSM with a two-level inverter should be possible, and the results can be maintained with the obtained amusing results. the table who similarly picks the trading of the three inverter legs, and applies a huge load of voltage vectors across the motor terminals.

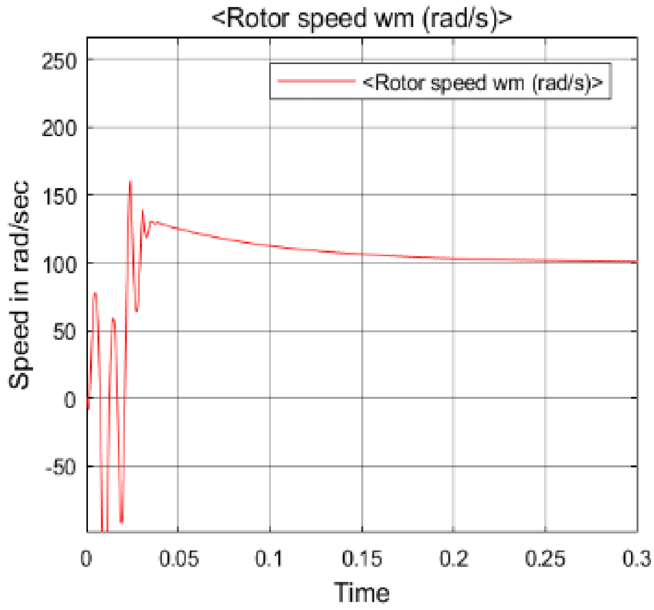

Fig6: Speed curve in DTC

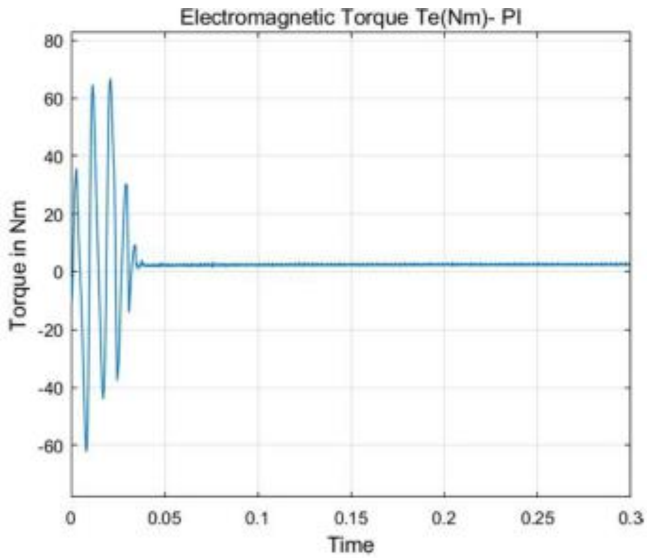

Fig7: Torque curve in DTC

IV. CONCLUSION

Performance characteristics of PMSM is analyzed using look up table based DTC. Speed and torque waveforms are shown based on direct torque control technique for PMSM. Results shows that torque and speed ripples are less when DTC is used for controlling PMSM. As PMSM is more suitable motor for many applications including Electric Vehicles than induction motor and dc motor due to its high power density and more efficient. From available control techniques DTC one of the efficient control method for PMSM.

REFERENCE

[1] Sharma, R., Prajapat, K. K., & Sood, A. (2012, May). Performance analysis of direct torque control of PMSM drive using two level inverter. In *2012 International Conference on Communication Systems*

[2] Kurihara, K., Wakui, G., & Kubota, T. (1994). Steady-state performance analysis of permanent magnet synchronous motors including space harmonics. *IEEE Transactions on Magnetics*, *30*(3), 1306-1315.

[3] Zhang, Y., & Zhu, J. (2010). Direct torque control of permanent magnet synchronous motor with reduced torque ripple and commutation frequency. *IEEE Transactions on Power Electronics*, *26*(1), 235-248.

[4] Zhong, L., Rahman, M. F., Hu, W. Y., & Lim, K. W. (1997). Analysis of direct torque control in permanent magnet synchronous motor drives. *IEEE transactions on power electronics*, *12*(3), 528-536.

[5] Singh, J., Singh, B., & Singh, S. P. (2011). Performance Evaluation of Direct Torque Control with Permanent Magnet Synchronous Motor. *SAMRIDDHI: A Journal of Physical Sciences, Engineering and Technology*, *2*(02), 25-35.

[6] Sharma, R., Prajapat, K. K., & Sood, A. (2012, May). Performance analysis of direct torque control of PMSM drive using two level inverter. In *2012 International Conference on Communication Systems and Network Technologies* (pp. 825-829). IEEE.

[7] Kurihara, K., Wakui, G., & Kubota, T. (1994). Steady-state performance analysis of permanent magnet synchronous motors including space harmonics. IEEE Transactions on Magnetics, 30(3), 1306-1315.

[8] Morales-Caporal, R., Bonilla-Huerta, E., Arjona, M. A., & Hernández, C. (2012). Sensorless predictive DTC of a surface-mounted permanent-magnet synchronous machine based on its magnetic anisotropy. *IEEE Transactions on Industrial Electronics*, *60*(8), 3016-3024.

[9] Marulasiddappa, H. B., & Pushparajesh, V. (2021, February). Review on different control techniques for induction motor drive in electric vehicle. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1055, No. 1, p. 012142). IOP Publishing.

[10] Boussak, M. (2005). Implementation and experimental investigation of sensorless speed control with initial rotor position estimation for interior permanent magnet synchronous motor drive. *IEEE transactions on power electronics*, *20*(6), 1413-1422.

[11] Pacas, M., & Weber, J. (2005). Predictive direct torque control for the PM synchronous machine. *IEEE transactions on industrial electronics*, *52*(5), 1350-1356.

[12] Jolly, L., Jabbar, M. A., & Qinghua, L. (2006). Optimization of the constant power speed range of a saturated permanent-magnet synchronous motor. *IEEE Transactions on Industry Applications*, *42*(4), 1024-1030.

[13] Kumar, G. V., & Jain, A. K. (2014, December). Robust design and analysis with wide speed operation of surface mounted PMSM drive. In 2014 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES) (pp. 1-6). IEEE.

[14] Pacas, M., & Weber, J. (2005). Predictive direct torque control for the PM synchronous machine. *IEEE transactions on industrial electronics*, *52*(5), 1350-1356.

[15] Mohan, A., Khalid, M., & Binojkumar, A. C. (2021, June). Performance Analysis of Permanent Magnet Synchronous Motor under DTC and Space Vector-based DTC schemes with MTPA control. In 2021 International Conference on Communication, Control and Information Sciences (ICCISc) (Vol. 1, pp. 1-8). IEEE.