SWITCHING LOSSES MINIMIZATION AND PERFORMANCE IMPROVEMENT OF PCC AND PTC METHODS OF MODEL PREDICTIVE DIRECT TORQUE CONTROL DRIVES WITH VOLTAGE SOURCE INVERTER

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Abstract- In Power Electronics, Predictive Current control (PCC) and Predictive Torque control (PTC) methods are advanced control strategy. To control a Permanent Magnet Synchronous motor machine (PMSM), the predictive torque control (PTC) method evaluates the stator flux and electromagnetic torque in the cost function and Predictive Current control (PCC) [1] considers the errors between the current reference and the measured current in the cost function. The switching vector selected for the use in IGBTs minimizes the error between the references and the predicted values. The system constraints can be easily included [4, 5]. The weighting factor is not necessary. Both the PTC and PCC methods are most useful direct control methods with PMSM method gives 10% to 30% more torque than an induction motor also not require modulator [3]. Induction motor work on only lagging power factor means it can produce only 70-90% of torque produced by PMSM with same current. PCC and PTC method with 2-level inverter using PMSM reduces 36% more THD in torque, speed and stator current compared to PCC and PTC method with 2-level inverter using induction motor [21]. In this paper, switching loses minimization technique through THD minimization. Switching losses are minimized because the transistors are only switched when it is needed to keep torque and flux within their bounds. The switching pattern of semiconductor switches used to get better performance of multilevel inverter. This scheme decreases the switching loss and also increases the efficiency & reduced losses. In this paper, the PTC and PCC methods with voltage source inverter using PMSM are carried out and gives excellent torque and flux responses, robust, and stable operation achieved compared to the PTC and PCC methods with 2-level voltage source inverter using IM. This novel method attracted the researchers very quickly due to its straightforward algorithm and good performances both in steady and transient states [8].

***Index Terms*—Electrical drives, predictive current control (PCC), predictive torque control (PTC).Permanent Magnet Synchronous Motor (PMSM), Induction Motor (IM), Voltage Source Inverter (VSI).**

INTRODUCTION:

DTC drive in last decade becomes one possible alternative to the well-known Vector Control of Induction Machines. Its main characteristic is better performance with several advantages based on its simpler structure and control diagram. DTC (Direct Torque Control) is described by the name, by directly controlled torque and flux and indirectly controlled stator current and voltage [2]. The DTC has some advantages comparison with the conventional vector-controlled drives, like Approximately sinusoidal stator currents and stator fluxes, High dynamic performance even at locked rotor and standstill, Absences of co-ordinates transform, Absences of mechanical transducers, Current regulators, PWM pulse generation, PI control of flux and torque and co-ordinate transformation are not required, Very simple control scheme and low computation time, Reduced parameters sensitivity, superior dynamic properties. Conventional DTC has also some pitfall are possible problems during starting and low speed operation, Variable switching frequency. To solve this demerit many research efforts have been made. Predictive DTC [4], DTC by using space vector modulation, Band-constraining DTC [2] [11] are available methods for the torque ripple reduction.

Predictive Current control (PCC) and Predictive Torque control (PTC) methods are promising methods [10]. Along reducing torque ripples, the FCS-PTC method also illustrates a number of advantages, like the easy inclusion of constraints, easy implementation, straightforward, algorithm and fast dynamic responses. The basic concept of model predictive direct torque control (MPDTC) method is to calculate the required control signals in advance [6]. In the MPDTC method, pulse width modulation is needless. The inverter model is required in the control method. During MPDTC, the PTC and PCC method calculates all possible voltage vectors within one sampling interval and selects the best one by using an optimization cost function [7]. To date, the PCC and PTC methods have been adapted in many operational situations and widely investigated, as given in the articles [8], [9].

Model predictive control (MPC) in recent years has received convincingly contemplation and has gained demand in the power electronics and industrial drives association. This MPC control strategy was first introduced in 1970, developed for process control applications, is used commonly in the industry with numerous applications reported [4]. The basic perception of model predictive control methods is that the decision of the controller is not centered on past state of the system, but with the predicted behavior of the state variables and proper selection of the controlled variables either offline or online. MPC is also referred as receding horizon control, as where its main perception is to reflect an infinite prediction horizon by constantly sliding the prediction horizon. The current expansion and new orientation in the area of MPC mentioned in [5]. Due to simple in concept, the

MPC also sometimes used to control the power converters because of its computational complexity is a burden to the processors. Now a day due to the evolution of new high speed processor, the usage of MPC became an increase. In [6] the MPC is used to control a VSI and multilevel inverter, where a discrete-time model of the VSI used to predict the forthcoming value of the load current for all possible voltage vectors generated by the inverter. According to this, MPC has been widely used in many applications in power electronics such as controlling various industrial drives like DC-DC converters [7], in matrix converters [8]. MPDTC can be also used for speed control Permanent magnet synchronous motor and induction motor [9] [10] based on a linearized state-space representation that describes the dynamic operation.

When MPC compared with the DTC method, the PTC method has two demerits: depend on speed and require higher calculation time. Due to the implementation of the optimal cost function, the PTC method takes more time; this problem can be solved easily, with better and faster microprocessing unit [10], [11]. The conventional PTC method for induction machine (IM) and PMSM motor applications demands the rotor electrical speed in the prediction steps. The predicted stator current values are dependent on the estimated speed and also on measured values of speed.

In this paper, the PTC and PCC methods with 2-level voltage source inverter using PMSM are carried out by simulation method and compared with the PTC and PCC methods with 2-level voltage source inverter using induction motor. PCC and PTC method with 2-level inverter using PMSM reduces 36% THD in torque, speed and stator current compared to PCC and PTC method with 2-level inverter using an induction motor [10] [21]. In this paper, switching loses minimization technique through THD minimization. Switching losses are minimized because the transistors are only switched when it is needed to keep torque and flux within their bounds. This novel method attracted the researchers very quickly due to its straightforward algorithm and good performances both in steady and transient states [8].

II. PMSM AND INVERTER MODEL

The mathematical model for the vector control of the PMSM can be derived from its dynamic d-q model which can be obtained from model of the synchronous machine without damper winding and field current dynamics. The synchronously rotating rotor reference frame is used so that stator winding quantities are transformed to the synchronously rotating reference frame that is revolving at rotor speed. The model of PMSM without damper winding has been developed on rotor reference frame using assumptions as Saturation is neglected, induced EMF is sinusoidal, core losses are negligible, there are no field current dynamics. It is also be assumed that rotor flux is constant at a given operating point and concentrated along the d-axis while there is zero flux along the q-axis, an assumption similarly made in the derivation of indirect vector controlled induction motor drives. The rotor reference frame is chosen because the position of the rotor magnets determine independently of the stator voltages and currents, the instantaneous induced emf and subsequently the stator currents and torque of the machine. When rotor references frame are considered, it means the equivalent q- and d- axis stator windings are transformed to the reference frames that are revolving at rotor speed. The consequences is that there is zero speed differential between the rotor and stator magnetic fields and the stator q- and d- axis windings have a fixed phase relationship with the rotor magnet axis which is the d-axis in the modelling[17,18].

The mathematical model of a PMSM given by complex equations in the rotor reference frame is as below:

Voltage equations are given by:

$$V_d = R_s i_d - \omega_r \lambda_q + \frac{d\lambda_d}{dt} \ldots.1, V_q = R_s i_q - \omega_r \lambda_d + \frac{d\lambda_q}{dt} \ldots..2$$

Flux linkage are given by

$$\lambda_q = L_q i_q \ldots 3, \lambda_d = L_d i_d + \lambda_f \ldots\ldots 4$$

Substituting Equation 3 and 4 into 1 and 2, we get,

$$V_q = R_s i_q - \omega_r \left(L_d i_d + \lambda_f\right) + \frac{d(L_q i_q)}{dt} \ldots 5, \quad V_d = R_s i_d - \omega_r L_q i_q. + \frac{d}{dt}\left(L_d i_d + \lambda_f\right) \ldots..6$$

Arranging equation 5 and 6 in matrix form,

$$\begin{pmatrix} V_q \\ V_d \end{pmatrix} = \begin{pmatrix} R_s + \frac{dL_q}{dt} & \omega_r L_d \\ -\omega_r L_q & R_s + \frac{dL_d}{dt} \end{pmatrix} \begin{pmatrix} i_q \\ i_d \end{pmatrix} + \begin{pmatrix} \omega_r \lambda_f \\ \frac{d\lambda_f}{dt} \end{pmatrix} \ldots\ldots 7$$

The developed motor torque is being given by

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\left(\lambda_d i_q - \lambda_q i_d\right) \ldots\ldots 8, \; T_e = \frac{3}{4} P\left[\lambda_f i_q + \left(L_d - L_q\right) i_q i_d\right] \ldots\ldots 9,$$

$$T_e = T_L + B\omega_m + J\frac{d\omega_m}{dt} \ldots\ldots 10$$

Solving for rotor mechanical speed from equation 10, we get,

$$\omega_m = \int \left(\frac{T_e - T_L - B\omega_m}{J}\right) dt \ldots\ldots 11$$

And rotor electrical speed is

$$\omega_r = \omega_m \left(\frac{P}{2}\right) \ldots\ldots 12$$

Voltage Source Inverter:

In this work, a two-level voltage source inverter is applied to PTC and PCC methods. The topology of the inverter and its feasible voltage vectors are presented in Fig. 1. The switching state S can be expressed by the following vector:

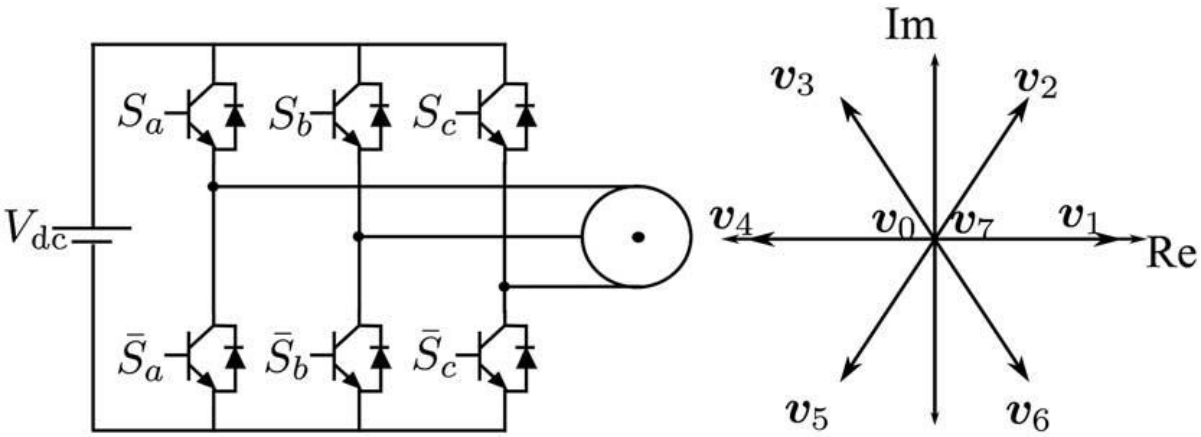

Fig. 1. *Left*: two-level voltage source inverter; *right*: voltage vectors

The stator voltage space vector representing the eight voltage vectors can be shown by using the switching states and the DC-link voltage,V_{dc}, as:

$V_s(S_a, S_b, S_c) = \left(\frac{2}{3}\right) V_{dc} \left(V_a + V_b e^{j\left(\frac{2}{3}\right)} + V_c e^{j\left(\frac{4}{3}\right)}\right)$.....13

Where V_{dc}, is the DC-link voltage and the coefficient of 2/3 is the coefficient comes from the Park's Transformation. Equation (13) can be derived by using the line-to-line voltages of the AC motor which can be expressed as[10]:

$V_{ab} = V_{dc}(S_a - S_b)$…14 , $V_{bc} = V_{dc}(S_b - S_c)$….15, $V_{ca} = V_{dc}(S_c - S_a)$.....16

The stator phase voltages (line-to-neutral voltages) are required & can be obtained from the line-to-line voltages as.

$V_a = (V_{ab} - V_{ca})/3$…….17,$V_b = (V_{bc} - V_{ab})/3$……18,$V_c = (V_{ca} - V_{bc})/3$……..19

If the line-to-line voltages in terms of the DC-link voltage, *Vdc*, and switching states are Substituted into the stator phase voltages it gives:

$V_a = \left(\frac{1}{3}\right) V_{dc}(2S_a - S_b - S_c)$…20, $V_b = \left(\frac{1}{3}\right) V_{dc}(-S_a + 2S_b - S_c)$…21,

$V_a = \left(\frac{1}{3}\right) V_{dc}(-S_a - S_b + 2S_c)$…22

Equation (3.14) can be summarized by combining with (3.12) as:

$V_a = Re(V_s) = \left(\frac{1}{3}\right) V_{dc}(2S_a - S_b - S_c)$…23, $V_b = Re(V_s) = \left(\frac{1}{3}\right) V_{dc}(-S_a + 2S_b - S_c)$…24

$V_c = Re(V_s) = \left(\frac{1}{3}\right) V_{dc}(-S_a - S_b + 2S_c)$…25, $S = \frac{2}{3}(S_a + aS_b + a^2 S_c)$.....26

where $a = e^{j\frac{2\pi}{3}}$, S_i = 1 meansS_i ON, $\bar{S}_i$ means OFF, and $i = a, b, c$. The voltage vector V is related to the switching state S by $v = V_{dc}S$.....27

where V_{dc} is the dc-link voltage

V. Switching Losses

The losses in the semiconductors can be divided into two parts, namely switching losses (arising when the devices are switched on or off) and conduction losses (due to the ohmic resistance). These losses depend on the applied voltage, the commutated current and the semiconductor characteristics. Observing that in a VSI inverter, the voltage seen by each semiconductor is always half the total DC-link voltage leads to the Ideal switch turn-on (energy) loss

$E_{on} = e_{on} \frac{1}{2} V_{dc} i_{ph}$.....(10)

Where e_{on} is a coefficient and i_{ph} is the phase current. For the Ideal switch, turn-off losses, a corresponding equation results with the coefficient e_{off}. Typically, e_{off} is an order of magnitude larger than eon. For a diode, the switch-on losses are effectively zero. The turn-off losses, however, which are reverse recovery losses, are linear in the voltage, but nonlinear in the commutated phase current. Similar to the switching losses, the conduction losses also depend on the applied voltage and the phase current. The DC link voltage is constant despite the neutral point fluctuations. The phase current is the sum of the current ripple and the fundamental component, which in turn depends only on the operating point given by the torque and the speed, but not on the switching pattern. Since the ripple is small compared to the fundamental current (typically in the range of 10% for a 3-level inverter), the conduction losses can be considered to be independent of the switching pattern.

III. PREDICTIVE DIRECT CONTROL METHODS FOR PMSM

A. PCC:

Predictive Current Control (PCC) uses only the predicted stator currents in the stationary reference frame in order to control the multiphase drive. Current references are obtained in the rotating reference frame from an outer PI speed control loop and a constant *d*-component current and then mapped in the stationary reference frame in order to be used in the cost function, as shown in Fig. 2. This simple predictive controller scheme has been implemented in multiphase drives, with different number of windings[10].

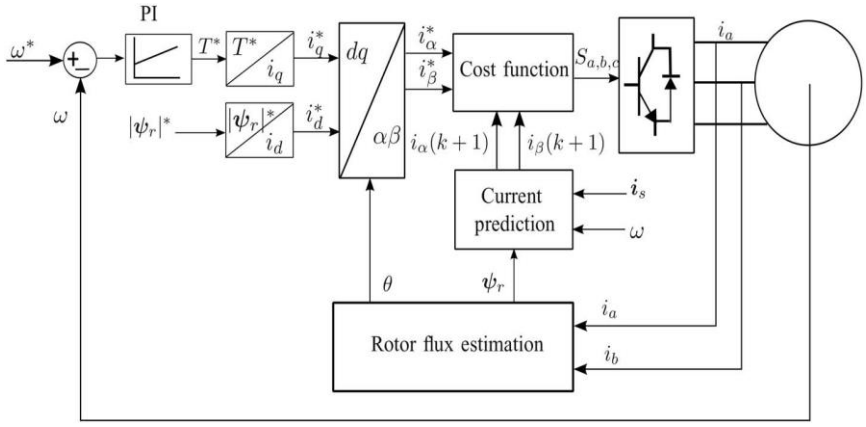

Fig.2 MPC based Predictive Current Control with an outer speed control loop

Aim is to generate a desired electric torque which implies sinusoidal stator current references in a-b-c phase coordinates. In the stationary α-β-x-y reference frame, the control aim is traduced into a reference stator current vector in the α-β plane, which is constant in magnitude but changing its electrical angle following a circular trajectory, and depending on the implemented multiphase machine, either null or non-null reference stator current vector in the x-y plane. For instance, if a three-phase machine with distributed windings is implemented, the α-β stator current components contribute to torque production while x-y stator current components do not, thus a zero reference is set for the x-y current components[20].

$J = A|\overline{\overline{i_{s\alpha}}}| + B|\overline{\overline{i_{s\beta}}}| + C|\overline{\overline{i_{sx}}}| + D|\overline{\overline{i_{sy}}}|$…28

where each α-β-x-y current term is defined as:

$|\overline{\overline{i_{s\alpha}}}| = i^*{}_{s\alpha}(k+1) - \hat{\imath}_{s\alpha}(k+1)$ …..29, $|\overline{\overline{i_{s\beta}}}| = i^*{}_{s\beta}(k+1) - \hat{\imath}_{s\beta}(k+1)$…30

$|\overline{\overline{i_{sx}}}| = i^*{}_{sx}(k+1) - \hat{\imath}_{sx}(k+1)$ …..31, $|\overline{\overline{i_{sy}}}| = i^*{}_{sy}(k+1) - \hat{\imath}_{sy}(k+1)$….32

The classical cost function is presented as follows:

$$g_j = \sum_{h=1}^{N} \{|i_\alpha^* - i_\alpha(k+h)_j| + |i_\beta^* - i_\beta(k+h)_j|\} \ldots\ldots 33$$

Where j = 0 , . . 6 because a two-level voltage source inverter is applied in this system. All feasible voltage vectors are presented in Fig. 1. It is easy to see that the inverter has eight different switching states but only seven different voltage vectors. Thus, the cost function only needs to be calculated seven times. Therefore, g_j has seven different values. In this values, the one that minimizes the g_j is selected as the output vector. h is the predictive horizon. In this work, only one step of PCC is considered, thus h = 1. In the cost function, the state's current values in $\alpha\beta$ frame are required. The inverse Park transformation is presented to satisfy this requirement as follows:

$$\begin{pmatrix}\alpha\\ \beta\end{pmatrix} = \begin{pmatrix} cos(\theta) & -sin(\theta)\\ sin(\theta) & cos(\theta)\end{pmatrix}\begin{pmatrix} d\\ q\end{pmatrix} \ldots\ldots 34$$

It was concluded that the PCC controller provided better transient state performance and low order harmonic minimization. Where each d-q-x-y current term is defined as:

$J = \bar{\bar{\imath}}_{sd} + \bar{\bar{\imath}}_{sq} + W_{xy}[\overline{\overline{i_{sxy}}}]$….35

$\bar{\bar{\imath}}_{sd} = (i^*{}_{sd}(k+2) - \hat{\imath}_{sd}(k+2))^2$, $\bar{\bar{\imath}}_{sq} = (i^*{}_{sq}(k+2) - \hat{\imath}_{sq}(k+2))^2$ ….36

$\bar{\bar{\imath}}_{sxy} = (i^*{}_{sx}(k+2) - \hat{\imath}_{sx}(k+2))^2 + (i^*{}_{sy}(k+2) - \hat{\imath}_{sy}(k+2))^2$ ….37

B.PREDICTIVE TORQUE CONTROL (PTC)

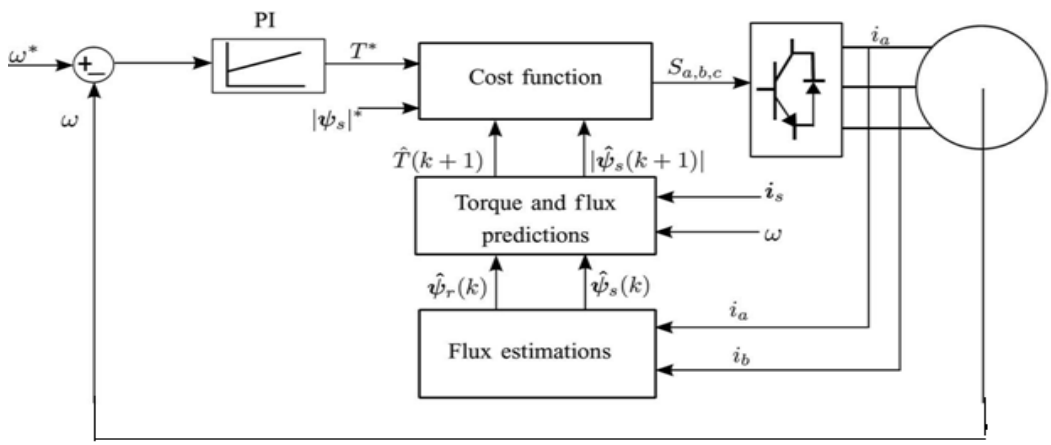

Fig.3 MPC based Predictive Torque Control with an outer speed control loop.

Predictive Torque Control (PTC) based on FCS-MPC for three phase two-level induction motor drives given in [20] is shown in Fig. 3. It is done by an outer PI based speed control and an inner PTC and controlled variables are the stator flux and torque. Torque reference is provided by an external PI, based on the speed error, while the stator flux reference has been set at its nominal value for base speed operation**.** Then the cost function (10) is evaluated and the switching state with lower cost (J) is applied to the VSI. In order to improve PTC performance in [17] a modified cost function was presented, aimed to not only control stator flux and produced torque but also limit the maximum achievable α-β stator currents to ($i\alpha\beta{-}MAX$) and reducing harmonic components in the x-y plane.

$$J = \frac{1}{T_n^2}\left(T_e^*(k) - T_e(k+1)\right)^2 + \frac{1}{\Lambda_{sn}^2}\left(\Lambda_s^*(k) - \Lambda_s(k+1)\right)^2 \ldots.38$$

$$J = \frac{1}{T_n^2}\bar{\bar{T}}_e + \frac{1}{\Lambda_{sn}^2}\bar{\bar{\Lambda}}_s + K_{\propto\beta}\left(\left|i_{s\alpha\beta}[k+1]\right| > i_{\alpha\beta-MAX}\right) + \frac{1}{i_{sn}^2}\left|i_{sxy}[k+1]\right|^2 \ldots 39$$

Where torque and flux terms are defined as:

$$\bar{\bar{T}}_e = (T_e^*(k) - T_e(k+1))^2, \bar{\bar{\Lambda}}_s = (\Lambda_s^*(k) - \Lambda_s(k+1))^2 \ldots 40$$

In the predictive algorithm, the next-step stator flux $\hat{\psi}_s(k+1)$ and the electromagnetic torque $\hat{T}(k+1)$ must be calculated. The stator flux prediction can be obtained [15,16]

.

$$\hat{\psi}_s(k+1) = \psi_s(k) + T_s.v_s(k) - R_s.T_s.i_s(k) \ldots\ldots 41$$

The electromagnetic torque can be predicted as

$$\hat{T}(k+1) = \frac{3}{2}.p.Im\{\hat{\psi}_s(k+1)^*.\hat{\imath}_s(k+1)\} \ldots\ldots\ldots 42$$

The classical cost function for the PTC method is

$$g_j = \sum_{h=1}^{N}\{|T^* - \hat{T}(k+h)_j| + \Lambda.\left|\|\psi_s^*\| - \|\hat{\psi}_s(k+h)_j\|\right|\} \ldots\ldots 43$$

IV. Implementation and Results

A. Simulation Results:

To verify the potential of the two schemes, a simulation comparison in MATLAB Simulink is performed. The parameters of PMSM motor are given in Table 1. For all simulation, the motor characteristics will be utilized as below.

Stator phase resistance Rs (ohm)		= 4.3
Armature Inductance	(H)	= 0.0001
Flux linkage established by magnets	(V.s)	= 0.05
Voltage Constant	(V_peak L-L / krpm)	= 18.138
Torque Constant	(N.m / A_peak)	=0.15
Inertia, friction factor, pole pairs	[J (kg.m^2)]	=0.000183
Friction factor	F (N.m.s)	= 0.001
Pole pairs	p()	=2
Initial conditions	[wm(rad/s) thetam(deg) ia,ib(A)]= [0,0, 0,0]	
Sampling Time	(Sec)	=1

Table. 1: PMSM parameters

The Matlab, Simulink model of PCC and PTC methods with PMSM using 2-level inverter shown in Fig.4(a) and Fig.4(b). and the Simulink model of PCC and PTC methods with IM using 2-level inverter shown in Fig.5(a) and Fig.5(b). To achieve a comparison between the two methods, the external PI speed controllers are configured with the same parameters. The simulation results of the PCC method and the PTC method with PMSM and IM using 2-level inverter is shown in Fig.6, Fig.7 respectively. From the pictures, we can see that both methods have good and similar behaviors at this point in the operation. The PCC method has a slightly better current response; however, the torque ripples of the PTC method are lower than those of the PCC method. The performances in the whole speed range are investigated in the simulations. The motor rotates from positive nominal speed to negative nominal speed. During this dynamic process, the measured speed, the torque, and the stator current are observed. It is clear that both methods have very similar waveforms [10]. They each have almost the same settling time to complete this reversal process due to the same external speed PI parameters. The torque ripples of the PTC method are slightly lower than those of the PCC method. From these simulations, we can conclude that two methods can work well in the whole speed range and have good behaviors with full load at steady states. Induction motor work on only lagging power factor means it can produce only 70-90% of torque produced by PMSM with same current.

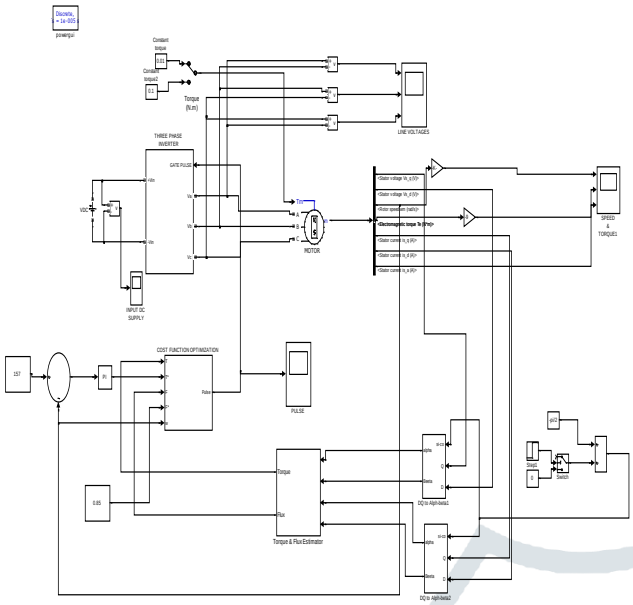

Fig.4(a)

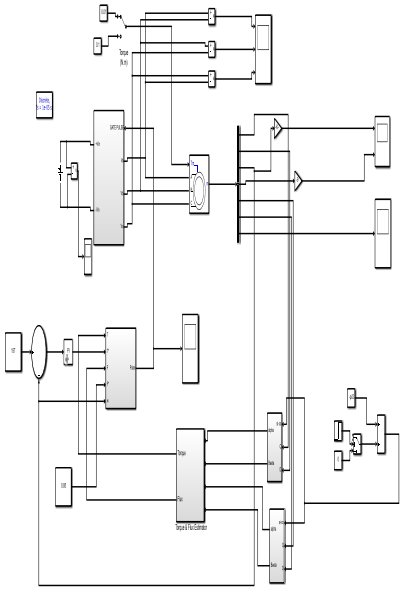

Fig.4(b)

Fig.4 Matlab Simulink model of PCC method with a)PMSM b) IM

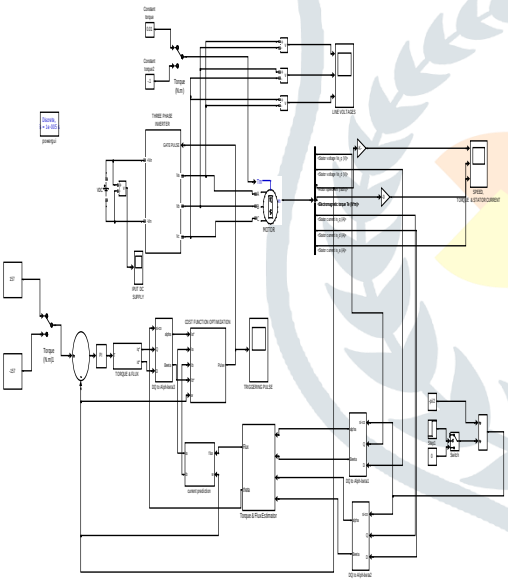

Fig.5(a)

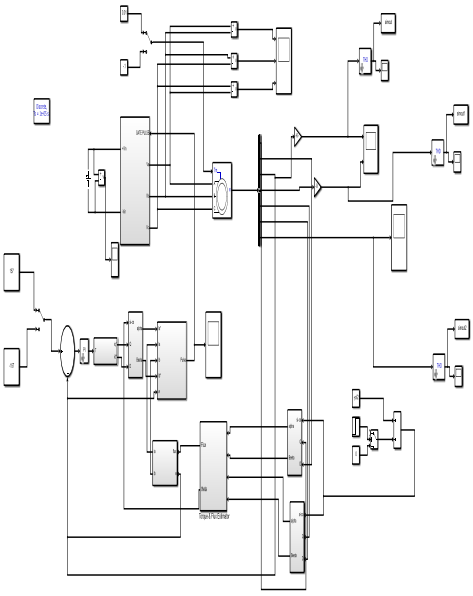

Fig.5(b)

Fig.5 Matlab Simulink model of PTC method with a)PMSM b) IM

Fig.6 (a) Rotor speed in PCC

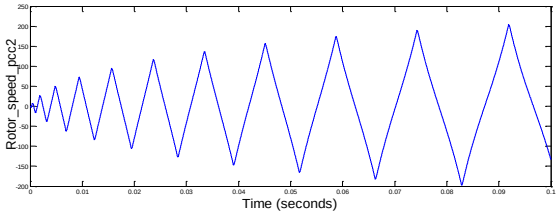

Fig.7 (a) Rotor speed in PTC

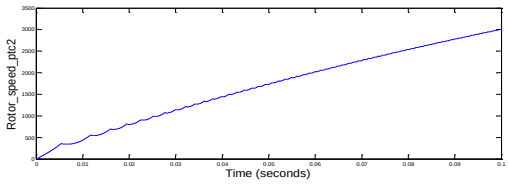

Fig.6 (b) Stator current in PCC

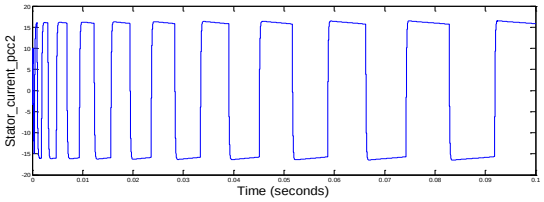

Fig.6 (c) Obtained torque in PCC

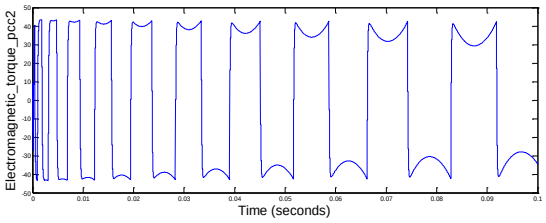

Fig.6(d) THD in rotor speed

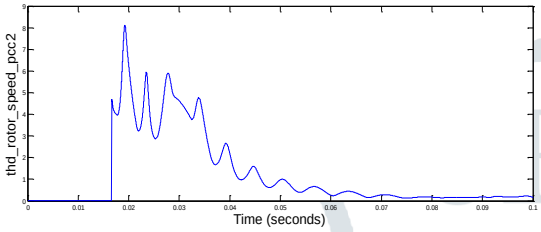

Fig.6(e) THD in electromagnetic torque

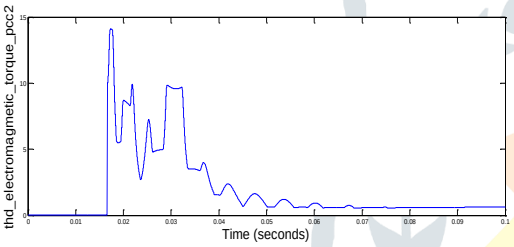

Fig.6 (f) THD in stator current

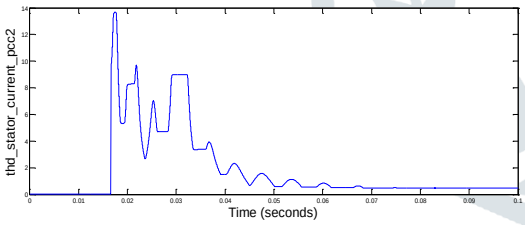

Fig.6 PCC using 2-level VSI with PMSM Simulations results: speed, torque, and current current waveforms of PCC in steady state.

Fig.7 (b) Stator current in PTC

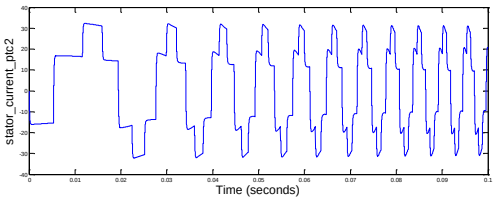

Fig.7 (c) Obtained torque in PTC

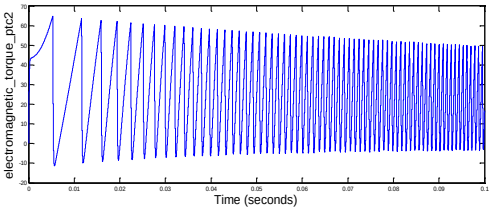

Fig.7(d) THD in rotor speed

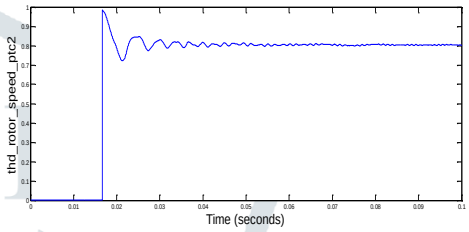

Fig.7(d) THD in electromagnetic torque

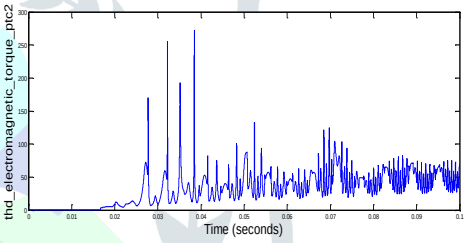

Fig.7 (f) THD in stator current

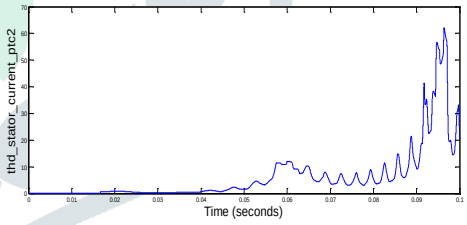

Fig.7 PTC using 2-level VSI with PMSM Simulations results: speed, torque, and waveforms of PCC in steady state.

Fig.8 (a) Rotor speed in PCC

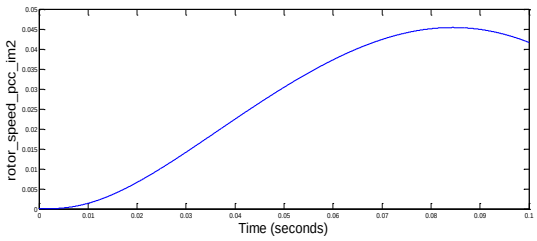

Fig.9 (a) Rotor speed in PTC

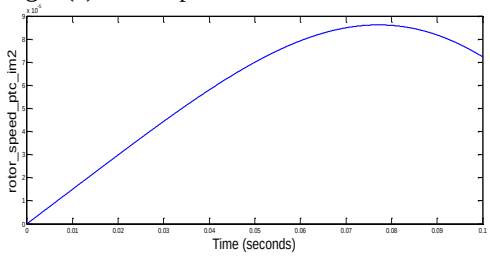

Fig.8 (b) Stator current in PCC

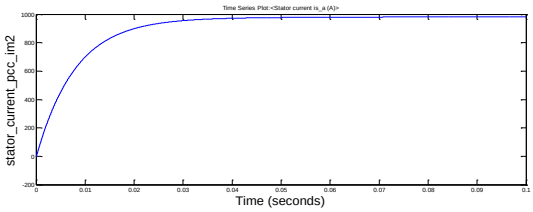

Fig.8 (c) Obtained torque in PCC

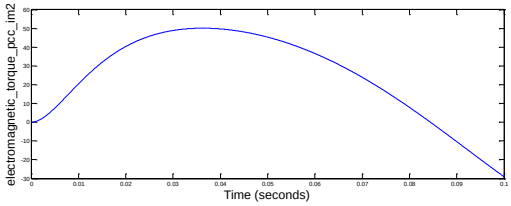

Fig.8 (d) THD in rotor speed

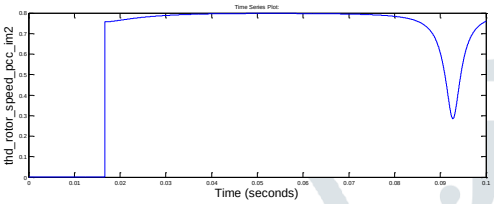

Fig.8 (e) THD in electromagnetic torque

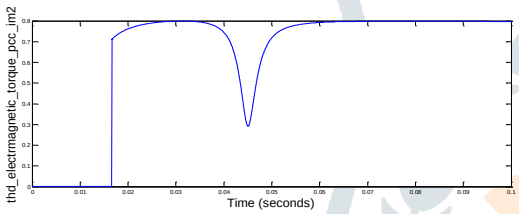

Fig.8 (f) THD in stator current

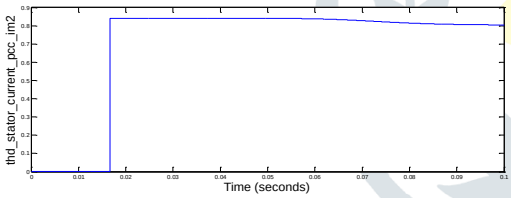

Fig.8 PCC using 2-level VSI with IM
Simulations results: speed, torque, and current current waveforms of PCC in steady state.

Fig.9 (b) Stator current in PTC

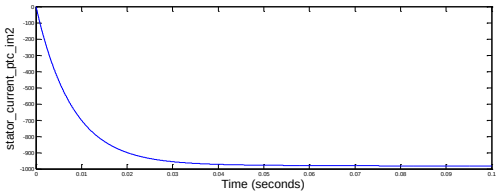

Fig.9 (c) Obtained torque in PTC

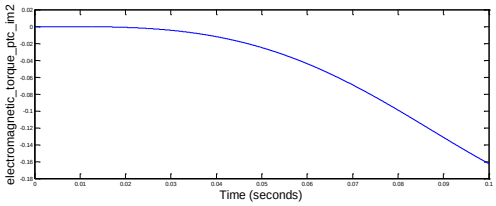

Fig.9 (d) THD in rotor speed

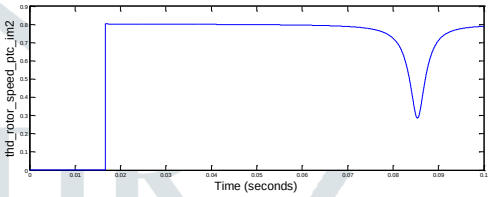

Fig.9 (e) THD in electromagnetic torque

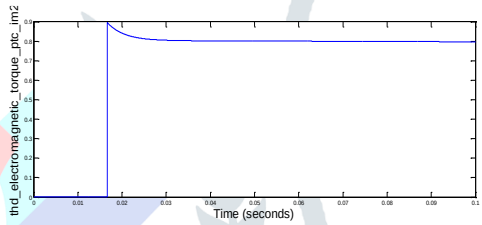

Fig.9 (f) THD in stator current

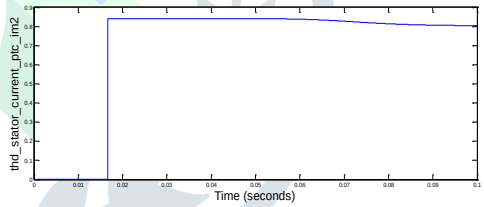

Fig.9 PTC using 2-level VSI with IM
Simulations results: speed, torque, and waveforms of PCC in steady state.

Both the PTC and PCC methods are most useful direct control methods with PMSM method gives 10% to 30% more torque than an induction motor also not require modulator [3]. Induction motor work on only lagging power factor means it can produce only 70-90% of torque produced by PMSM with same current. In this paper, switching loses minimization technique through THD minimization. Total harmonic distortion (THD) has calculated successfully in this article by using MATLAB 2013 compare to (10). The THD calculation of electromagnetic torque in the PCC and PTC Simulink model for PMSM with 2-level inverter is shown in Fig.6 (d,e,f) and Fig.7 (d,e,f). The THD calculation of electromagnetic torque in the PCC and PTC Simulink model for IM with 2-level inverter is shown in Fig.8 (d,e,f) and Fig.9 (d,e,f). The PCC and PTC method with 2-level inverter using PMSM reduces 36% more THD in torque, speed and stator current compared to PCC and PTC method with 2-level inverter using an induction motor shown detail in Table.3 [21].Graphical representation of % THD in rotor speed, electromagnetic torque and stator current also shown in graph-1,2,3. The comparative issues between PCC and PTC also shown in Table.2. Switching losses are minimized because the transistors are only switched when it is needed to keep torque and flux within their bounds. The switching pattern of semiconductor switches used to get better performance of multilevel inverter. This scheme decreases the switching loss and also increases the efficiency & reduced losses. In this paper, the PTC and PCC methods with 2-level inverter using PMSM and IM are carried out and gives excellent torque and flux responses, robust, and stable operation achieved compared to the PTC and PCC methods with 2-level voltage source inverter. This novel method attracted the researchers very quickly due to its straightforward algorithm and good performances both in steady and transient states. The proposed scheme shows better response as compared to the conventional one in terms of ripple in speed, torque and stator current during transient conditions [10].

Sr. No	Different Methods	%THD in		
		Rotor Speed (w_r)	Torque (T_e)	Stator Current
1	PCC with PMSM using 2-level voltage source inverter(VSI)	82.45%	68.60%	39.39%
2	PTC with PMSM using 2-level voltage source inverter(VSI)	84.11%	41.40%	90.02%
3	PCC with IM using 2-level voltage source inverter(VSI)	118.86%	104.14%	75.21%
4	PTC with IM using 2-level voltage source inverter(VSI)	120.20%	77.38%	125.34%

Table.2: %THD Calculation comparison

V. CONCLUSION

In this paper, PCC and PTC methods of MPC family with 2-level inverter have been presented and discussed.The PCC and PTC methods with 2-level inverter are direct control methods without an inner current PI controller or a modulator, the PCC method with 2-level inverter has lower calculation time than the PTC method with 2-level inverter, fast dynamic response, and Lower stator current harmonics than PTC. This advantage makes the PCC method more accurate for applications with longer prediction horizons. From the test results, it is clear that the PCC method and the PTC method with 2-level inverter have very good and similar performances in both steady and transient states. PTC method with 2-level inverter has lower torque ripples; however, the PCC method with 2-level inverter is better when the currents are evaluated. This novel method attracted the researchers very quickly due to its straightforward algorithm and good performances both in steady and transient states. Future work is to test switched reluctance motor, and servo motor with 2-level VSI and multilevel inverter is applied to PCC and PTC method, we can imagine that the PCC algorithm and PCC algorithm will greatly reduce the calculation time. The PCC method shows strong robustness with respect to the stator resistance; however, the PTC method shows much better robustness with respect to the magnetizing inductance.

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