International Journal of Latest Engineering Research and Applications (IJLERA) ISSN: 2455-7137

Volume – 02, Issue – 10, October – 2017, PP – 72-77

A three phase closed loop vector control for IPMSM drive

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Abstract: This paper presents a three phase closed loop vector control for IPMSM drives. The proposed control technique gives the simple and high-performance motor drive. In addition maximum torque per ampere block is implemented to optimize torque generation efficiency without power factor angle calculation. This makes more robust against disturbances. This proposed technique is more preferred for small and medium rating applications. This proposed technique is ideal for applications which require good performance over the wide operating speed rages. It also presents robustness to parameters variation causes by temperature or flux. This paper discusses the theoretical analysis along with simulation results.

Keywords: closed loop vector control, interior permanent-magnet synchronous motor, SVPWM technique.

I. INTRODUCTION

Recently there has a significant research interest to control of interior permanent magnet synchronous motor (IPMSM). It involves some features robust control, better efficiency constant power density [1]. In this proposed technique also says sensor less control way because it does not require for any positional sensors and encoders. These sensor less control is also sub-divide into two types 1) field oriented control and 2) v/f control. Above two techniques used to control the IPMSM drives. Suppose positional sensors such as incremental encoders, resolvers it enables highly accurate torque and speed control, but it minimizes possible synchronous issues [1]. This paper proposes the vector control technique, in this vector control takes rotor speed and which compares the reference speed.

Another control technique is field-oriented technique, by using d-axis and q-axis values may be voltage or currents depending on our requirements to changes the SVPWM pulses. But this technique not better for dynamic conditions.

Compare to control technique performances vector control technique is simple operation than v/f control technique.

Designing of vector control technique is very simpler compared to v/f control technique. Interior permanent magnet synchronous motor (IPMSM). It is the one of the type for permanent synchronous motor, generally PMSM divided in to two types 1) surface mounted 2) interior or buried.

These two types are divided depending upon rotor inductance values (nothing but Ld. and Lq). In this proposed circuit uses the interior type motor.

In this proposed technique uses mostly for which system operate the three phase drives, at that conditions this circuit better suitable for operating. This technique also uses maximum torque per ampere (MTPA) technique. This proposed technique involves abc/dq techniques, by using mathematical equations to design the related block. The vector control is simple control structure and low cost implementation feasibility [4]. To control the motor speed and torque values by using the d-axis and q-axis parameters.

In sensor less FOC, the rotor position information obtained through observers determines the current vector phase angle such that the angular difference between the stator flux vector and the rotor flux vector can be optimized by current controllers. In order to take advantage of IPMSM rotor saliency, strategies based on maximum torque per ampere (MTPA) point determination have been developed to find the optimal references for *d–q* axis currents in [4]so that torque generation efficiency can be optimized. For sensor less FOC, the knowledge of the rotor position is crucial, and methods such as model-based observers [5] and high frequency signal injection [5] have been developed and employed for IPMSM control. Due to IPMSM's rotor saliency, extended electromotive force models are used for the observer design [5-6] either in the stationary reference frame or the rotating reference frame. The observer performance is parameter dependent and even small errors caused by parameter variation can easily jeopardize the stability of the control systems.

Another important parameter is load angle calculation it involves supply voltage and current parameters to find out the load angle. Total proposed control technique depends on these load angle parameter variation.

II. PROPOSED CIRCUIT

These proposed vector control technique variation depends upon the d-axis and q-axis voltages. By using some mathematical equations to covert the ABC reference voltages to d-axis and q-axis voltages [4]. Without rotor position information, the voltage reference can be determined in the Gama and delta frame.

In the proposed vector control scheme, the VSI voltage reference is directly derived from the speed command.

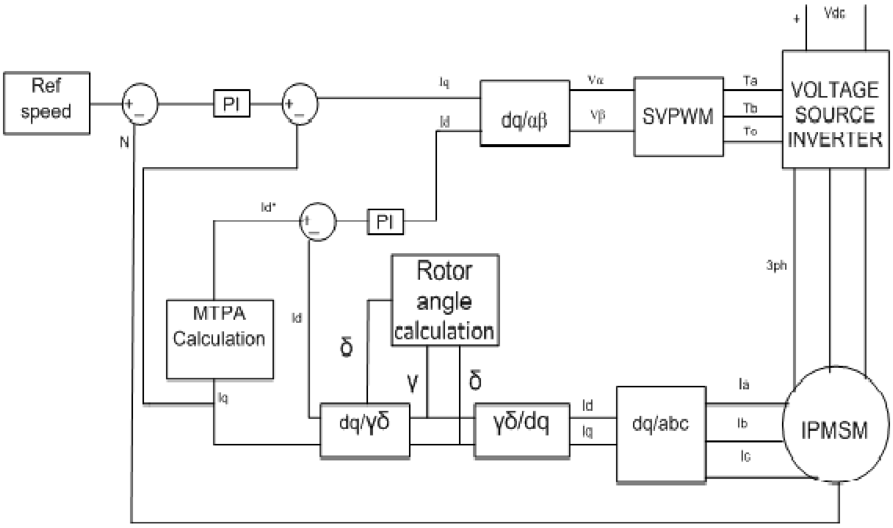

Fig.1. proposed vector control circuit.

$$\begin{bmatrix} Vd \\ Vq \end{bmatrix} = \begin{bmatrix} R + pLd & -w_r Lq \\ wrLd & R + pLq \end{bmatrix} \begin{bmatrix} Id \\ Iq \end{bmatrix} + w_r \varphi \text{pm} \begin{bmatrix} 0 \\ 1 \end{bmatrix} \qquad (1)$$

Where Vd and Vq are d-axis and q-axis voltages, Id and Iq are d-axis and q-axis currents, respectively. R, w_r, Ld, Lq, and φpm are stator resistance, rotor electrical angular frequency, d-axis inductance, q-axis inductance, and permanent magnet flux linkage, respectively.

Without rotor position information $\gamma - \delta$ reference frames will be calculated.

$$\begin{bmatrix} V\gamma \\ V\delta \end{bmatrix} = \begin{bmatrix} R + pLd & -w_e Lq \\ weLd & R + pLq \end{bmatrix} \begin{bmatrix} I\gamma \\ I\delta \end{bmatrix} + w_e \varphi pm \begin{bmatrix} \sin\delta \\ \cos\delta \end{bmatrix} \qquad (2)$$

$$\begin{bmatrix} Id \\ Iq \end{bmatrix} = \begin{bmatrix} \cos\delta & -\sin\delta \\ \sin\delta & \cos\delta \end{bmatrix} \begin{bmatrix} I\gamma \\ I\delta \end{bmatrix} \qquad (3)$$

Where Vγ and Vδ are $\gamma -$ axis and $\delta -$ axis voltages, Iγ and Iδ are $\gamma -$ axis and $\delta -$ axis currents, respectively. δ is the load angle and w_e denotes the voltage electrical angular frequency.

In the proposed closed loop vector control circuit having the two parameter correction d-axis and q-axis voltages error and frequency errors, these two correction parameters use to control the voltage source inverter pulses [5]. This proposed circuit does not require for any stabilizing loops.

In general, Id and Iq can only derived with performance of the rotor position either by sensor measurements or observer estimation. To control the motor performance compulsory required for load angleδ. That's why these proposed control technique calculate the load angle.

$$\varphi = \tan^{-1}\left[\frac{V\delta\ I\gamma}{V\delta\ I\delta}\right] = \tan^{-1}\left[\frac{V\gamma}{V\delta}\right] \qquad (4)$$

$$\delta = \tan^{-1}\left[\frac{I\,X_q\,cos\varphi\ - I\,R\,sin\varphi}{U - I\,R\,cos\varphi\ - I\,X_q\ sin\varphi}\right] \qquad (5)$$

While I and V are the rated voltage and currents, by using these two values to calculate the load angleδ. By use this load angleδ we can control the $\gamma - \delta$ reference frames [7]. Overall system output values depend on this load angle. Does not require for any positional sensors we can control this load angle positions that's why these proposed technique says sensor less control.

I. TABLE I
IPMSM PARAMETER

S.No	Parameters	Values
1	Resistance R	1.07Ω
2	d-axis inductance	0.0099 H
3	q-axis inductance	0.021H
4	Flux linkage	0.20wb
5	Pole pairs	3
6	inertia	0.0018kg/m^2
7	Rated speed	1800rpm
8	Rated torque	3N-m
9	Rated current	2.58A
10	Rated voltage	300V

I_d,I_q,δ, and rotor angular frequency ω_r are chosen to be the state variables. The voltage amplitude V and angular frequency ω_e as well as the load torque T_L are the system inputs.

III. MAXIMUM TORQUE PER AMPERE (MPTA)

The control system optimizes torque generation by determining both Id and Iq references. In the constant region, there is a load dependent Id – Iq combination to achieve maximum torque generation efficiency, nothing but MTPA [6-9]. That's why after finding the d-axis value and q-axis values we are applying the maximum torque per ampere calculation.

In the steady state, the average electromagnetic torque developed by the PMSM is expressed as in (6).

$$T_e = \frac{3}{2}\,\mathrm{p}\,[Iq\varphi pm + (Ld - Lq)IqId] \quad (6)$$

$$V_d = \frac{\varphi_{pm}}{2\,(L_q - L_d)} - \sqrt{\frac{{\varphi_{pm}}^2}{4\,(L_q - L_d)^2} + {V_q}^2} \quad (7)$$

This equation consists of two terms. First term is reactance torque and second term represents the current- induced magnetic fluxes along the two axes interact with corresponding current components to the second reluctance torque term. MTPA is achieved when the current component is aligned with q-axis. When there is no rotor saliency, MTPA is achieved when the current vector is aligned with q-axis. In other words, I_d should be zero, and I_q should be linearly proportional to the generated torque in the constant torque region. However, because of IPMSM rotor saliency, MTPA is achieved by maintaining a certain combination of I_d and I_q under different circumstances.

In the constant torque region, the MTPA objective is to minimize the stator current amplitude, while I_d and I_q are subject to [6] for demanded torque generation. Under this condition, the amplitude of the stator current is the only constraint. Then, the relationship between I_d and I_q for maximum torque generation in the constant torque region. IPMSM performance can be improved if PI parameters are properly tuned for different operation conditions.

Recently, there are many also many studies in the literature on MTPA taking many tradeoffs and factors into account such as machine parameter variation. Mainly, such efficiency optimization methods are expressed in terms of Id, Iq. MTPA is usually achieved indirectly by regulating the reactive power or power factor angle [6-7]. Load angleδ is calculated in the proposed closed loop vector control technique, Id and Iq can easily be derived leading convenient integration of efficiency optimization theories including MTPA.

IV. CONVERTION CIRCUIT

In this proposed technique using three phase voltage source inverter. Available supply DC but we are connecting IPMSM drive, to drive the motor required AC supply that's why we are using three phase voltage source inverter. It converts DC supply to AC. Converting AC supply very small not suitable for to operate the heavy loads.

VOLTAGE SOURCE INVERTER:

Three-phase dc-ac inverter is commonly used in the industry. There are many applications in industry that used this type of conversion (dc-ac) in order to operate. In this inverter having six switches T1, T2, T3, T4, T5, and T6, also it having three legs. Every leg require two switches, first leg connecting T1 and T4, second leg connecting T3 and T6, third leg connecting T5 and T2. Every 60 degrees conduction period will be changes.

SIMULATION RESULTS

The simulation of a three phase closed loop vector control for IPMSM drive is done in MATLAB/SIMULINK. The inverter output voltages and currents, motor output parameters can be analyzed through Simulink. Also compare the theoretical analysis and simulation results.

The simulations are implemented in MATLAB in order to justify the necessity and effectiveness of the proposed stabilizing loops. First, the capability to tolerate sudden load change is tested. When the motor is running at 800 rpm, the load is stepped up from 0%to 50% and 50% to 100% of the rated load.

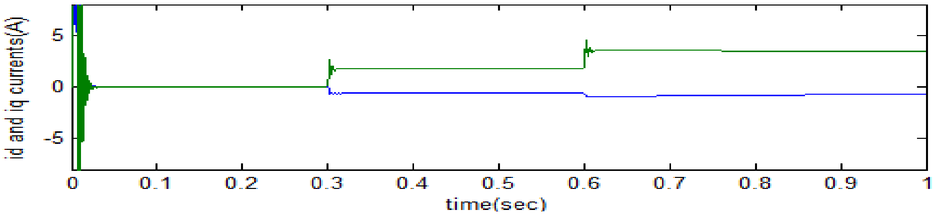

Fig.2. Simulation result for id and iq currents.

The accurate derivation of I_d and I_q is critically important and it depends on precise load angle calculation.

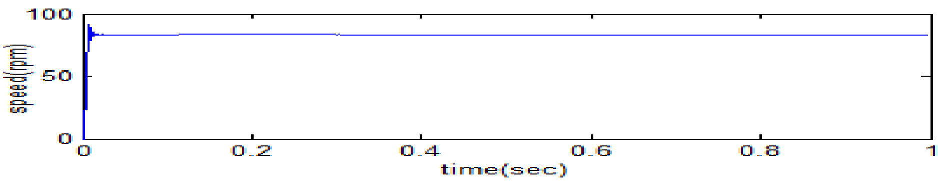

Fig.3. Simulation result for IPMSM speed.

When the load angle is increased from 0% to 50% of the rated load, the IPMSM drive runs at 90 rpm.

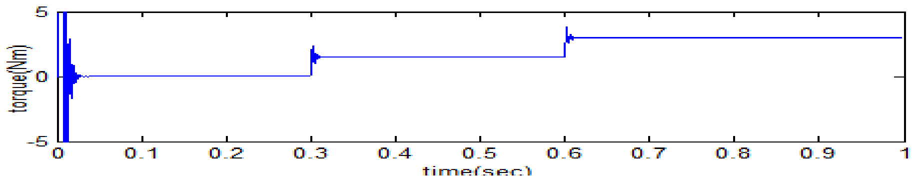

Fig.4. Simulation result for IPMSM torque.

When the inverter voltage and currents changes, suddenly IPMSM torque will be varied.

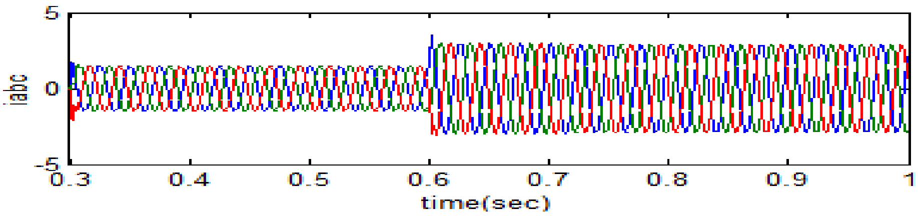

Fig.5. Simulation result for iabc currents.

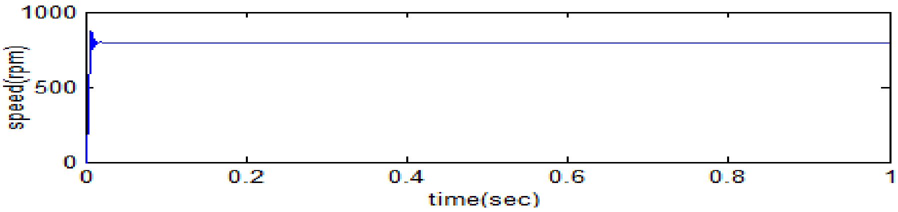

Fig.6. Simulation result for IPMSM speed.

When the load angle is increased from 50% to 100% of the rated load, the IPMSM drive runs at 800 rpm.

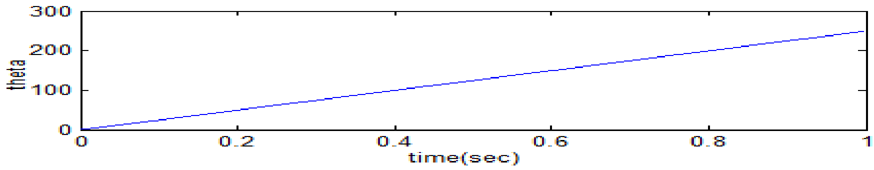

Fig.7. Simulation result for angle theta.

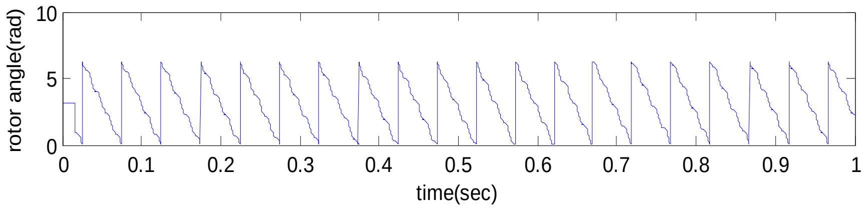

Fig.8. Simulation result for IPMSM rotor angle.

When the d-axis and q-axis currents (Id, Iq) changes, corresponding rotor angle will be changed. When the torque generation efficiency is effected by two factors, Id and Iq currents, MTPA integrated calculations.

CONCLUSION

This paper presents three phase closed loop vector control for IPMSM drives. The proposed closed loop vector control not only controls the wide speed ranges it also obtain the maximum torque per ampere (MTPA). This circuit maintains stable operation under very low speed ranges it is most challenging task in sensor less control. Its robustness to machine parameter variation and achieving better control performance without using any speed feedbacks. Robustness and advantages of the proposed closed loop vector control circuit are verified through simulation results.

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