TRANSIENT PERFORMANCE OF VSI-FED IM DRIVE WITH SPACE VECTOR PULSE WIDTH MODULATION METHODS BY CONVENTIONAL CONTROLLERS

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***Abstract*:** This research paper has been endeavored to presents transient performance of VSI (Voltage Source Inverter)-fed IM (Induction Motor) drives with SVPWM (Space Vector Pulse with Modulation) method based on P (Proportional), PI (Proportional Integral), and PID (Proportional Integral Derivative) controllers. Generally, the principle of working a 3-phase IM (Induction Motor) specifies that speed of motor is unswervingly linked to frequency of supply. This information has made inverter fed IM (Induction Motor) having a very common configuration in popular of industrial applications. The VSI (Voltage Source Inverter)-fed IM (Induction Motor) drives are progressively applied in numerous topical industrial applications that need excellent transient performance of drives. There is a growing trend of using SVPWM (Space Vector Pulse with Modulation) due to their easier digital realization and improved DC bus utilization ability. Benefits of lower harmonics and a greater modulation index in count to aspects of whole digital implementation by a sole chip microprocessor, due to it flexibility of manipulation; SVPWM (Space Vector Pulse with Modulation) has growing applications in power converters and motor control. Simulation consequences and deliberations concerning with SIMULINK model of VSI (Voltage Source Inverter)-fed IM (Induction Motor) drives with SVPWM (Space Vector Pulse with Modulation) method based on P, PI, & PID controllers are attained using MATLAB/SIMULINK surroundings for efficacy of anticipated method.

***Keywords*—**VSI, P, PI, and PID Controllers, IM Drives, SVPWM.

I. INTRODUCTION

IM are today a standard for industrial electrical drives and high performance variable speed drive application have a series of advantages. There are several ways for speed control of IMs fed through the VSIs using different modulation techniques. Researchers, scientist and engineers are continuously inventing the new techniques and methods that cover the speed control requirements of the drive. Advanced control techniques such as fuzzy, neuro-fuzzy, genetic algorithm, sliding mode control, etc. have also been extensively used in motion control applications. The transient performance of a closed loop VSI-fed IM drive using different speed controllers has been analyzed and discussed for step variation in reference speed and reference load torque. Today IM is a standard for industrial electrical drives and high performance variable speed drive application have a series of advantages. High dynamic performance of IM drive is obligatory in many applications of today's automatic control machine [1].

VSIs are used to regulate the speed of three-phase squirrel cage IM (SCIM) by changing the frequency and voltage and consist of input rectifier, DC link and output converter. They are available for low voltage range and medium voltage range. The basic action involved in adjustable speed control of IM is to apply a variable voltage magnitude, and variable frequency to the motor so as to obtain variable speed operation. Both the VSI and Current Source Inverter (CSI) are used in adjustable speed AC drives [2]-[3]. Fig.1. shows the block diagram block diagram of VSI-fed IM drive using P, PI and PID controllers' technique in this theory.

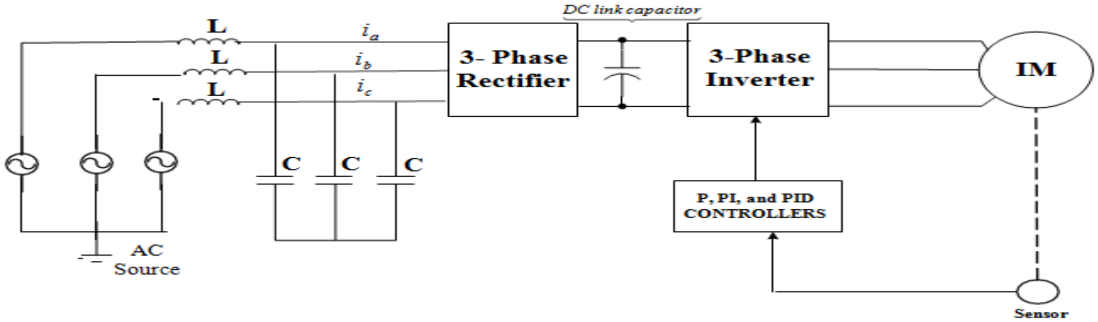

Figure.1 Block Diagram of VSI-Fed IM Drive using P, PI and PID Controllers

The transient performance of VSI-fed IM drive has been used in high-horse power adjustable-speed applications. Many strategies have been proposed in open literatures, for controlling the motion of VSI-fed IM drives such as slip control, synchronous control, angle control, field-oriented control (FOC), and others.

II. MATHEMATICAL MODELING OF VSI-FED THREE-PHASE IM DRIVES

The mathematical model of the SCIM system used in our work consists of SVPWM VSI, IM. The power circuit of the three phases IM is shown in the Fig. 2.

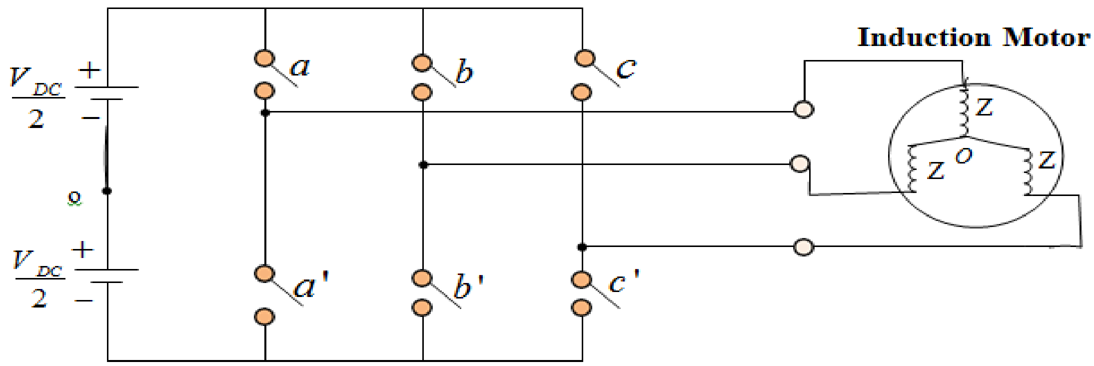

Figure.2 Power Circuit Diagram of IM

The equivalent circuit used for obtaining the mathematical model of the IM is shown in the Fig. 3. An IM model is then used to predict the voltage required to drive the flux and torque to the demanded values. This calculated voltage is then synthesized using the space vector modulation (SVM). The stator & rotor voltage equations are given.

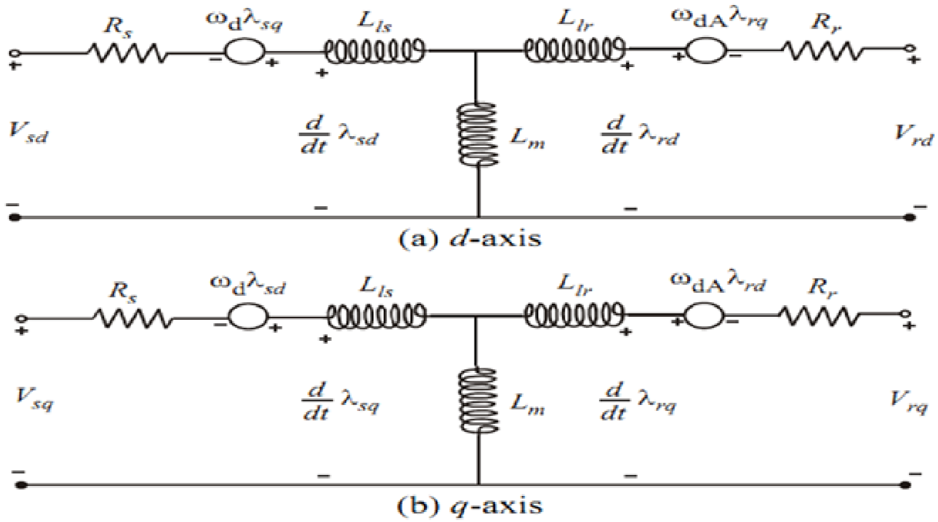

Figure.3 Equivalent Circuit of IM in D-Q Frame

$$V_{sd} = R_s i_{sd} + \frac{d}{dt}\lambda_{sd} - \omega_d \lambda_{sq} \quad (1)$$

$$V_{sq} = R_s i_{sq} + \frac{d}{dt}\lambda_{sq} - \omega_d \lambda_{sd} \quad (2)$$

$$V_{rd} = R_r i_{rd} + \frac{d}{dt}\lambda_{rd} - \omega_{dA} \lambda_{rq} \quad (3)$$

$$V_{rq} = R_r i_{rq} + \frac{d}{dt}\lambda_{rq} - \omega_{dA} \lambda_{rq} \quad (4)$$

where *sd V sq V* , *rd V* and *rq V* are the direct & quadrature axes stator and rotor voltages. The SCIM has the d-axis and q-axis components of the rotor voltage zero. The flux linkages to the currents are related by the eqn. (4) as;

$$\begin{bmatrix}\lambda_{sd}\\ \lambda_{sq}\\ \lambda_{rd}\\ \lambda_{rq}\end{bmatrix} = M \begin{bmatrix} i_{sd}\\ i_{sq}\\ i_{rd}\\ i_{rq}\end{bmatrix}; M = \begin{bmatrix} L_s & 0 & L_m & 0\\ 0 & L_s & 0 & L_m\\ L_m & 0 & L_r & 0\\ 0 & L_m & 0 & L_r\end{bmatrix} \quad (5)$$

The electrical part of an IM thus be described by a fourth order state space model (4 × 4), which is given in eqn. (5), by combining eqns. (1)-(4);

$$\begin{bmatrix} i_{sd}\\ i_{sq}\\ i_{rd}\\ i_{rq}\end{bmatrix} = \frac{1}{L_m^2 - L_r L_m} \times \left(A \begin{bmatrix} i_{sd}\\ i_{sq}\\ i_{rd}\\ i_{rq}\end{bmatrix} + \begin{bmatrix} L_s & 0 & L_m & 0\\ 0 & L_s & 0 & L_m\\ L_m & 0 & L_r & 0\\ 0 & L_m & 0 & L_r\end{bmatrix} \begin{bmatrix} iV_{sd}\\ V_{sq}\\ V_{rd}\\ V_{rq}\end{bmatrix} \right) \quad (6)$$

Where, A is given by

$$A = \begin{bmatrix} L_sR_s & \omega_{dA}L_m^2 - \omega_sL_rL_s & -L_mR_r & -L_rL_m(\omega_s - \omega_{dA}) \\ -(\omega_{dA}L_m^2 - \omega_sL_rL_s) & L_rR_s & -L_rL_m(\omega_s - \omega_{dA}) & -L_mR_r \\ -L_mR_s & L_sL_m(\omega_s - \omega_{dA}) & L_sR_r & \omega_sL_m^2 - \omega_{dA}L_r \\ -L_sL_m(\omega_s - \omega_{dA}) & -L_mR_s & -(\omega_sL_m^2 - \omega_{dA}L_rL_s) & L_sR_r \end{bmatrix} \quad (7)$$

By superposition, i.e., adding the torques acting on the d-axis and the q-axis of the rotor windings, the instantaneous torque produced in the electromechanical torque is given by;

$$T_{em} = \frac{P}{2}(\lambda_{rq}i_{rd} - \lambda_{rd}i_{rq}) \quad (8)$$

The electromagnetic torque expressed in terms of inductances is given by

$$T_{em} = \frac{P}{2}L_m(i_{sq}i_{rd} - i_{sd}i_{rq}) \quad (9)$$

The mechanical part of the motor is modeled by the equation

$$\frac{d}{dt}\omega_{Mech} = \frac{T_{em}-T_L}{J_{eq}} = \frac{\frac{P}{2}L_m(i_{sq}i_{rd}-i_{sd}i_{rq})-T_L}{J_{eq}} \quad (10)$$

Where, J_{eq} = Equivalent Moment of Inertia

$$\omega_{dA} = \omega_{slip} = \omega_s - \omega_m$$

$$\omega_m = \frac{P}{2}\omega_{mech}, \omega_d = \omega_s$$

$$L_s = L_{sl} + L_m, L_r = L_{rl} + L_m$$

III. CONCEPT OF SVPWM TECHNIQUE

In this proposed for speed a three-phase IM technique, control based on the fact that three phase voltage vectors of the IM can be converted in to single rotating vector. Rotation of this space vector can be implemented by the variable frequency drives (VFD) to generate three phase sine waves [4]. The process of obtaining the rotating space vector is explained in the following section, considering the stationary reference frame. The three phase sinusoidal and balance voltages given by the equations as follows

$$V_{An} = V_m cos\omega t \quad (11)$$

$$V_{Bn} = V_m cos\left(\omega t - \frac{2\pi}{3}\right) \quad (12)$$

$$V_{Cn} = V_m cos\left(\omega t + \frac{2\pi}{3}\right) \quad (13)$$

$$\bar{V} = \frac{2}{3}(V_{An} + aV_{Bn} + a^2V_{Cn}) \quad (14)$$

When this three-phase voltage is applied to the AC machine it produces a rotating flux in the air gap of the AC machine. This rotating flux component can be represented as single rotating voltage vector. The magnitude and angle of the rotating vector can be found by mean of Clark's Transformation as explained below in the stationary reference frame. Space Vector representation of the three phase quantity. Are applied to the three phase IM, using Eqn. (14). A three phase bridge inverter, From Fig. 4, has 8 permissible switching states.

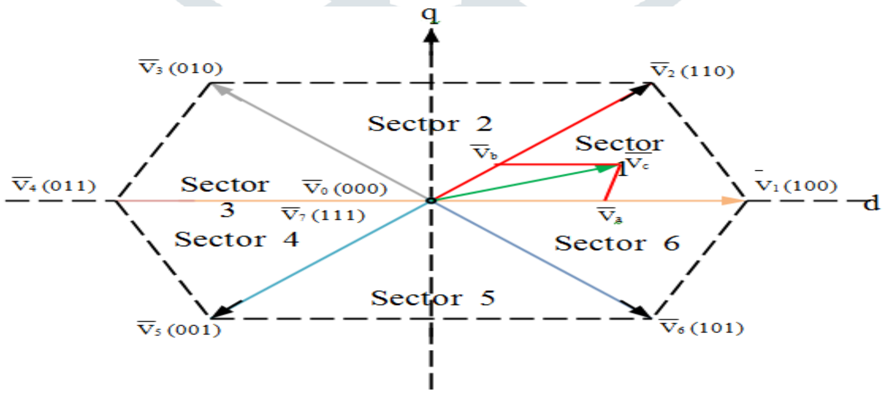

Figure.4 Space Vector of Voltage

$$\bar{V_2} = \frac{2}{3}\left[\frac{V_{DC}}{3} + a\frac{V_{DC}}{3} - a^2\frac{2V_{DC}}{3}\right] = \frac{2}{3}V_{DC}e^{j\frac{\pi}{3}} \quad (15)$$

$$V_{no} = \frac{1}{2}median(V_{An}, V_{Bn}, V_{Cn}) \quad (16)$$

Double edge modulations of reference voltage, Ao Bo V V and Co V are equal as follows:

$$V_{Ao} = V_{An} + V_{no}$$

$$V_{Bo} = V_{Bn} + V_{no} \quad (17)$$

$$V_{Co} = V_{Cn} + V_{no}$$

IV. FUNDAMENTALS OF CONVENTIONALCOTROLLERS

P-I-D controllers use three basic manners kinds of modes: P (Proportional), I (Integral) and D (Derivative). Even though P (Proportional) and I (Integral) modes are as well used as single control modes a D (Derivative) mode is seldom used on its own in control schemes. Such amalgamations for instance PI (Proportional-Integral) and PID ((Proportional-Integral-Derivative) controller are very regularly in practical schemes.

(A) P (PROPORTIONAL) CONTROLLER

A P (Proportional) controller scheme is a kind of linear feedback control scheme. The P (Proportional) controller scheme is more difficult than on-off control schemes similar a bi-metallic domestic thermostat, but modest than a P-I-D control scheme used in somewhat like an automobile cruise control. Generally it can be said that P (Proportional) controller can't stabilize upper order processes.

For 1st order processes, connotation procedures with one energy stowage, a large intensification in gain can be tolerated.

P (Proportional) controller can stabilize only 1st order unstable procedure. Varying controller gain K can change closed-loop dynamics. A great controller gain will consequence in control scheme with:

a) Better reference following i.e. lesser steady state error.

b) Broader signal frequency band of closed-loop scheme and higher sensitivity w.r.t. measuring noise i.e. Faster dynamics

c) Lesser amplitude and phase margin

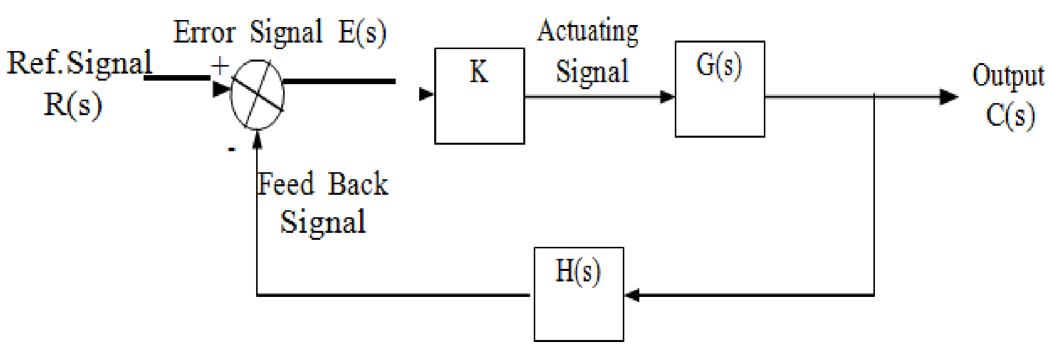

Figure.5 Block Diagram of P (Proportional) Controller

In P (Proportional) controller procedure, controller output is comparative to error signal, which is difference amid set point and procedure adjustable. In P (Proportional) controller actuating signal for control act in a control scheme is proportional to error signal. The error signal being difference amid reference input signal and feed-back signal attained from output.

The actuating signal is relative to error signal consequently; scheme is so-called P (Proportional) controller scheme.

The error of signal assumed as follows:

$$e(t) = k[r(t) - h(t)] \tag{18}$$

It is anticipated that control scheme be under-damped for perspective of quick reply. An under-damped control scheme displays exponentially crumbling in output time response all through transient period.

$$E_{ss} = \lim_{s \to 0} \frac{SR(s)}{1+KG(s)H(s)} \tag{19}$$

(B) PI (PROPORTIONAL INTEGRAL) CONTROLLER

At present-day, P-I (Proportional-Integral) controller is most broadly accepted in industrial application because of its simple structure, simple to design and low price. In spite of these benefits, the P-I (Proportional-Integral) controller fails when controlled entity is very much nonlinear and undefined. P-I (Proportional-Integral) controller will eradicate forced oscillations and steady-state error ensuing in action of on-off controller and P (Proportional) controller correspondingly. Though, introducing I (Integral) mode has a negative (-ive) effect on speed of response and whole stability of scheme. Consequently, P-I (Proportional-Integral) controller will not escalation speed of response. It can be anticipated since P-I (Proportional-Integral) controller doesn't have means to foresee what will occur with error in nearby future. This problematic can be resolved by presenting D (Derivative) mode which has capability to foresee what will happen with error in nearby future and consequently to diminution a reaction time of controller. P-I (Proportional-Integral) controllers are very regularly used in industry, particularly when response speed is not a matter. A control deprived of D (Derivative) mode is used when:

1. Fast response of scheme is not essential.
2. Enormous disturbances and noise are present all through the operation of procedure.
3. There is merely one energy stowage in procedure (capacitive or inductive).
4. There are enormous transport delays in scheme.

Consequently, keep benefits of P-I (Proportional-Integral) controller. This indication to suggest a P-I (Proportional-Integral) controller shown in Figure. This controller uses of P (Proportional) term even though I (Integral) term is kept, unaffected.

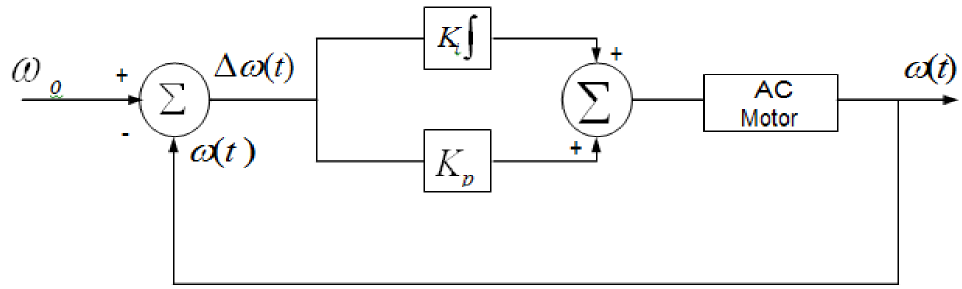

Figure.6 Block Diagram of P-I (Proportional-Integral) Controller

The controller output in this circumstance is

u (t) = K p . e (t) + K i∫ e (t) dt (20)

Fig.6. Block diagram P-I (Proportional-Integral) controller an integral error compensation system, output response is subject to in some way upon integral of actuating signal. This kind of compensation is presented by means of a controller which produces an output signal entailing of 2-terms, one proportional to actuating signal & other proportional to its integral. Such a controller is so-called PI controller or proportional plus integral controller.

(C) PID (PROPORTIONAL-INTEGRAL-DERIVATIVE) CONTROLLER

Numerous industrial controllers employ a P (Proportional), I (Integral) plus D (Differential) i.e. PID regulator making ready that can be tailored to enhance a specific control scheme. PID (Proportional-Integral-Derivative) controller is utmost generally used algorithm for controller design and it is utmost broadly used controller in industry. The controllers used in industry are either one PID controller or its enhanced version. The basic kinds of PID (Proportional-Integral-Derivative) controller are parallel, serial and mixed controller. The PID (Proportional-Integral-Derivative) controller algorithm exploited for is design velocity algorithm; it is furthermore so-called incremental algorithm. In industry, PID (Proportional-Integral-Derivative) controllers are utmost common control approach to use in real applications.

PID (Proportional-Integral-Derivative) controller has all essential dynamics: fast reaction on variation of controller input (Derivative mode), rise in control signal to lead error towards zero (Integral mode) and appropriate act inside control error area to eradicate oscillations (Proportional mode). Derivative (D) mode mends stability of scheme and permits escalation in gain K and diminution in integral time constant T_i, which escalations speed of controller response. PID (Proportional-Integral-Derivative) controllers are utmost regularly used controllers in process industry. The majority of control schemes in world are operated PID (Proportional-Integral-Derivative) controllers. It has been described that 98 percent of control loops in pulp industries and paper industries are controlled by single-input single-output (SISO) PI (Proportional-Integral) controllers and that in process control applications, more than 95 percent of controllers are of PID (Proportional-Integral-Derivative) kind controller. PID (Proportional-Integral-Derivative) controller associations benefit of P (Proportional), D (Derivative) and I (Integral) control action.

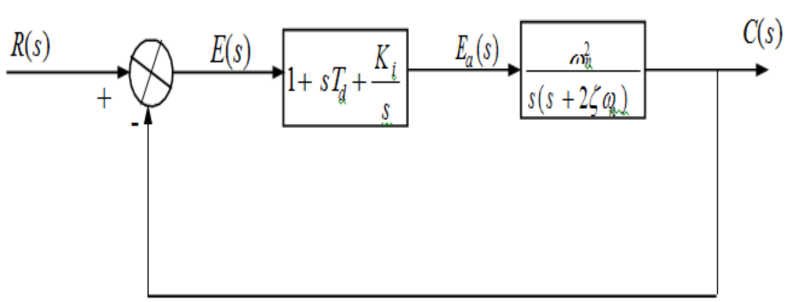

Figure.7 Block Diagram of PID (Proportional-Integral-Derivative) Controller

$$u(t) = K_P e(t) + K_i \int e(t).dt + K_d \frac{d\,e(t)}{dt} \quad (21)$$

The control-signal is proportional to error signal and K_p (Proportional gain). A P (Proportional) controller will have effect of decreasing rise time and will diminish, but never eradicate. If an integrator is added, control signal is proportional to integral of error and Ki (Integral gain). I (Integral) control will have effect of diminished error, in standard, to zero value. The in standard must be added, since there are continually limits on correctness in any scheme. D (Derivative) control is used to antedate future conduct of error signal by means of remedial actions based on rate of change in error signal. The control signal is proportional to D (derivative) of error and K_d is derivative gain.

D (Derivative) control will have effect of growing stability of scheme, diminishing overreach, and refining the transient response. D (Derivative) control action can by no means be used alone since this control action is in effect only during transient eras. The PID (Proportional-Integral-Derivative) controller makes a control loop retort faster with fewer overshoot and greatest popular technique of control by an excessive margin. The collective action has benefits of each of 3-individual control activities.

V. SIMULATION RESULTS OF P, PI, AND PID CONTROLLERS

Fig.8. Block diagram of VSI-fed IM drive using P, PI, and PID controllers developed in MATLAB/SIMULINK environment.

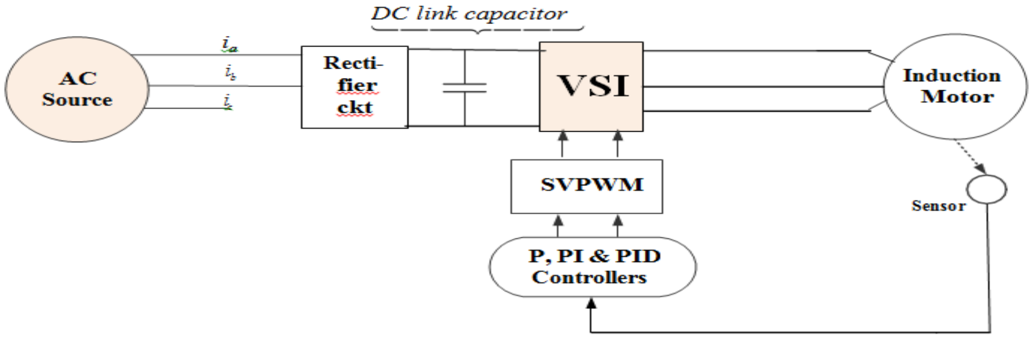

Figure.8 MATLAB/ SIMULINK Block Diagram of VSI-Fed IM Drive using P, PI, and PID Controllers

Transient Response of Drive during Entire Operation

Fig. 9 to 12 shows the transient performance curves of drive the for successive step changes in reference speed and torque after each time interval of 1 second of complete drive operation. The effectiveness of controller can be analyzed by considering the response of motor speed, torque and current for each alteration in reference speed and load torque. Firstly the speed have been step accelerated from 0 to 500 rpm, 500 rpm to 1000 rpm, 1000 rpm to 1400 rpm, and from 1400 rpm to 1725 rpm and then step decelerated from 1725 rpm to 1400 rpm, 1400 rpm to 1000 rpm, and from 1000 rpm to 500 rpm.

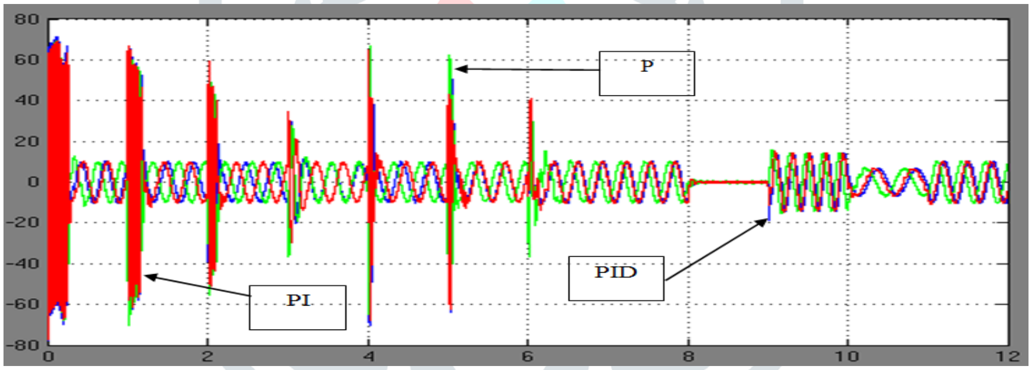

Figure.9 Rotor Current (Current Vs Time) using P, PI, and PID Controllers

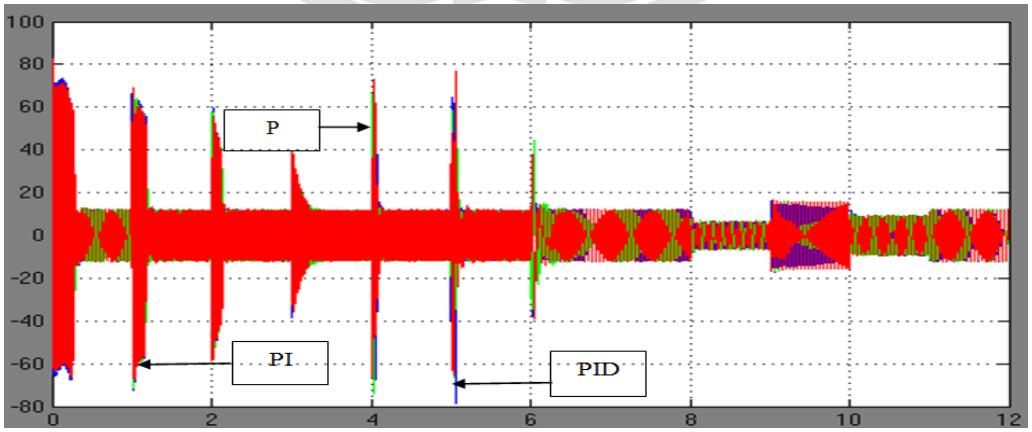

Figure.10 Stator Current (Current Vs Time) using P, PI, And PID Controllers

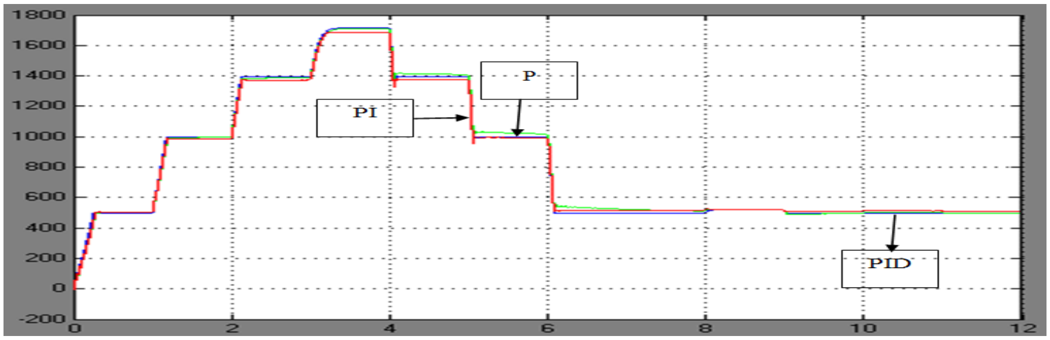

Figure.11 Rotor Speed in RPM (Speed Vs Time) using P, PI, and PID Controllers

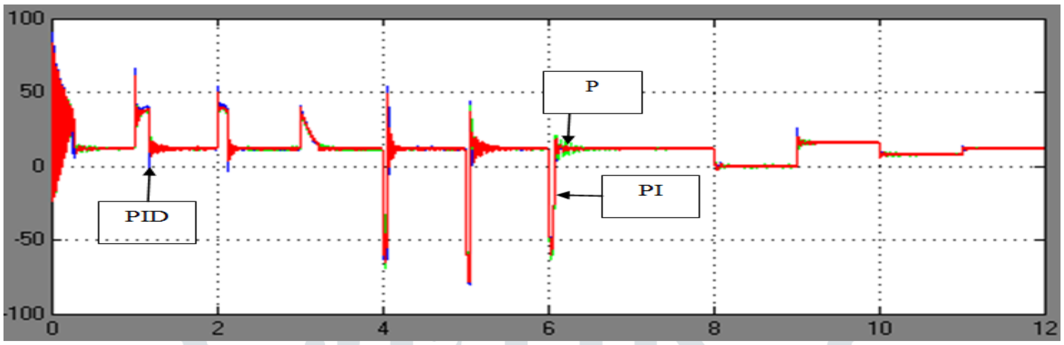

Figure.12 Electromagnetic Torque in N-M (Torque Vs Time) using P, PI, and PID Controllers

Fig. 9 shows the combine waveform of rotor current response, Fig. 10 shows the combine waveform of stator current response and Fig. 11 shows the combine waveform of rotor speed response and Fig. 12 shows the combine waveform of electromagnetic torque of the drive when the reference speed or load torque is increased and decreased instantaneously after each time interval of 1 second.

VI. PERFORMANCE COMPARISON OF VSI-FED IM DRIVE USING P, PI, AND PID CONTROLLERS

It is to be noted that in each case, when VSI-fed system was operated using P, PI, and PID controllers, the final output using PID controller contains less rotor speed, settling time and stator current. So it is clear that PID controller strategy gives better performance response as compared to P and PI controllers. Hence the system is working well under speed step changes.

TABLE I

Performance Comparisons of VSI-FED IM at Constant Load Torque ($Tl = 11.9\ N - M$) and Variable Reference Speed using P, PI and PID Controllers

Sr. No.	Reference Speed (rpm)		Rotor current (A)			Stator current (A)			Rotor speed (rpm)			Settling time (s)			Load command (N-m)
	From	To	Controllers												Load command (N-m)
			P	PI	PID	P	PI	PID	P	PI	PID	P	PI	PID	
1.	0	500	7.453	9.723	29.1	0.4932	11.6	8.659	995.3	994.2	509.4	0.29	0.295	0.31	11.9
2.	500	1000	9.291	9.131	6.476	11.52	5.415	4.515	995.3	996.4	986.9	1.19	1.23	1.20	11.9
3.	1000	1400	9.131	5.28	8.215	10.41	8.336	10.52	1394	1390	1373	2.12	2.13	2.15	11.9
4.	1400	1725	0.8491	3.677	6.967	10.84	2.032	4.548	1716	1711	1688	3.31	3.21	3.24	11.9
5	1725	1400	6.191	9.978	9.592	11.00	0.4824	11.51	1394	1409	1378	4.08	4.14	4.09	11.9
6	1400	1000	4.047	8.709	4.284	2.327	7.589	0.482	995.3	1018	994.9	4.08	5.01	5.15	11.9
7	1000	500	5.403	9.644	2.461	11.84	10.97	11.40	497.4	522.8	514.3	6.01	6.19	6.49	11.9

TABLE II

Performance Comparisons of VSI-Fed IM at Constant Speed (1725 RPM) and Variable Loading Conditions using P, PI and PID Controllers

Sr. No.	Reference Speed (rpm)	Rotor current (A)			Stator current (A)			Rotor speed (rpm)			Settling time (s)			Load command (N-m)
		Controllers												Load command (N-m)
		P	PI	PID	P	PI	PID	P	PI	PID	P	PI	PID	
1	1725	9.309	1.546	9.799	7.231	5.586	10.79	497.4	510.9	513.5	7.01	7.03	7.04	0- 11.9
2	1725	0.144	0.055	0.105	4.022	6.247	1.117	521.9	521.9	521.9	8.01	8.09	8.11	11.9-0
3	1725	6.026	13.93	0.354	13.61	7.09	10.07	497.2	495.7	509.7	9.01	9.221	9.11	0-16
4	1725	1.182	5.43	4.116	5.54	8.04	1.19	497.6	501.2	512.7	10.01	10.68	10.01	16-8
5	1725	8.99	8.55	5.233	9.031	10.229	8.50	497.4	499	510	11.08	11.21	11.23	8-16

VII. CONCLUSIONS

This paper presents a simulation result of VSI-fed IM drive with SVPWM technique based on P, PI, and PID controllers for investigation of Transient performance of drive, with the help of waveforms for different references speed and torque loading. On the basis of performance comparison Table I &II it can be concluded that P. PI, and PID controller has been successfully implemented on IM drive and performance results shows that PID exhibits better in comparison to P and PI controllers. Drive system overcomes the transients in fraction of seconds and also the motor current is within limit. The simulation results show that drive exhibit excellent dynamic performance both in transient state as well as steady state condition for different reference speed and load torque.

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