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Tracking Position Control of AC Servo Motor Using Enhanced Iterative Learning Control Strategy

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Abstract*—A permanent magnet two phase AC servo motor is widely used for high performance position control applications. Nevertheless with the presence of nonlinearities, and the input is periodic, conventional type controller is not sufficient to provide satisfactory time-varying trajectory position control. In order to improve the tracking performance for periodic reference trajectory, this article proposed the control scheme consisting of a linear conventional position controller together with a plug-in Enhanced Iterative Learning Control strategy (EILCS). The proposed controller is implemented in an AC servo motor and the simulation runs are carried out for a periodic reference tracking. The simple Iterative learning Control Strategy (ILCS) and conventional PD controller are taken for comparative studies. The performance measures of the above said controllers are analyzed in terms of tracking error and the results confirm the supremacy of EILCS controller. A robustness of the proposed control strategy is also tested.

***Keywords*—ILCS, ZPETC, PD controller**

I. INTRODUCTION

The permanent magnet AC servo motor is typically engaged in various control applications [1-3], such as computer numerical control, machining centre, robot actuator, and precise industrial robot. The existence of mechanical, electrical properties and a high efficiency, AC servo motor is require to have an precise response for the position tracking and a fast improvement for the external disturbances or load variations. Because of the typical precision positioning requirements and low offset tolerance of their applications, the control of these systems is particularly challenging since conventional Proportional Integral Derivative (PID) control usually may not suffice in these application domains.To meet out these problems, Iterative Learning Control Strategies (ILCS) is a powerful method for suppressing systematic errors in motion systems which perform repetitive tasks.Arimoto et al [4] proposed a general learning method for a class of nonlinear systems whose input and output are periodic in nature.This approach is motivated by the observation that the same reproducible effect will introduce the same error each run. These can be recorded and used to adopt the control signal that will be applied to the process during the next run in order to reduce the error. The main goal of learning control is that the tracking error decreases with increasing number of trials. Several researchers contributed their findings towards the development of ILC and applied to wide fields such as robots, rotary systems, chemical processes, biomedical systems, actuators and non linear systems.In recent years, increasing efforts have been made on the design issue of ILC [5].A survey on ILC design issue [6] documented various practically tested design schemes. Newly, P-type steady-state Iterative Learning Control (ILC) [7] scheme is applied to the boundary control of a class of nonlinear processes described by Partial Differential Equations (PDEs), which cover many important industrial processes such as heat exchangers, industrial chemical reactors, biochemical reactors, and bio filters.When ILCS is implemented in nonlinear system, the learning control loop is not performed adequately. The trade off between convergence and tracking performance is considered to be an important problem in the Learning control system**.** To meet out the above said problems, an Enhanced iterative Learning Control Strategy (EILCS) is considered. Some of the highlights of EILCS are, the tracking ability of this controller can adapt itself and it has robustness against noises in the real time implementation. Moreover it does not require complex control theories, knowledge of system, or other environment models. The main contributions of the work presented in this paper are precisely real time implementation of the Enhanced Iterative Learning Control strategy in an AC motor system and analyzes the tracking performance. In section 2 the mathematical model of DC Motor system is summarized. The design and structure of Enhanced Iterative Learning Control Strategy is detailed in section 3. Simulation results are analyzed in section 4 to exemplify the better performance of the EILC in closed loop. Finally, section 5 concludes the paper.

II. IDENTIFICATION OF AC SERVO MOTOR MODEL

A. AC servo motor model

The AC servo motor consists of a motor coupled to a gear box and an inertia load rigidly fixed to output shaft. The control torque (Tc) for the two phase AC servo motor is described as [8]

$$T_C = k_1 E(t) - k_2 \theta\ (t) \qquad (1)$$

k_1 & k_2 are motor constants (Nm/V, Nm/rad/s) and the values are identified by conducting the suitable experimental test.

θ is the angular velocity (rad/s) of the given motor

E is the input voltage (v)

The dynamic equation of the mechanical system is given by

$T_{C} = J\ddot{\theta}+B\dot{\theta}+ T_{L}$ (2)

θ is the angular position of the AC servo motor (rad)
$\ddot{\theta}$ *is the* angular acceleration of the AC servo motor (rad/s^2)
B is the Friction coefficient
J is the Moment of inertia (Kg.cm^2)
Equating (1) and (2)

$T_{C} = J\ddot{\theta}+B\dot{\theta}+ T_{L}$
$= k_1E(t) - k_2\theta(t)$ (3)

By the taking Laplace transform, the above equations can be rewritten as

$k_1E(s) - k_2s(s) = Js^2\theta(s) + Bs\theta(s) + T_L(s)$ (4)

Now the transfer function involving $\theta(s)$ and E(s) is att**a**ined as (i.e.$T_L(s) = 0$)

$$\frac{\theta(s)}{E(s)} = \frac{k_1}{Js^2+k_2s+Bs} = \frac{K_m}{s(\tau_m s+1)} \quad (5)$$

$K_m = \frac{k_1}{k_2+B}$, $\tau_m = \frac{J}{k_2+B}$; K_m = Motor gain constant ; and τ_m = Motor time constant

The important specifications of AC servo system, which has considered for simulation study, are given in table.1.By using equation (5) and considering the numerical values in Table.1, the transfer function model for the AC servo system is obtained as

$$G(s) = \frac{0.4}{s(2.7763s+1)} \quad (6)$$

Table I **: AC servo motor Specifications**

Type	**GSM62AE**
Voltage	230V
Power	100W
Speed	50 rpm
Moment of inertia (J)	0.052 kg.cm2
Friction coefficient (B)	0.01875
GB ratio	36
Radius of the output shaft	0.0175m

B. PD Controller Design

A conventional PD controller is designed to control the position of AC servo motor. The PD controller settings (Kc and Kd) are identified using signal constraint block of simulink optimization tool in MATLAB [9]. The signal constraint is a block where response signals can be graphically controlled and model parameters are optimized to get the desired performance requirements. By considering the equation 6 and performance requirements in table II, the optimized PD settings are identified as $K_c = 2.0203$ and $K_d = 1.8826$.

Table.II. **Performance requirements for PD control design**

Rise time (tr)	20
Settling time (ts)	22.2
Over shoot (Mp)	20%

III. CONTROL SCHEMES

A. Enhanced Iterative Learning Control Strategy (EILCS)

Fig.1and Fig.2 shows a block diagram of the control configuration considered in this work. In figure 1, simple ILC control loop is connected with a feedback controller. The features of this control scheme are the design of learning filter 'L' and Lowpass filter 'Q'. Here Learning gain k_l, which determines the rate of convergence of the error signal. The value of k_l is preferred by executing the optimization program. When simple ILCS is implemented in nonlinear process, the ILC control loop is not performed adequately. Besides, the filter location in the ILC scheme is also significant for convergence and tracking performance.

To meet out these problems, an Enhanced structure is proposed by incorporating a low pass filter 'Q' in the learning control loop. The overall structure is named as Enhanced Iterative Learning Control Strategy (EILCS) as shown in Fig 2.The main idea behind in the proposed structure is, the filter be placed and applied to the error signal prior to computation of the control signal for the next trial.

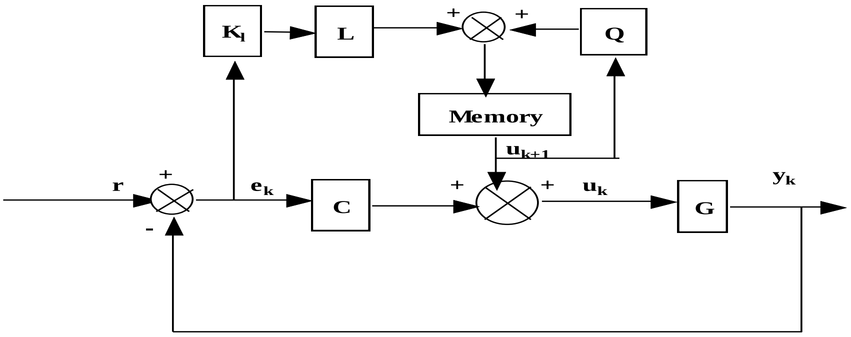

Fig.1 Simple ILCS

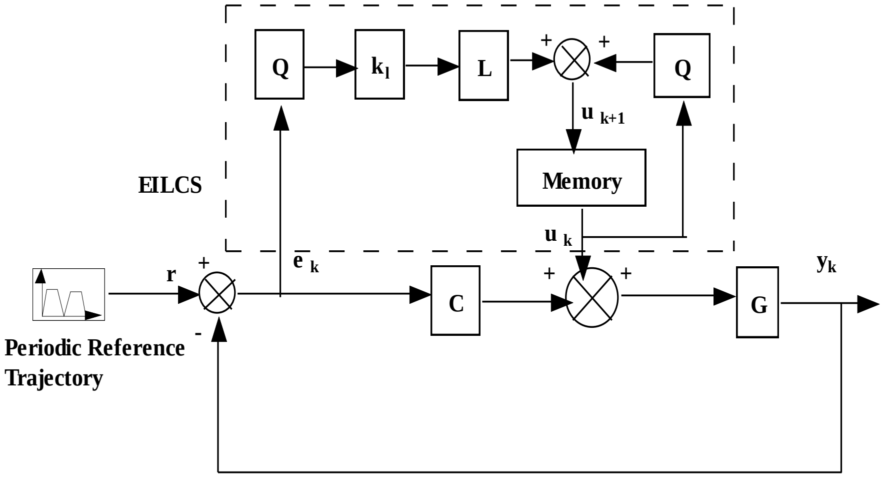

Fig.2 Enhanced Iterative Learning Control Strategy

B. Design of the Learning filter and Low pass filter

Step 1: From Figure 2,

$$e_k = \frac{-G}{1+GC} u_k \tag{7}$$

Step 2: Adapt the learning up-date rule is:

$$u_{k+1} = Q.\, u_k + Q.L.e_k \tag{8}$$

Step 3: Eliminate u:

$$e_{k+1} = \frac{-G}{1+GC} u_{k+1} \tag{9}$$

$$e_{k+1} = \frac{-G}{1+GC} . [Q.\, u_k + Q.L.e_k\,] \tag{10}$$

$$= Q\left(1 + \frac{-G}{1+GC} * L\right) e_k \tag{11}$$

$$e_{k+1} = Q\left(1 + \frac{-G}{1+GC} * L\right) e_k \tag{12}$$

It shows the propagation of the error signal from run to run. Convergence take place if

$$\left|Q\left(1 - \frac{G}{1+GC} L\right)\right| < 1 \tag{13}$$

Step 4: Actually, a appropriate option for L would be L= $\frac{1+GC}{G}$. The inverse of L is nothing but the process-sensitivity P= $\frac{G}{1+GC}$ i.e L = P^{-1}. Due to the unstability and non-proper characterisitics of inverse complementary sensitivity,L can not be act as a filter. This problem is overcome by adapting Zero Phase Error Tracking Controller (ZPETC) algorithm [10].

The evaluation of ZPETC method is done by comparing bode plot of the original inverse complementary sensitivity P^{-1} and the approximated inverse complementary sensitivity 'L' (from ZPETC). It seems that the magnitude and phase plots of both cases are the same. It discloses that 'L' is the approximated inverse of plant model. In this the phase plot, the phase caused by the delay has been taken into account. Fig.3 shows the bode plot of Inverse Complementary sensitivity (Original vs ZPETC).

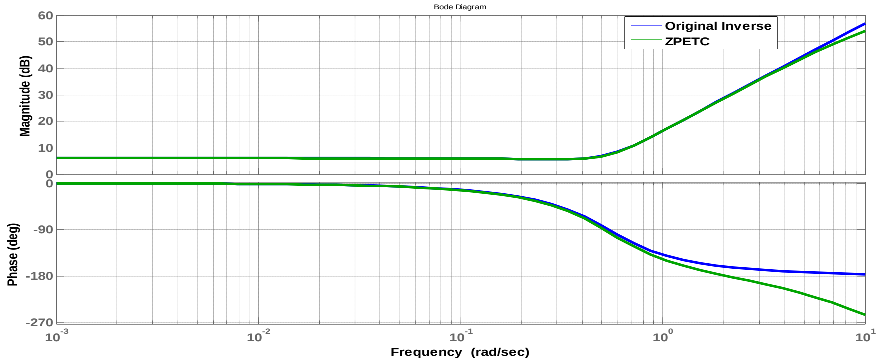

Fig.3 Bode plot of Inverse Complementary sensitivity (Original vs ZPETC)

C. Design of Low pass Filter (Q)

In practice, there may be an insignificant deviation of the developed process model from the actual process. This deviation leads the L filter to cause some disturbances in stability condition of the control loop for high frequencies. To overcome this problem, the low pass filter is included in the control loop. A first order continuous time low pass filter is considered here. i.e $Q(s) = \frac{\omega_c}{s+\omega_c}$,where ω_c is the cut-off frequency in rad /sec. The cut-off frequency is obtained from the Bode plot of the AC servo motor system and it is found to be 0.1 as shown in Fig.4.

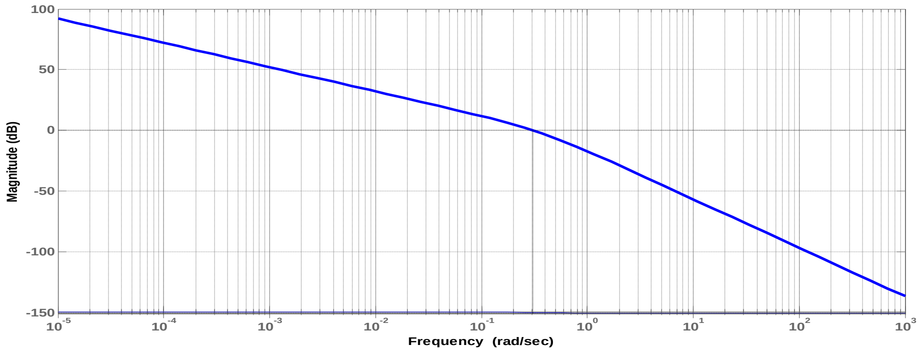

Fig.4 Bode plot of the AC servo motor

IV. RESULTS AND DISCUSSION

A sine wave with known period and amplitude (T=62, A=5) is generated and it is applied to AC servo motor system with EILCS, Simple ILCS and conventional PD controller. Simulation run of the AC servo motor system is carried out for sinusoidal periodic tracking in EILCS control loop. In addition, simulation trial of Simple ILCS and conventional PD control loop are carried out. In all the cases the nominal operating point of 40% position angle is maintained. Tracking responses are recorded in Fig. 5. to Fig. 7., and tracking errors are calculated in terms of Absolute Tracking Error (ATE) and charted in Fig.8. All the responses clearly show that the EILCS is capable of tracking the required trajectory with minimum tracking errors. To analyze the robustness of the proposed structure, a simulation runs of the AC servo motor system for a sinusoidal input signal with different known period (T = 62) and amplitude (A = 6),(T=45) and (A = 5) are carried out. The results are recorded in Fig. 9. to Fig. 16. The variations of ‘T’ and ‘A’ in control loop are evidently demonstrated the merits of the EILCS structure.

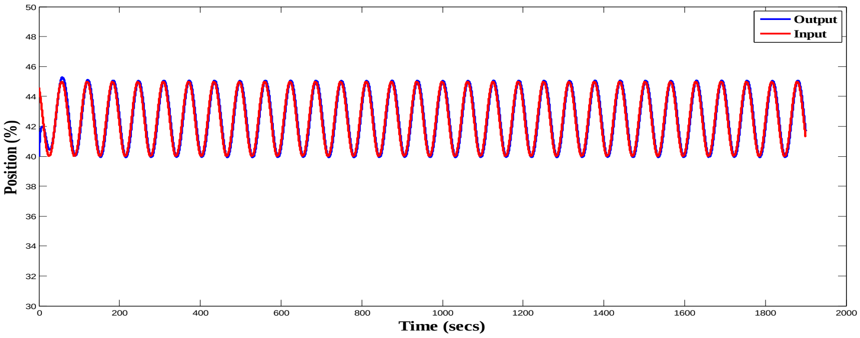

Fig.5. Simulation tracking response of sinusoidal periodic reference trajectories for EILCS with [Period (T) =62, (A) =5, operating point = 40%]

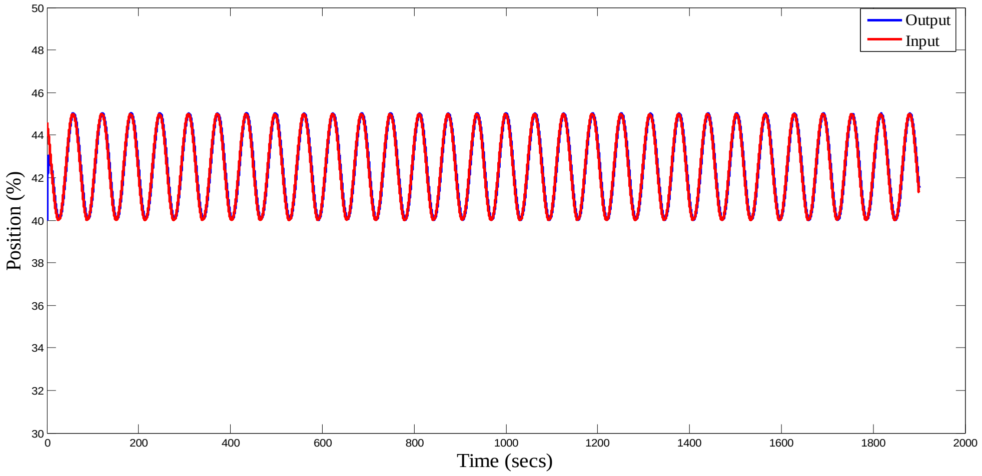

Fig.6 Simulation tracking response of sinusoidal periodic reference trajectories for Simple ILCS with [Period (T) =62, (A) =5, operating point = 40%]

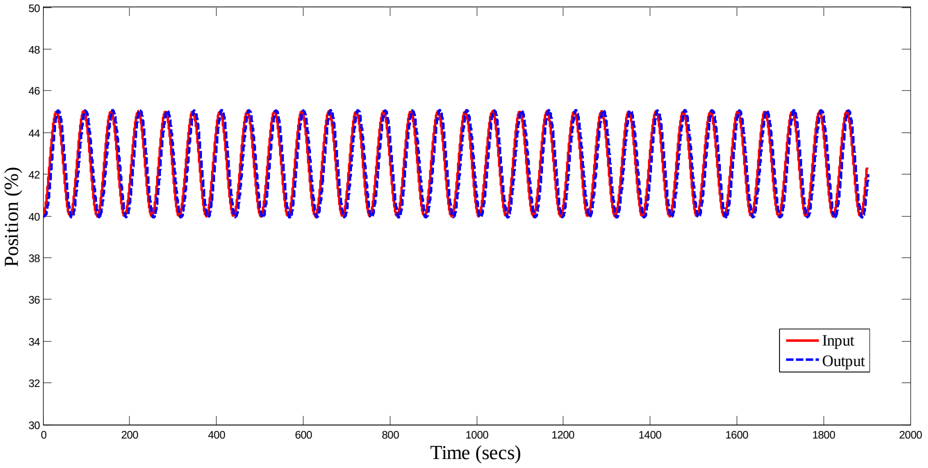

Fig.7 Simulation tracking response of sinusoidal periodic reference trajectories for Conventional PD with [Period (T) =62, (A) =5, operating point = 40%]

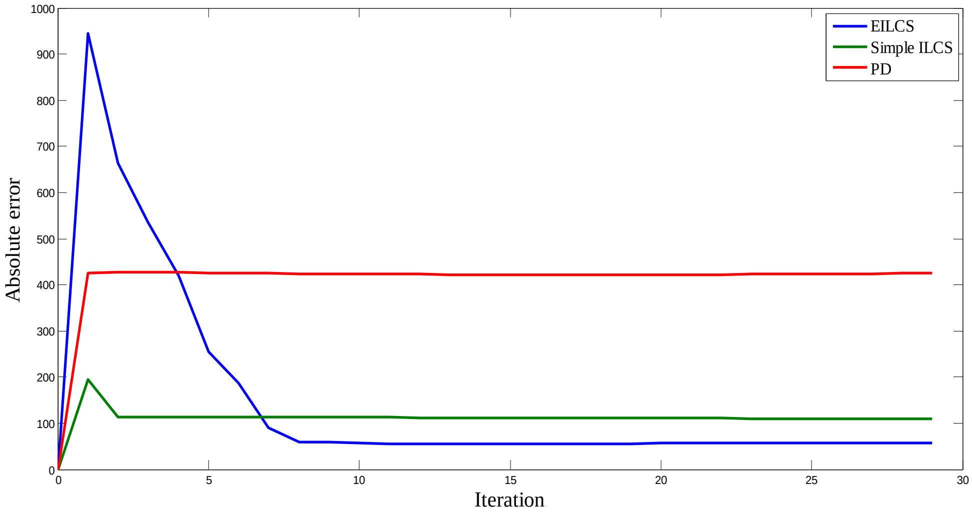

Fig.8 Tracking error response for EILCS, Simple ILCS and PD control strategies with [Period (T) =62, amplitude (A) =5, operating point = 40%]

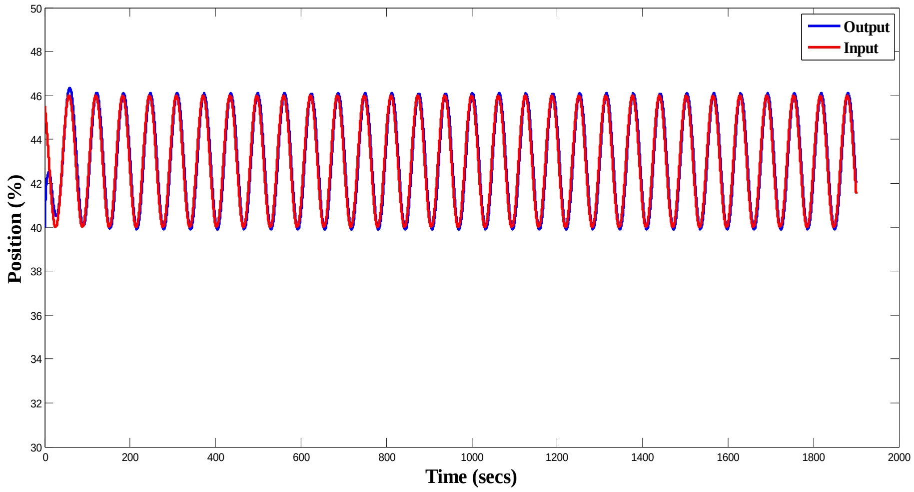

Fig.9 Simulation tracking response of sinusoidal periodic reference trajectories for EILCS with [Period (T) =62, (A) =6, operating point = 40%]

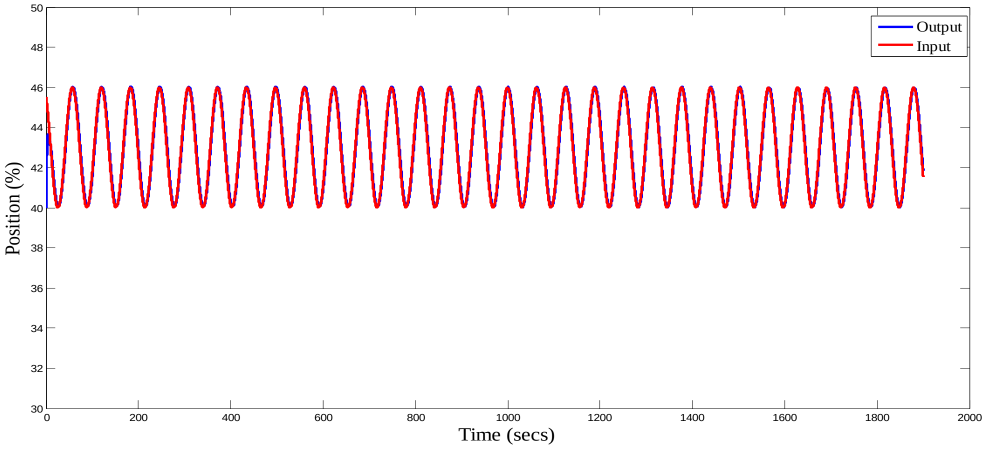

Fig.10 Simulation tracking response of sinusoidal periodic reference trajectories for Simple ILCS with [Period (T) =62, (A) =6, operating point = 40%].

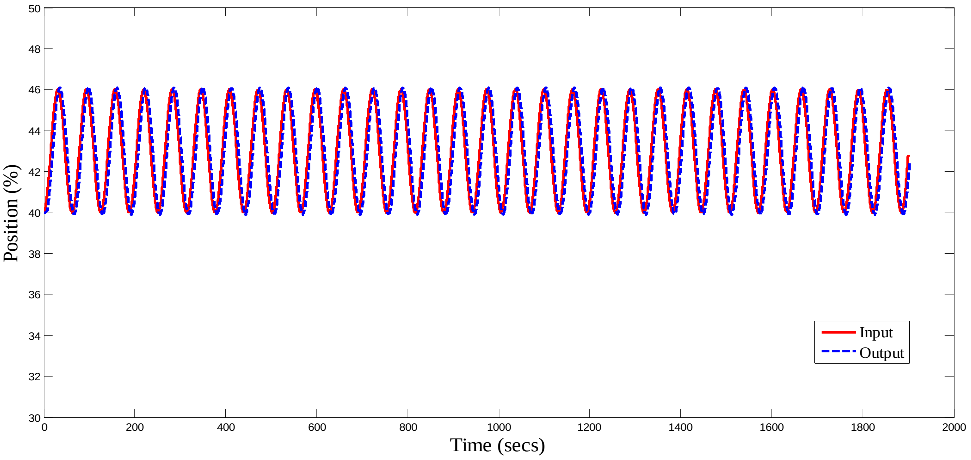

Fig.11 Simulation tracking response of sinusoidal periodic reference trajectories for Conventional PD with [Period (T) =62, (A) =6, operating point = 40%].

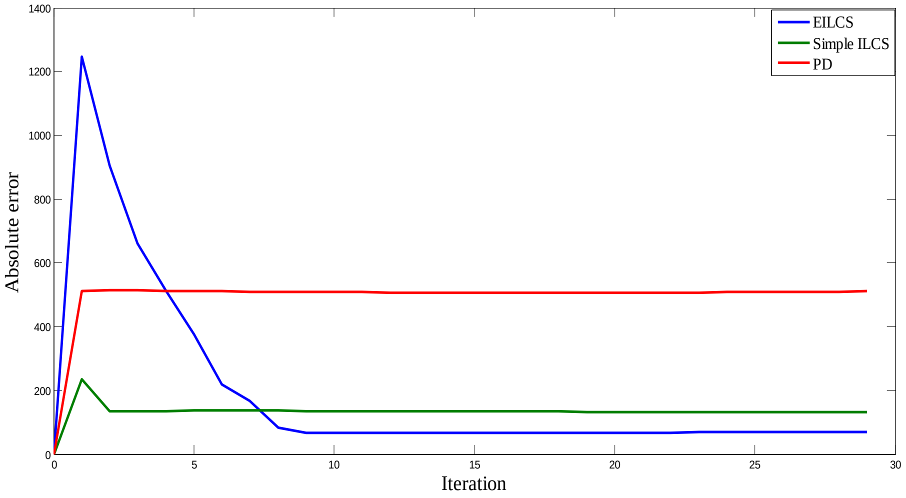

Fig.12 Tracking error response for EILCS, Simple ILCS and PD control strategies with [Period (T) =62, amplitude (A) =6, operating point = 40%]

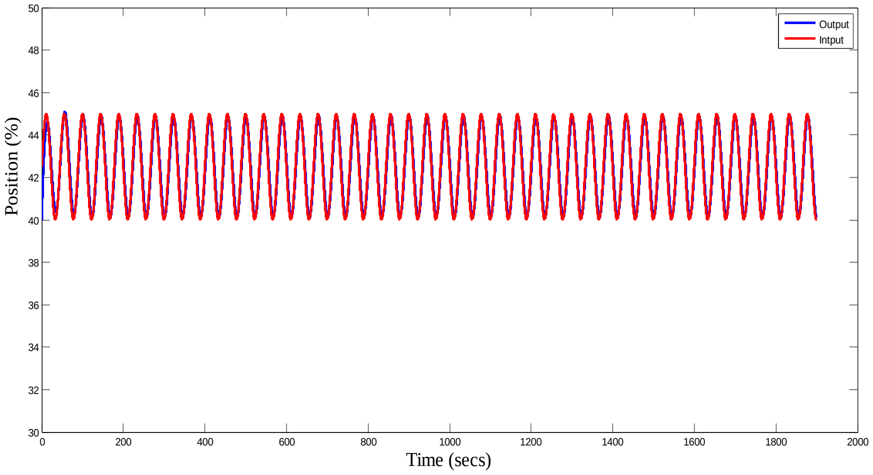

Fig.13 Simulation tracking response of sinusoidal periodic reference trajectories for EILCS with [Period (T) =45, (A) =5, operating point = 40%]

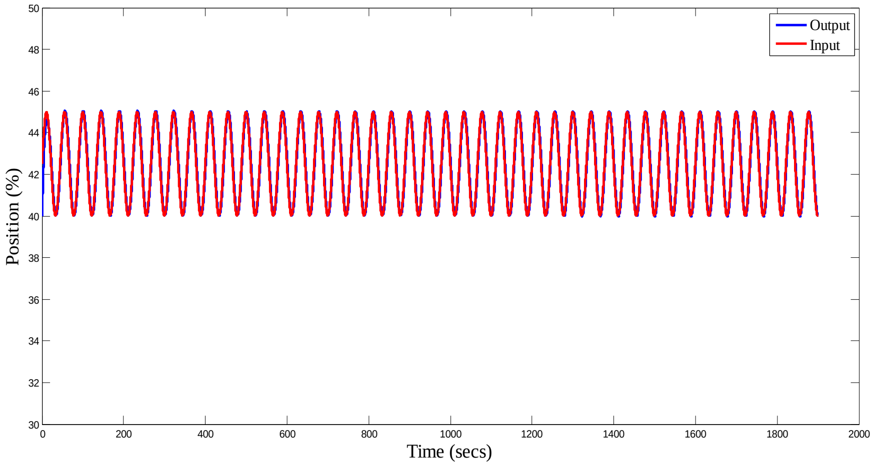

Fig.14 Simulation tracking response of sinusoidal periodic reference trajectories for Simple ILCS with [Period (T) =45, (A) =5, operating point = 40%].

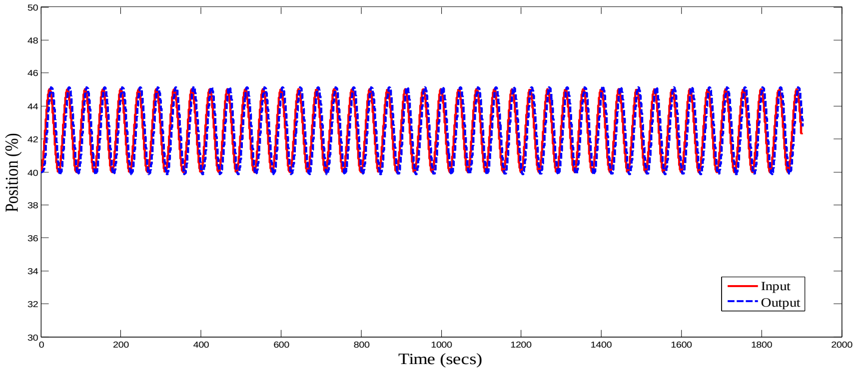

Fig.15 Simulation tracking response of sinusoidal periodic reference trajectories for Conventional PD with [Period (T) =45, (A) =5, operating point = 40%].

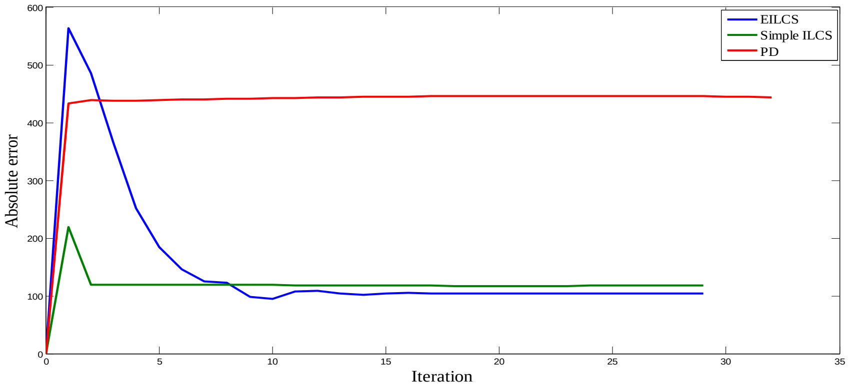

Fig.16 Tracking error response for EILCS, Simple ILCS and PD control strategies with [Period (T) =45, amplitude (A) =5, operating point = 40%].

V. CONCLUSION

An Enhanced Iterative Learning Control Strategy is proposed in this work for AC servo motor. Simulation runs are carried out with an input of periodic reference signal to proposed controller and performance analysis is done in terms of absolute tracking error. A comparative study with different control strategies such as simple ILCS and conventional PD is also carried out. The results clearly show the domination of the proposed EILCS in AC servo motor system. Robustness of the EILCS is also tested.

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