Super-Twisting Sliding Mode Control Design for Electric Dynamic Load Simulator

A

Minor project Report

Submitted towards

Partial fulfilment of the requirement for the award of degree

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BACHELOR OF TECHNOLOGY

in

ELECTRICAL ENGINEERING

SUBMITTED

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Finally, we take this opportunity to extend our deep appreciation to our family and friends, for all that they meant to us during the crucial times of the completion of our project.

<u>DECLARATION</u>

We hereby declare that the project entitled “**Super-Twisting Sliding Mode Control Design for Electric Dynamic Load Simulator”** Submitted by us in the department of Electrical Engineering , VSSUT is a record of an original work done by us under the guidance of Dr. Bidyadhar Routand the project is submitted in the partial fulfilment of the requirement for award of Bachelor’s degree from VSSUT,Burla. We further declare that this report will not be submitted either in part or in full to any other institution or university.

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CERTIFICATE

This is to certify that we have examined the dissertation entitled **"Super-Twisting Sliding Mode Control Design for Electric Dynamic Load Simulator"** submitted by **Sanjeeb Sah, Regd No. 1904050020, Pradyumna Saha, Regd No. 2003050010**, **Sameer Bhoi, Regd No. 1902050076,** and **Kiran Sankar Murmu, Regd No. 1904050006** in partial fulfillment for the degree of Bachelor of Technology at the Department of **Electrical Engineering** of **Veer Surendra Sai University of Technology, Burla, Odisha,** is an authentic work carried out by them under my supervision and guidance. I believe that the thesis fulfills part of the requirements for the award of the degree of Bachelor Of Technology. Neither this dissertation nor any part of it has been submitted for any degree or academic award elsewhere.

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CERTIFICATE OF APPROVAL*

This is to certify that we have examined the project report entitled **"Super-Twisting Sliding Mode Control Design for Electric Dynamic Load Simulator"**, submitted by **Sanjeeb Sah, Regd No. 1904050020**, **Pradyumna Saha,Regd No. 2003050010**, **Sameer Bhoi, Regd No. 1902050076** and **Kiran Sankar Murmu, Regd No. 1904050006** in partial fulfillment for the degree of **Bachelor of Technology** with at the Department of Electrical Engineering of **Veer Surendra Sai University of Technology, Burla, Odisha.**

We hereby accord our approval of it as a project work carried out and presented in a manner required for its acceptance for the partial fulfillment of the award of the degree of Bachelor of Technology in Electrical Engineering for which it has been submitted. The approval does not necessarily endorse or accept every statement made, or opinion expressed conclusion drawn as recorded in this thesis. It only signifies the acceptance of the thesis for the purpose it has been submitted.

(Internal Examiner) **(ExternalExamin)**

ABSTRACT

Abstract: Electric dynamic load simulator (EDLS) plays a vital role in new product invention for it can be used to produce desired load torque on loaded object to test its performance and stability, which is preferred by researchers for its high-speed response and high precision loading. However, conventional control methods are hard to obtain satisfactory results, for the interfere of nonlinearity and surplus torque in EDLS. In order to realize high precision loading, this paper proposes and implements a super-twisting sliding mode (STSM) control strategy for electric dynamic load simulator. The mathematical model of EDLS is built first in this paper, to establish foundation for designing the STSM controller. The finite time convergence condition of the STSM control law is presented. The STSM control law is designed based on the real-time tracking error of load torque, which can get high dynamic and high precision loading. Experimental results are provided and compared with conventional PID control strategy to validate the effectiveness of the proposed control approach.
Key Words: Electric dynamic load simulator, super-twisting sliding mode, mathematical model, load torque.

Contents :

1. INTRODUCTION:

Electric dynamic load system (EDLS) is a typical servo system of torque which is used us reproduce desired load torque for mechanical equipment such as electromechanical actuator (EMA) and test its performance under laboratory conditions.The EDLS is a typical passive loading system, and also a nonlinear system, such as backlash and friction in mechanism, and other uncertainties. When it operates, the motion of EMA can cause the surplus torque which is very difficult to be compensated and suppressed by conventional control methods and can affect the response speed and precision of EDLS. In order to improve dynamic performance of EDLS and eliminate surplus torque simultaneously. Some control strategies have been developed.one of the stategy is based on the optimal deviation PID, and it achieved good results to eliminate surplus torque, but it uses only one closed loop to eliminate multiple disturbance which cannot guarantee the accuracy.Based on the nonlinear characteristics of EDLS, this paper focus on super-twisting algorithm, and a second-order sliding mode controller is designed for EDLS to realize high precision leading and compensate the extra torque disturbance. The proposed super-twisting sliding mode (STMC) controller is compared with a PID type tracking performance controller. As result the experiments show that the EDLS with the proposed super-twisting sliding mode controller has better dynamic performance and robustness.

2. Motivation of the project:

In recent years, the research of EMA used in aircraft nose wheel steering system has become a research hotspot and tracking control for air-breathing hypersonic vehicles in cruising flight is also uses super-twisting algorithm to design a continuous controller.

3. System structure:

The EDES is consists of the following components - small inertia surface permanent magnet synchronous motor (SPMSM) and its driver, encoder, gear, torque sensor, encoder, EMA and its driver, encoder. A schematic representation of the EDIS is shown in Fig. The left side are the tested EMA which operates according to its position reference. Simultaneously, the right side are the electrical dynamic load system which is used to realize load torque control.Encoders installed on drive and load sides are used to collect position and speed signals. The torque sensor which has high bandwidth makes it possible to apply close-loop torque control. It is obvious that the small inertia SPMSM is connected to the EMA through a gear and torque sensor in order to simulate the real large load torque.

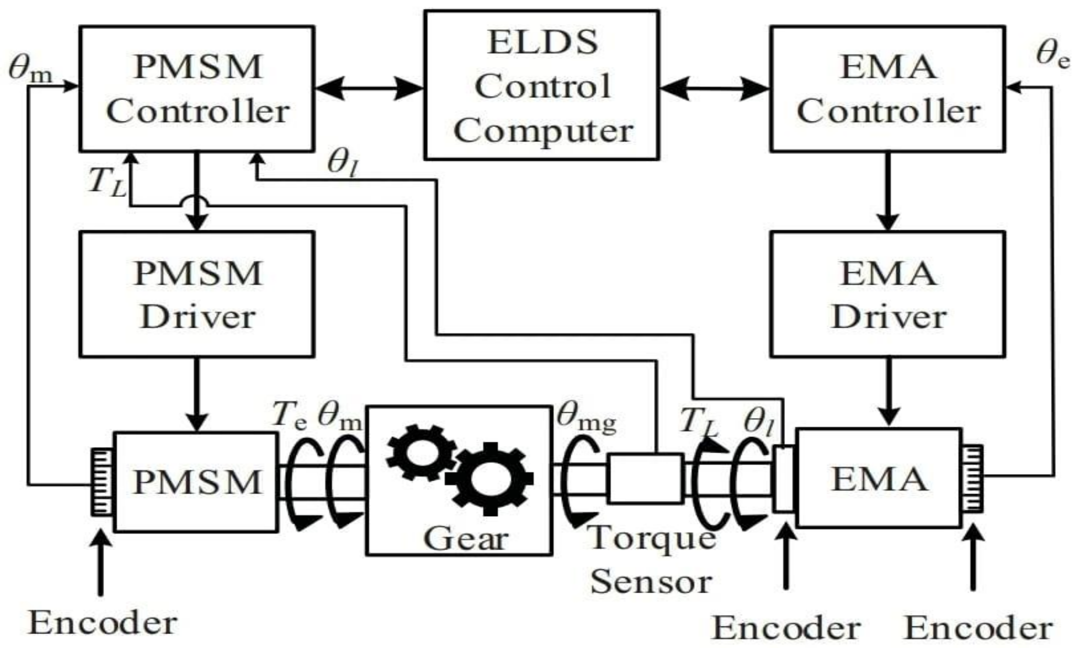


Fig:1 Schematic representation of EDLS

4. The Mathematical Model of EDLS :

The SPMSM is used as the loading motor. In order to guarantee the high dynamic and high-precision torque performance of EDLS, the torque output of the driver with direct torque control (DTC) is applied to the torque servo motor (SPMSM), and the update frequency of the torque output is 4KHz. According to the technical requirements of the system, the EDLS system usually does not operate to exceed 10 Hz. Therefore, when designing the control algorithm, ignoring the dynamic characteristics of the driver. For simplicity, the torque servo system of SPMSM can be used in proportional mode. Then, the electromagnetic torque $T_e$is directly proportional to the control input $u_m$of the SPMSM DTC driver, and the relationship can be expressed as,

$$T_e(t) = K_m u_m(t) \qquad (2)$$

(whereK_m is the proportionality constant)

A SPMSM is used as a loading motor. The mathematical model of SPMSM is displayed as follows:

$$\frac{\boldsymbol{d}}{\boldsymbol{dt}}\boldsymbol{\theta}_m = \boldsymbol{\omega}_m \qquad (3)$$

$$J_m\frac{d}{dt}\omega m = T_e - b_m\boldsymbol{\omega}_m - \mathrm{T_g} \qquad (4)$$

where$\boldsymbol{\theta}_m$and $\boldsymbol{\omega}_m$are the rotor mechanical angular and speed, respectively; $J_m$is the moment of inertia of the SPMSM; b_m is the damping coefficient; $T_g$the load torque that is converted to the motor shaft.

The dynamic equation of the EMA servo system is shown by,

$$\frac{d}{dt}\theta_l = \omega_l \qquad (5)$$

$$J_l\frac{d}{dt}\omega_l = T_f - b_l\boldsymbol{\omega}_l - T_L \qquad (6)$$

Whereθ_m and $\omega_m$are the angular and speed of EMA servo system, respectively; $J_l$is the moment of inertia of the PMSM; b_l is the damping coefficient; T_L is the load torque is the driving torque; N is reducer ratio.

The torque sensor is used to connect the EMA and EDLS, which has small inertia, so it can be treated as a proportional component in its working range. So the torque sensor model can be described as ,

$$T_L = K_G\Delta\boldsymbol{\theta} \qquad (8)$$

Where K_G is the torsional rigidity of the torque sensor.

It can be expressed as follows:

$$\Delta\theta = \theta_{mg} - \theta_l \qquad (9)$$

which represents the difference between the input and output positions of the torque sensor, with T the output position of the reducer, given by

$$\theta_{mg} = \frac{\theta m}{N} \qquad (10)$$

According to equations (4), (6), (8) and (9) it can be found that the position servo system of EMA is occupied with the torque servo system of EDLS.
Taking Laplace transforms from initial conditions for equations above. Then, the complete mathematical model of EDLS can be obtained as Fig.2.

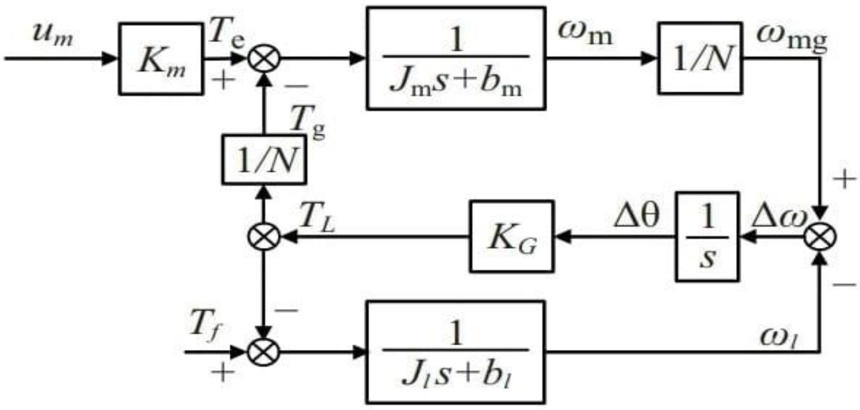


Fig. 2: Block diagram of EDLS without a closed loop

As mentioned before, EDLS focuses on controlling the dynamic load torque of the EMA. In addition, the load torque output of the EDLS can be expressed as follows,

$$T_L(s) = G_T(s)\, T_e(s) - G\theta(s)\, \theta_l(s) \qquad (11)$$

$$G_T(s) = \frac{K_G/N}{J_m S^2 + b_m + K_G/N^2} \qquad (12)$$

$$G_\theta(s) = \frac{K_G(J_m s^2 + b_m s)}{J_m S^2 + b_m s + K_G/N^2} \qquad (13)$$

From (11), it can be found that the load torque output of EDLS consists of two parts, the torque output of SPMSM which is amplified by the reducer and the disturbance from EMA angles output to the EDLS torque servo system. The desired system trackingperformance is that the load torque T_L (t) tracksa given reference

$T_{ref}(t)$ as close as possible. So it is important to eliminate the disturbance torque caused by the motion of EMA, which is called extraneous torque. Extraneous torque is a function of the acceleration and velocity components of the EMA movement.

In the actual test, position servo system of EMA is occupied with torque servo system of ELDS. The position servo system of EMA is required to follow certain desired trajectory with external torque disturbance. And the torque servo system of EDLS is used to track the required load torque on the EMA, so the motion of EMA can be treated as the external disturbance acting on the torque control loop.

Equation (11) indicates that the output load torque is determined by the electromagnetic torque output of SPMSM and the position of EMA. The main control objective is to design the control input so that the trajectory tracking errors of the load torque will converge to zero in finite time.

Two assumptions are listed as follows for the subsequent analysis.

Assumption 1: The load torque reference is smooth with bounded derivatives, i.e $\|T_{ref}(t)\| \leq L$, $\|\dot{T}_{ref}(t)\| \leq \bar{L}$, $\|\ddot{T}_{ref}(t)\| \leq \bar{\bar{L}}$.

Assumption 2. The actual position θ_l of EMA can be collected by the encoder, and it can be regarded as the given signal. So, the given signals θ and $\dot{\theta}$ are bounded and continuous, i.e., $\|\theta_l(t)\| \leq M$, $\|\dot{\theta}_L(t)\| \leq \bar{M}$, $\|\ddot{\theta}_l(t)\| \leq \bar{\bar{M}}$

According to the assumption 1 and 2, it follows that

$$T_L = k_1 u_m - k_2 \dot{T} - k_3 T_L - k_4 \ddot{\theta} - k_5 \dot{\theta} \qquad (14)$$

Where,

$$k_1 = \frac{K_G K_m}{N J_m} \ , \ k_2 = \frac{b_m}{J_m} \ , \ k_3 = \frac{K_G}{N^2 J_m} \ , \ k_4 = K_G \ ;$$

$$k_5 = \frac{K_G b_m}{J_m}$$

Choosing $x_1 = T_L$ and $x_2 = \dot{T}_L$ as the state variables, $y = T_L$ as the output and $u = k_1 u_m$ as the control input, then the form of this model is given by,

$$\dot{x}_1 = x_2 \ , \quad \dot{x}_2 = u + \varphi(x, \theta_l) \qquad (15)$$

$$y = T_l \qquad (16)$$

5. Super-twisting sliding mode control strategy

The desired system tracking performance is that the load torque $T_L(t)$ tracks a given reference T_{ref} (t) as close as possible. So the approach here is to converter the system dynamic model into an error dynamic model in error coordinates. Let $e=e_1$ and $\dot{e}$ = e_2 be the tracking errors of the EDLS and are defined as

$$e_1 = T_{ref} - T_L$$
$$e_2 = \dot{T}_{ref} - \dot{T}_L \qquad (21)$$

By combining Eqs. (14), (15), (16) and (21), the error dynamic model follows as

$$\dot{e}_1 = e_2$$
$$\dot{e}_2 = \ddot{T} - u - \varphi(x, \theta_1) \qquad (22)$$

Then sliding surface error is defined as

$$S = e_2 + ce_1 , c > 0 \qquad (23)$$

The sliding mode controller based on the super-twisting algorithm is designed. When the sliding surface S = 0 is reached, then the load torque T_L (t) reaches T_{ref} (t) in finite Time. In order to use the super-twisting algorithm to design the second order sliding mode controller, a new assumption is listed as follows ,

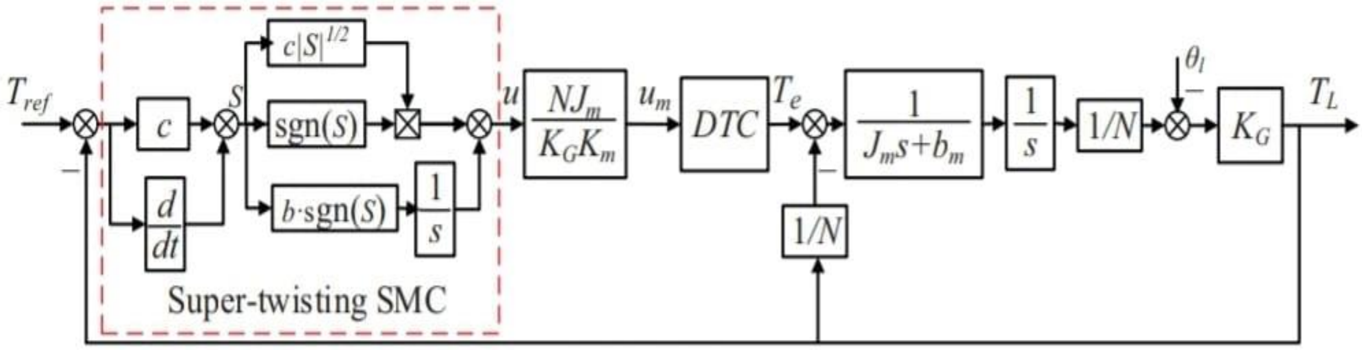
Assumption 4. The cumulative disturbance is bounded, i.e., $\| \psi(x, T_{ref}, T_L, \theta_1 \| \leq M$ and in addition that it is smooth with bounded derivative $\| \psi(x, T_{ref}, T_L, \theta_1 \| \leq \bar{M}$.

According to the assumption 1, 2, 3, and 4, the proposed control input u(t) is given as follows

$$u = c\left|S^{\frac{1}{2}}\right| sgn(S) + \int bsgn(S)dt \qquad \text{Type equation here.} \qquad (25)$$

Where, c , b and $\| \psi \| \leq \bar{M}$ fulfill the stability condition. The block diagram of load torque controller of EDLS is obtained, where v can compensate the disturbance ψ in finite time, and $(u - v)$ force S to zero. This means that both e and $\dot{e}$ can become zero in finite time, and the system trajectory stays on the surface thereafter.

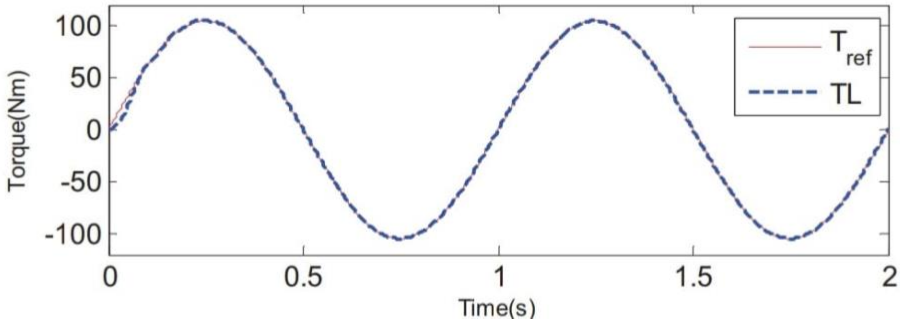
6. SCHEMATIC MODEL:



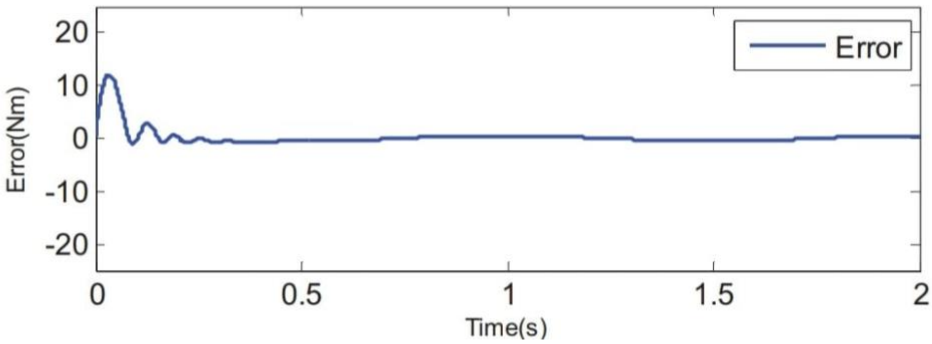
7. RESULT:

In these tests, the loaded EMA follows a given sine curve, and the load torque command is the function of the real position of EMA which is also a sine curve. It show that when the output load torque under a 1Hz sine load torque reference there exists larger tracking error with conventional PID control than STSM control. STSM control shows excellent tracking accuracy. it can be seen that the load torque commands are under 4Hz, and there exists larger discrepancy in phase and conventional PID control than STSM control. The proposed STSM control law can get excellent high load torque tracking precision. From these curves, it can be seen that the proposed controller can reduce the tracking error and the phase delay, which can get better dynamic response and higher accuracy than the conventional PID control. Fig.9 and Fig.10 show that when the load torque commands are under 8Hz, both PID control method and STSM control strategy have larger tracking error than the EDLS worked under 4Hz and 1Hz. The proposed STSM control law can get better load torque tracking precision than PID control.

With STSM controller:

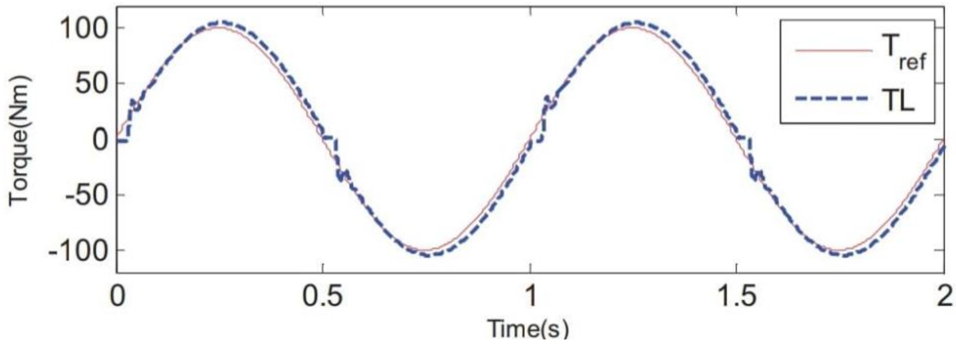


Tracking trajectory of STSM at 1hz

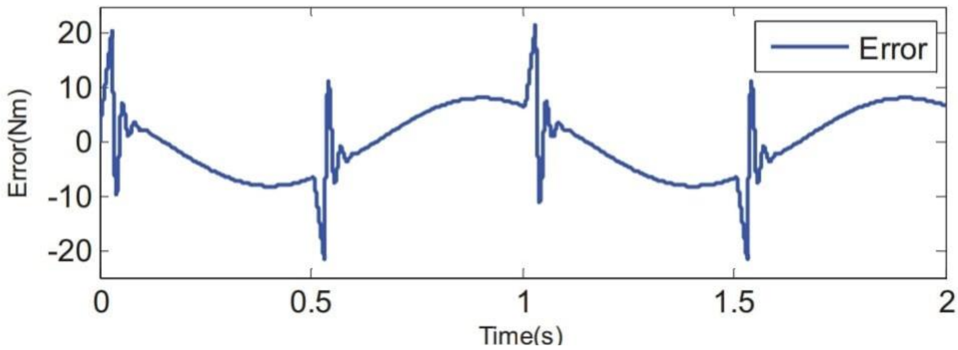


Tracking error of STSM at 1 HZ

With PID controller

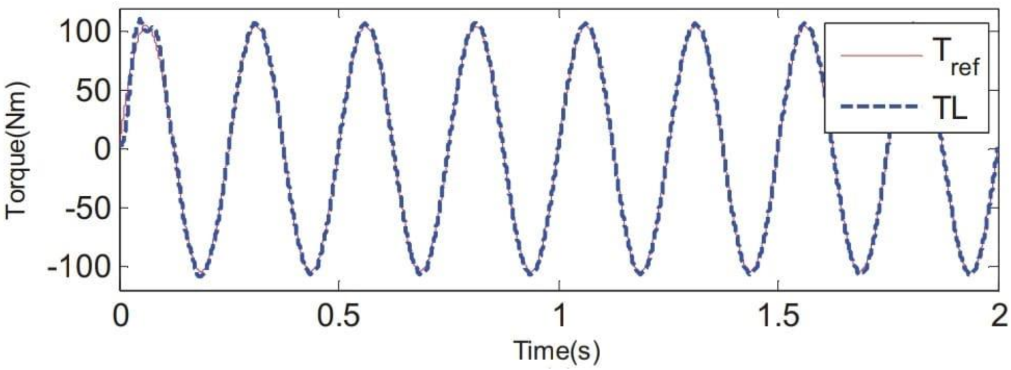


Tracking trajectory of PID at 1HZ

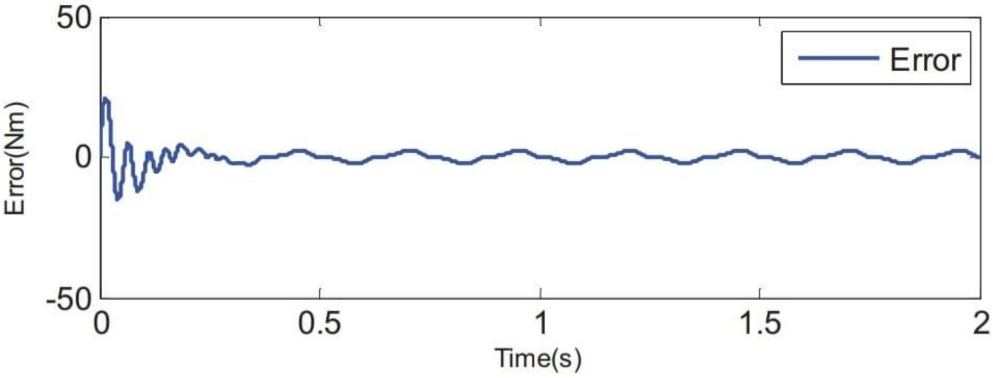


Tracking error of PID at 1HZ

With STSM Controller:

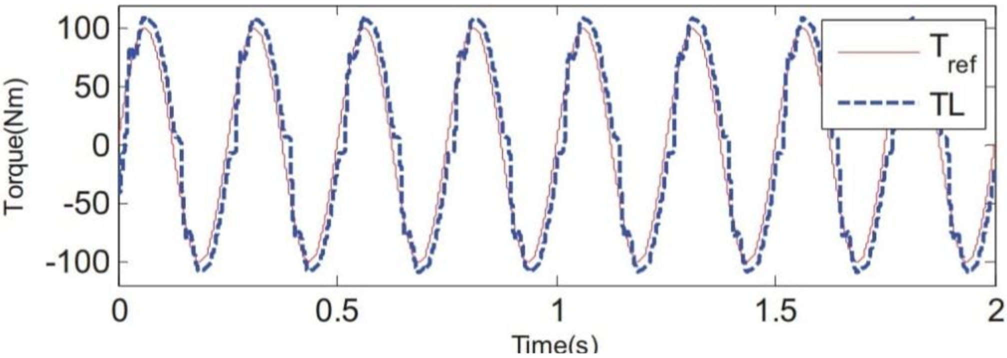


Tracking trajectory of STSM at 4hz

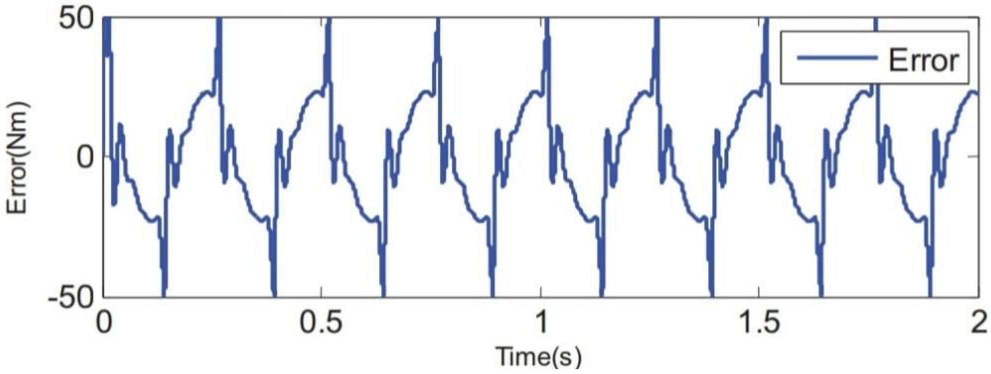


Tracking error of STSM at 4hz

With PID Controller:

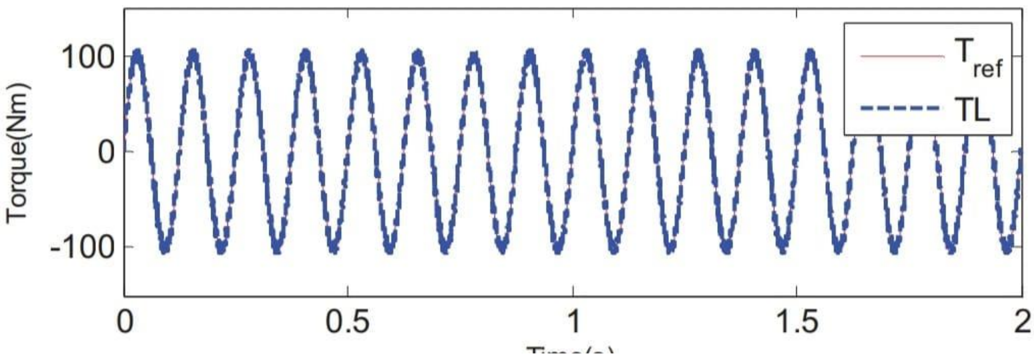


Tracking trajectory of PID at 4hz

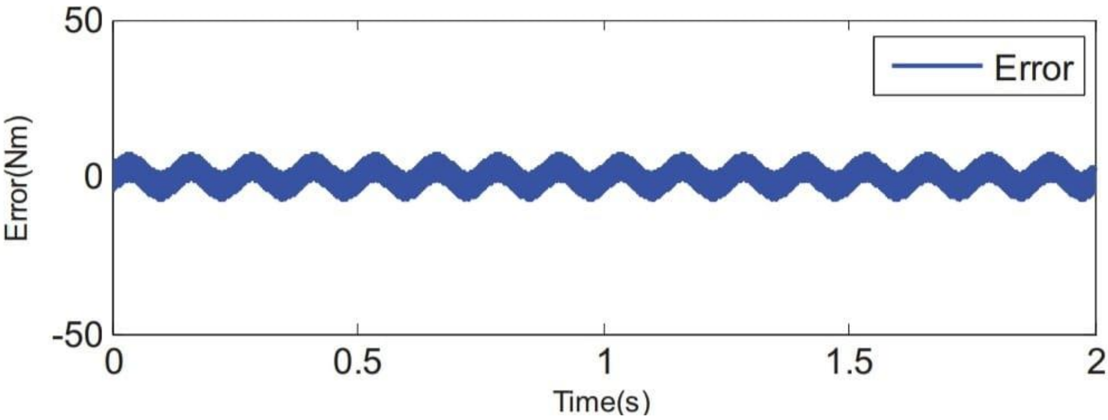


Tracking error of PID at 4hz

With STSM Controller:

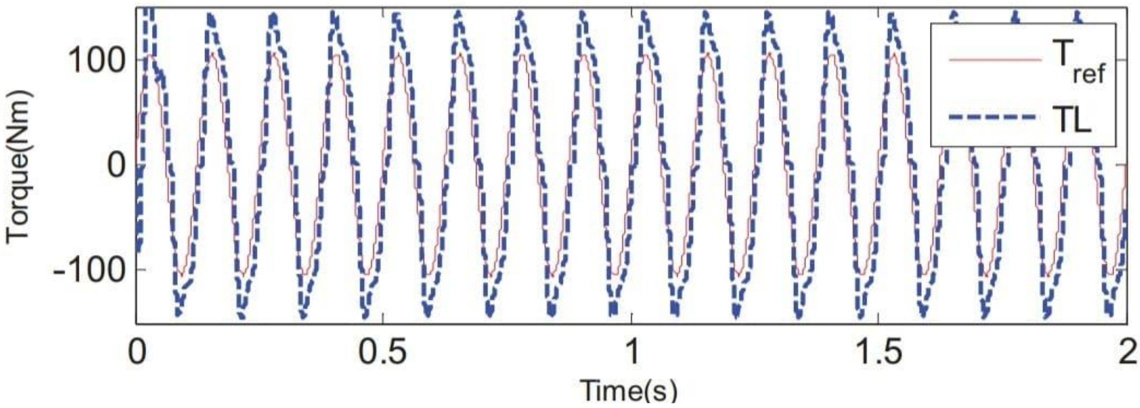


Tracking trajectory of STSM at 8hz

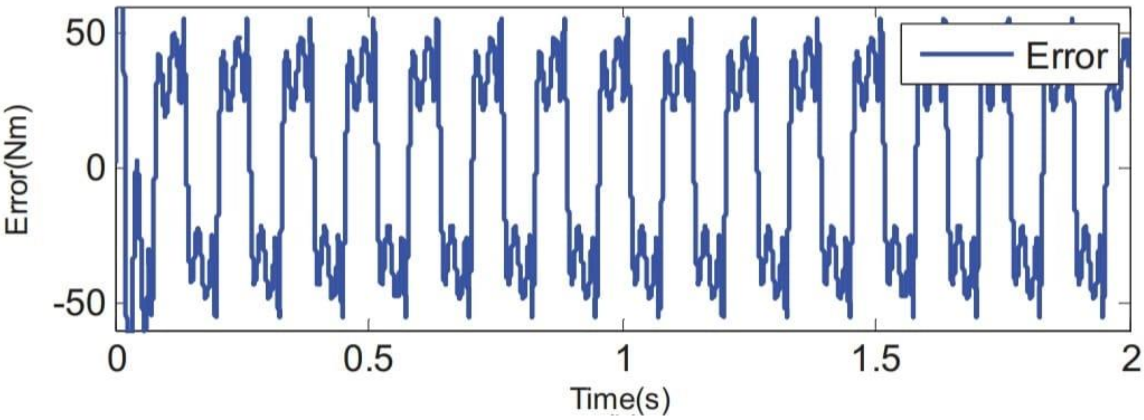


Tracking error of STSM at 4hz

With PID Controller:



Tracking trajectory of PID at 8hz



Tracking error of PID at 4hz

8. Future Work

We would like to extend our experiment further by using other controller and components of Super – Twisting sliding mode control design for electric dynamic load simulator. We look forward to obtain an increase in the accuracy of the obtained results.

9. CONCLUSION

In this paper, a new type EDLS with STSM control strategy is presented to get well dynamic response and high load torque tracking accuracy. For comparison purpose, a PID control strategy is introduced. The experiment results showed that the STSM control can successfully track the desired load torque and eliminate the surplus torque which is caused by the motion of EMA. The research offers insight into the future work regarding on electrical dynamic load simulating.

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