Control Strategy of The Permanent Magnet Stepper Motor

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ABSTRACT

The stepper motor is an electromechanical converter that transforms a pulsed electrical signal into a mechanical movement (angular or linear). Its basic structure is in the form of two mechanically separated parts, the stator and the rotor. The electromagnetic interaction between these two parts ensures rotation. In the design of automatic systems, one always seeks to improve the dynamic performances and to minimize the response time. Conventional control algorithms, for example, with integral proportional action, may be sufficient if the requirements on the accuracy and performance of the systems are not too strict.

I. Introduction

A stepper motor converts control pulses into a rotation of "n" not the rotor: it allows precise positioning without servo loop. Of many industrial applications use stepper motors: in robotics (Servomechanism), microcomputer (floppy disk drives, hard disk...) in printers and plotters, in the medical field: push syringe (the stepper motor allows a regular flow for infusion). It was possible to control the motor using microprocessors, which made its integration into various numerically controlled systems, [1]. The stepper motor can produce incremental displacements without servo loop. The generation of a finite number of pulses constitutes a position control while the frequency of these same pulses controls the speed of the motor. In most industrialized countries the stepper motor is very popular. In France, it is less used, only one company manufactures it in large series. It seems that the lack of closed loop make the French more reluctant [2]. As said before, the stepper motor allows positioning without servo loop (open loop control), that the output is independent of the input. The disadvantage of open loop control lies in the presence of external disturbances, it can only compensate for measurable disturbances. Several control methods can be used to solve this problem; we distinguish the closed-loop control. The closed-loop control is based on conventional markers, is intended to regulate the adverse effect of any external disturbances (measurable or unmeasurable) and to give the system a direction developed and established in advance. The goal of our work is to apply closed-loop control to the permanent magnet stepper motor. Whatever the purpose of modeling, the model obtained is often an imperfect representation due to a real process, either because of a lack of knowledge of certain phenomena, or because of a deliberate simplification that responds to practical constraints [13]. A problem was found when the load torque was present. It has been shown that the position shifts (position error). This affects the accuracy of the motor and therefore their applications. To reduce the influence of the load torque, which is considering in this case as a disturbance in our system? In this chapter, we propose a regulation method capable of avoiding the harmful effect of any disturbance. In this part, we present the principle of the position control of the permanent magnet step motor, in which the possibility of decoupling the two behaviors (electrical and mechanical) is analyzed. This simplifies the current, speed and position control loops.

II. Modelling of

1. Prediction of Aerodynamic Coefficients.

The motor is supplied with voltage, it is therefore necessary to establish the electrical model of the process in order to develop the algorithms necessary for the definition of Ud and Uq control variables [8]. Expression (1),

$$\begin{cases} L\dfrac{dI_d}{dt} = U_d - RI_d + N_r L\omega\, I_q \\ L\dfrac{dI_q}{dt} = U_q - RI_q - N_r L\omega\, I_d - K\omega \\ J\dfrac{d\omega}{dt} = KI_q - f_r\omega - f_{sec}\,\mathrm{sign}(\omega) - C_r \\ \dfrac{d\theta}{dt} = \omega \end{cases} \qquad (1)$$

Describes how our system works. This expression presents a complex coupling between the input-output variables, that is to say that the variation of such a quantity generates a disturbance on the input. This can be problematic when we want quick transient responses [8].

2. Decoupling of greatness input-output.

In a DC machine, the magnetomotive force of the armature establishes an angle of 90° with the axis of the inducing flux, and whatever the speed of rotation of the motor, the torque is proportional to the inductive flux and the armature current. In the case of a separate excitation machine, if the inductor flux is kept constant, the torque is directly proportional to the armature current, so we obtain good dynamic performance since the torque can be controlled as separate as the induced current. can be [10] [11]. As we said before, our problem lies in the existence of a complex coupling between the input-output variables. To obtain a situation equivalent to that of a DC motor, we need to decouple these quantities. For this, decoupling methods are proposed; decoupling by a regulator [49], decoupling by state feedback [12] and decoupling by compensation [14,12]. We present the last type of decoupling. From the relation (1) describing the motor model, the electrical equations are given by:

$$\begin{cases} U_d = RI_d + L\dfrac{dI_d}{dt} - N_r L\omega\, I_q \\ U_q = RI_q + L\dfrac{dI_q}{dt} + N_r L\omega\, I_d + k\omega \end{cases} \qquad (2)$$

Let's define two new command variables Vd and Vq as:

$$\begin{cases} V_d = U_d - e_d \\ V_q = U_q - e_q \end{cases} \qquad (3)$$

Where ed and eq represent the coupling terms defined by:

$$\begin{cases} e_d = N_r L\omega\, I_q \\ e_q = -N_r L\omega\, I_d - k\omega \end{cases} \qquad (4)$$

As shown in FIG. 1, the compensation decoupling consists in injecting these two opposing interfering terms, reconstituted by the control device.

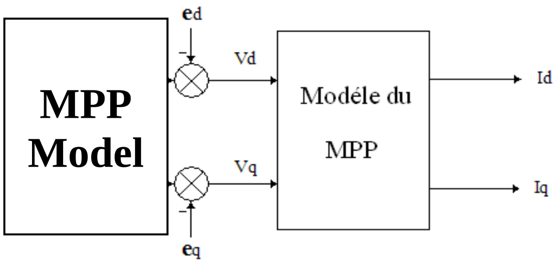

Fig. 1: Decoupling by compensation.

3. Implantation of the order.

The command can be summed up by the figure (2). We can see in figure (2) the appearance of two current loops to control the currents Id and Iq, an intermediate loop to control the mechanical rotation speed ω and an external loop to control the position as well as the transformation blocks direct and reverse park.

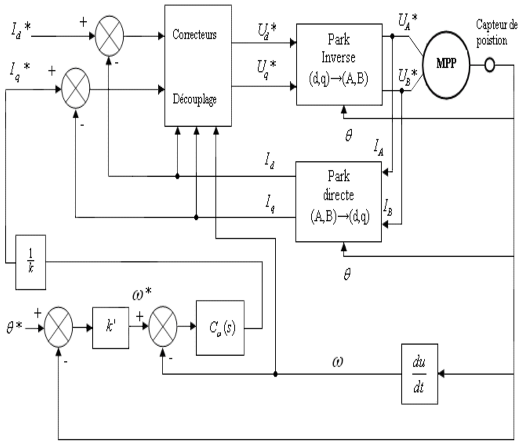

Fig.2. Schematic diagram of the classical control.

The speed set point is obtained from the output of the regulator k to adjust the position, and the speed controller will supply the reference torque Cem*. The reference Iq* is the image of the reference position. * Given. The correction-decoupling block is detailed in Figure (3). The outputs of the two inner loops are the image of the two-phase voltages applied to the motor.

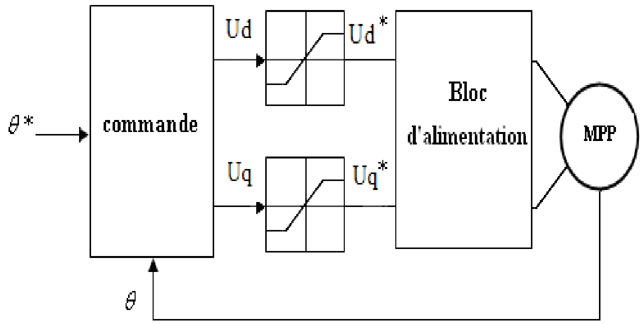

Fig.3. Limiting supply voltages of the motor.

This limitation consists in maintaining the modulus of the vector of tension defined by the relation:

$$|U| = \sqrt{|U_d|^2 + |U_q|^2} \qquad (5)$$

4. Regulation of currents.

The PI regulator acts in two actions; proportional action characterized by a gain Kp, and the second said integral represented by a gain Ki.

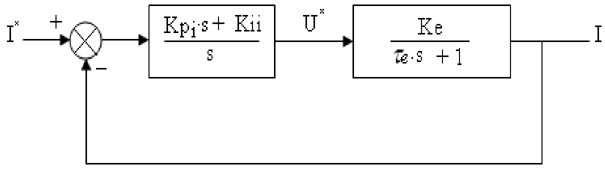

Fig.4: Structural scheme of current regulation.

With:

K_e : Electrical constant of the machine, given by:

$$K_e = \frac{1}{R}$$

τ_e : Electrical time constant of the machine, given by: $\tau_e = \dfrac{L}{R}$

The regulator is defined by a transfer function of the form: $C_p(s) = \dfrac{K_{pi} \cdot s + K_{ii}}{s}$

The numerical values of Kpi and Kii are given in the following table:

Table 1. Kpi and Kii values for the current loop.

ζ= 0.707	τ_e= 0.001
ω_n= 2484.76	K_{pi}= 10.56
K_e= 0.238	K_{ii}= 25941.4

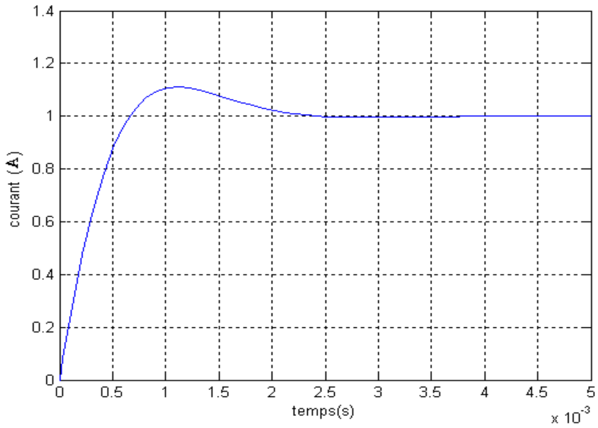

Fig.5. Index response of the current loop.

5. Regulation of the speed.

The structure of control and regulation of the speed can be shown schematically in Figure (6). The function of transfer in open loop compared to the command is given by:

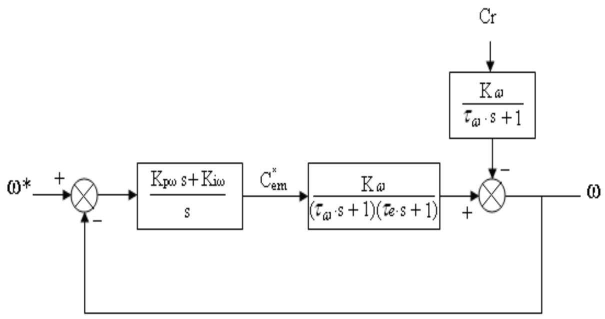

Fig.6. Structural diagram of speed control.

The closed-loop transfer function has the final expression given by:

$$G(s)=\frac{K_\omega K_{p\omega}\,s+K_\omega K_{i\omega}}{\tau_e\,\tau_\omega\,s^3+(\tau_e+\tau_\omega)s^2+(K_\omega K_{p\omega}+1)s+K_\omega K_{i\omega}}$$

For the calculation of the controller parameters, we proceed in the same way as for the current controller and we find:

$$\begin{cases} K_{i\omega}=\dfrac{\omega_n^2\,\tau_\omega}{K_\omega} \\ K_{p\omega}=\dfrac{2\zeta\omega_n\tau_\omega-1}{K_\omega} \end{cases} \qquad (6)$$

By a numerical application, the values of Kpω and Kiω of the speed controller given in Table (2) are determined:

Table 2: Values of Kpω and Kiω for the speed loop

ζ= 0.707	τ_e= 10
ω_n= 161.13 rad/sec	K_p= 0.00227
K_i= 0.25963	K_ω= 1000000

The simulation shown in Figure (7) concerns the index response of the speed loop

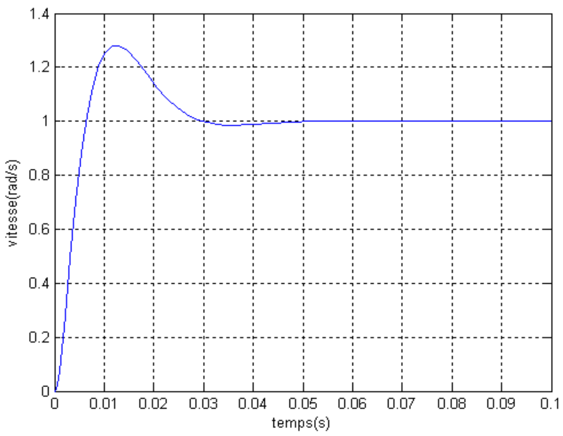

Fig.7. Index response of the speed loop.

Based on the index response of the speed loop, the desired response time and damping are checked.

6. Regulation of the position.

The regulator of the angular position of the stepping motor with permanent magnet, allows us to generate the speed of reference. We propose a simplified control scheme for the adjustment of the position, see figure (8).

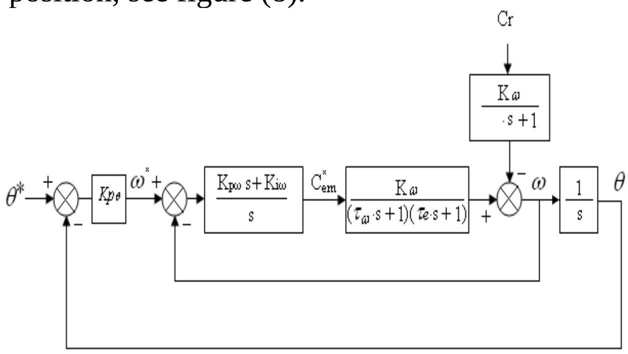

Fig.8. structural scheme of regulation of the position.

Note that the cascade; position, speed and current impose a dynamic position slow relative to that of speed or current.

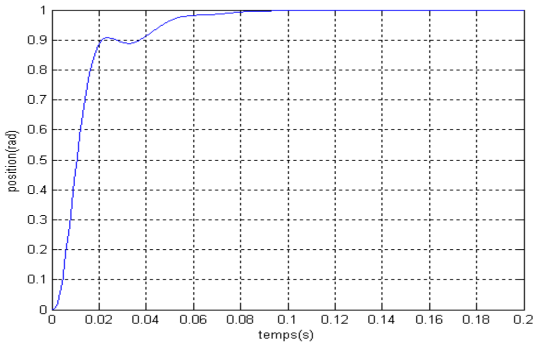

Fig.9. Index response of the position loop.

According to the index response of the position loop (FIG. 9), the latter reaches the steady state in a time equal to 95 ms and with a static error of zero.

III. Results and Discussion

The figures below present the results of a simulation of the position adjustment to evaluate the behavior of the MPP with the control provided with position, speed and current (direct and quadrature) control. The simulation was carried out with a no-load start, then application of a load torque (Cr = 0.1 Nm) at the instant 0.5s.

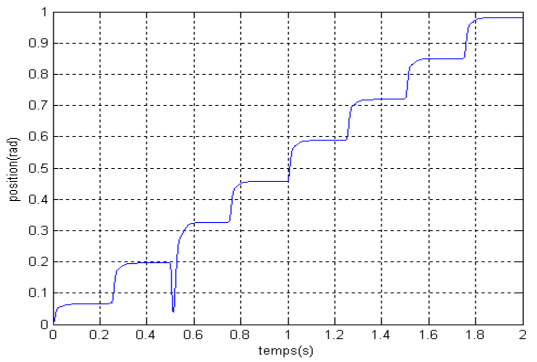

Fig.10. Response in position.

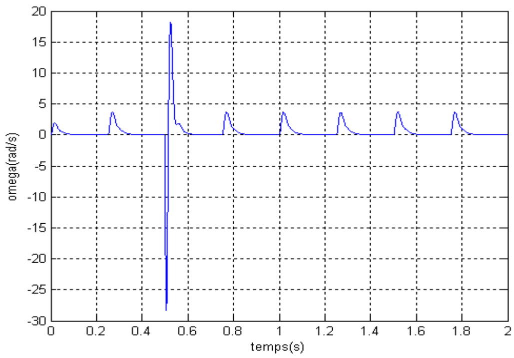

Fig.11. Speed response.

The closed-loop response of the MPP (bold line) to a position reference (dashed) is shown in Figure (10). Note that the position follows perfectly its reference. The presence of external disturbance does not affect the adjustment performance.
The curve that appears in Figure (11), represents the evolution of the speed of rotation as a function of time, as it is noted that the latter takes the same values for each switching. At the moment of application of the load torque (disturbance), the curve is stranded because of the additional inertia, but just after, the effect of this disturbance is compensated by the corrector.

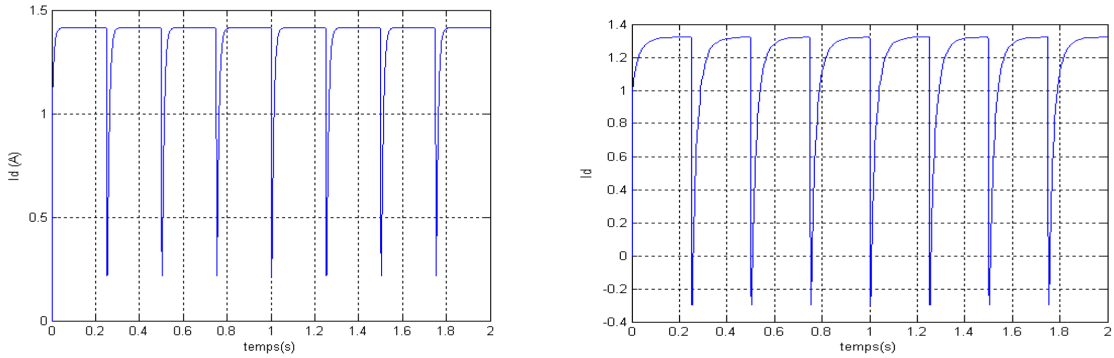

Fig12-a: The evolution of the current Id. **b:** The current on the direct axis.

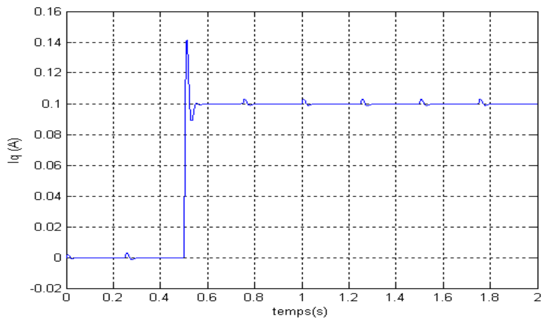

Fig.13. the evolution of the current Iq.

Figure (12-a) above shows the evolution of the direct component of the current as a function of time. Note that the latter takes the same pace as that of the current during the vacuum test Figure (12-a)**.** What can be said about this component that the application of a load torque has no effect on this axis, which proves the effectiveness of the decoupling method.
From Figure (13), which represents the evolution of the quadrature component of the current, it is noted that the latter is composed of slots, because not carried out. The effect of the resistive torque has clearly appeared on this axis, the current absorbed becomes larger than before, to compensate for the effect of the disturbance.

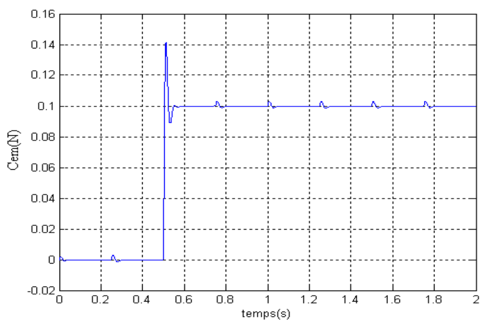

Fig.14. The evolution of the electromagnetic torque.

The electromagnetic torque (FIG. 14) is the image of the current on the axis in quadrature, that is to say that at the moment of application of the resistive torque, the control generates the necessary quantities, to bring the motor to develop a motor torque equal to salt resistant.

- **Comparison between controls, by power supply and closed loop**

In this part the control is presented by the supply circuit (in open loop) and the closed-loop control of a permanent magnet stepper motor. the evolution of the angular position is shown in Figure (15). the ideal trajectory (bold line) is different from the real one (in dotted lines) obtained for a system disturbed by a resistant torque. The difference between the two trajectories has been normalized compared to the reference.

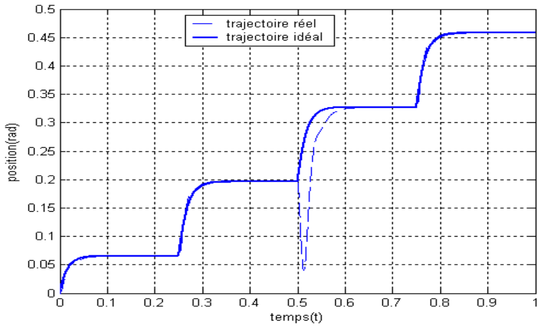

Fig.15. Ideal and real trajectory of the position

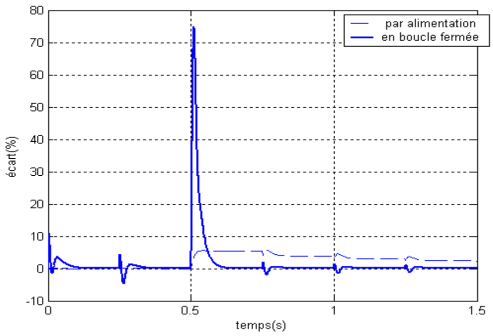

Fig.16. The gaps for both methods

The standard position deviation of the feed control (dotted), and the closed loop control (in bold) are shown in Fig. (16). From this figure, it is noted that the gap in the control of power is zero tan as the absence of disturbance. Now of application of the resisting torque, the gap increases and starts decreases in a very slow manner. The closed-loop control has a very large gap when applying the resistive torque, but it only lasts a very short time. Indeed, the closed loop control provides additional means for controlling this disturbance.

III. Conclusion

We have examined by simulation the effect of speed control and currents, the closed-loop index response of these quantities gives satisfactory results. We have also tested in this part the control of the position by introducing a proportional regulator in cascade with the speed regulation loop and the current on the axis in quadrature, one draws that this method of control presents satisfactory performances of adjustment, because the loss in position due to the load torque is compensated. A simulation was made to show the nuisance of the coupling between the two behaviors (mechanical and electrical), the results obtained show the efficiency of the method of decoupling by compensation. This tool makes the MPP comparable to that of a separate excitation DC machine.

References

[1] Johnstone C.M., Nielsen K., Lewis T., Sarmento A., Lemonis G. EC FPVI co-ordinated action on ocean energy: A European platform ford sharing technical information and research outcomes in wave and tidal energy systems. Renewable Energy, 2006, vol.31, no.2, pp. 191-196. doi: 10.1016/j.renene.2005.08.015.

[2] V. Fedak, P. Bauer, V. Hajek, H. Weiss, B. Davat, S. Manias, I. Nagy, P. Korondi, R. Miksiewicz, P.Duijsen, P. Smektal, "Interactive elearning in electrical engineering", in Proc. EDPE'03, pp. 368-373,Sep. 2003.

[3] H. Glaoui, A. Harrouz, “sliding mode control of the DFIG used in wind energy system”, Electrical engineering andElectromechanics Journal, ISSN 2309-3404, pp. 61-67, Vol.3 , 2018.

[4] Golam Sarwer Mohammed, Md. AbdurRafiq, B.C. Ghosh, "Sliding Mode Speed Controller of’ a D.C Motor Drive", Journal of Electrical Engineering The Institution of Engineers Bangladesh, vol. 31, no. I, December 2004.

[5] J. Y. Hung, w. GAO, J. C. Hung, "Variable Structure Control: A Survey", IEEE Trans. on Industrial Electronics, vol. 40, no. 1, pp. 2-22, February 1993.

[6] FJ Lin, SL Chiu -Adaptive fuzzy sliding-mode control for PM synchronous servo motor drives IEE Proceedings-Control Theory and Applications, 1998 - IET.

[7] A. Harrouz, H Becheri, I Colak, K Kayisli, “Backstepping control of a separately excited DC motor”, Electrical Engineering, Springer Berlin Heidelberg , ISSN: 0948-7921, Vol.100, Issue 3, September 2018, pp. 1393-1403.

[8] V.T. Utkin, "Sliding mode control design principles and applications to electric drivw", Industrial Electronics IEEE Transactions on, pp. 23-36.

[9] S. J. Chapman, "Electric Machinery Fundamentals" in , the Mcgraw-hill companies, 1999.

[10] A. Harrouz ; Ilhami Colak ; KorhanKayisli, “Control of a small wind turbine system application”, Journal "IEEE Xplore" of IEEE International Conference on Renewable Energy Research and Applications (ICRERA), 2016, DOI: 10.1109/ICRERA.2016.7884509, Pages: 1128 – 1133.

[11] M.A.Haller«Contributionàlamodélisationetl’indentificationd’unmoteur pasàpashybrideetdesonalimentation».ThèseDocteurIngénieur.I.N.P.L.Nancy1981.

[12] A.Hamzaoui,«ModèlesDynamiqueetCommandesenboucleferméed’unMoteurpasà pas», Thèse Doctorat,1992.

[13] K. D. Young, V. Utkin, U. Ozguner, "A control engineer's guide to sliding mode control", IEEE conference, pp. 1-14, 2002.

[14] Mohammed GodamSarwer, Md. AbdurRafiq, B.C. Gosh, "Sliding Mode Speed Controller of a D.C.Motor Drive" in Journal of Electrical Engineering, Bangladesh:The Institution of Engineers, Dec 2004.

[15] K.H. Ang, G.C.Y. Chong, Y. Li, "PID Control System Analysis Design and Technology", IEEE Transactions on Control Systems Technology., vol. 13, no. 4, pp. 559-576, July. 2005.

[16] C. Edward, S. K. Spurgeon, "Sliding mode control: theory and application in ,London:Taylor and Francis, 1998.