SPEED CONTROL OF D.C SERIES MOTOR BY USING POWER MOSFET CHOPPER

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Abstract

The aim of this paper is to construct a system which can control the speed of d.c series motor by using power MOSFET chopper .The system contains close loop control which has a performance and characteristics in the operation.The close loop control system contains digital pulse width modulation circuit, driving circuit, over speed, and over current protection circuit. The power MOSFET devices are now available in production quantities and are already being utilized from switched power applications including motor control.HEXFET power MOSFET type IRFK4H350 is selected for this application due to its relative high current -handling ability up to 50A and a maximum drain -to- source voltage of 400v. All the theoretical transient responses of speed and current reveal fairly close agreement with practical response, the maximum deviation between them is (5%) .

Key words: mosfet, chopper, motor, drain, source, thyristor, transistor.

السيطرة على سرعة محرك تيار مستمر باستخدام المقطعات

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الخلاصة :

الهدف من هذا البحث هو السيطرة على سرعة محرك تيار مستمر توالي باستخدام مقطع ترانزستور تأثير المجال المعدني . النظام يعتمد السيطرة المغلقة والذي يحوي شكل وخواص العمل ، نظام السيطرة المغلقة يحوي دائرة التحميل العرضي للنبضة ودائرة السوق وحماية من السرعة الفائقة والتيار العالي ودائرة قياس التيار وجهاز قياس السرعة . ترانسستور تأثير المجال المعدني يستعمل في المحركات كمفاتيح سيطرة وفي بحثنا هذا استخدام ترانزستور تأثير المجال نوع (HEXFET power MOSFET type IRFK4H350) وذلك للقابلية العالية لتحمل تيار عالي(50A) وفولتية بين المصدر والساحب (400V).

Nomenclature

Symbol	Notations	Units
id,if	= instantaneous armature current during conduction freewheeling intervals.	A.
J	= polar moment of inertia of motor pulse load .	$kg.m^2$
K	= motor voltage constants.	v/rad/sec.
L	= total inductance of armature circuit .	H
R	= total resistance of armature circuit .	Ω.
T	= periodic time of chopper.	s.
V	= source voltage.	v.
W	= instantaneous speed.	rad/sec .

Greek symbols

β = the sum of βv and kG , N.m/rad/sec

Ω = symbol of ohm (value of resistance)

Introduction.

The D.C series motor operates with decidedly drooping speed as load is added, the no-load speed usually being high, the torque is proportional to almost the square of the current at low saturation and to some power between one and two as saturation increases.By virtue of its ability to handle heavy torque overloads while reducing the associated power overload with speed drop, and by virtue of its ability to withstand severe starting duties, the series motor is best adopted to hoist, crane and traction -type load [Uman,1983]. From the basic equation for the speed of rotation

$$w = \frac{Va - IaRa}{KIa} \qquad (1)$$

The rotating speed can be varied by varying either the applied voltage, Va , or the armature current Ia[Rashid,1988] speed above the base speed (the speed when normal armature voltage and full armature current are applied) are obtained by armature current control (constant horsepower drive) .Speeds below base speed are obtained by armature voltage control (constant torque drive) [Uman,1983]. Classically the variation of the applied voltage is obtained from a fixed d.c voltage by two methods. In the first method variable resistance inserted between the fixed- voltage d.c source and the motor. This method is inefficient because of looses in the resistance.In the second method the motor -generator set is used to supply the power to the motor whose speed is to be controlled [sen,1981]. A variable d.c output voltage of generator is obtained by controlling the field current of d.c generator which is driven by a constant speed d.c motor. This system is still used in some industrial drives, therefore the system is bulky, costly, slow in response and less efficient. In 1960 high power thyristor devise became available to make the solid state d.c power converter practical. These converters offer greater efficiency, fast response, smooth operation, smaller size and lower weight and cost. The chopper circuit of force commutated thyristors is used to control the speed of D.C series motor. The extensive work has been done on mathematical analysis of the performance of the d.c series motor that is controlled by this circuit .The following survey for literature shows the methods which are used for analysis. Franklin[franklin,1972] found the theoretical relation between currents, fluxes and pulse duration in d.c series motor energized by power pulses obtained by using D.C thyristor. Mellit & Rashid[mellite,1974] presented a computer based method for analyzing the performance of d.c chopper circuit. Damle & Dubey[damle,1976] described the interdependence of armature induced voltage and armature" current and the 'fact that the radiation between them is nonlinear. Ahron & Applebaum[Ahron, 1981] analyzed the transient response of d.c series motor. Dubey & Shepherd[damle,1976] analyzed the transient response of d.c series motor controlled by chopper with time -ratio control (TRC) or current limit control (CLC) with square - output voltage. The object of the present work can be summarized as follows :-

1) Construct one quadrant chopper using power MOSFET , this chopper is used to drive a d.c series motor .
2) Construct over current and over speed protection circuit .
3) Analyze the performance of d.c series motor driven by power MOSFET chopper[Thomas,2001]. The analysis is simplified by taking the average values of voltage, current, speed and torque instead of the instantaneous values and this gives good approximation when the chopping frequency is high, also the nonlinearly of the magnetization curve is taken into account . MOSFT transistor that can be fabricated in single integrated circuit also it can modeled very simple as switch[Ken,2000].
4) Simulate the analysis in the microcomputer and drawing the transient response of speed and current for step change in the mean values of applied voltage and the load to compare with the experimental transient response.

Control strategies.

There are two types of control strategies employed in d.c chopper [Uman,1983] namely:

1) time ratio control (TRC)
2) current limit control (CLC)

In the time ratio control the value of T_{ON}/T is varied. This is effected in two ways. They are variable frequency operation and constant frequency operation. In form either T_{ON} or T_{OFF} is kept constant and the other one is varied, effectively changing chopper period and resulting in variable frequency operation. In this paper the values of T_{ON} or T_{OFF} are varied such that T is constant resulting in a constant frequency operation . In current limit control the chopper is switched ON and OFF so that the current in the load is maintained between two limits. When the current exceeds upper limit the chopper is switched OFF. During OFF period the load current freewheels and decreases exponentially. When it reaches the lower limit the chopper is switched ON . Current limit control is possible either with constant frequency or with constant T_{ON} .The current limit control is used only when the load has energy storage elements. The reference values are the load current or load voltage. These control strategies are the load current or load voltage. These control strategies are illustrated in **Fig.(1).** In this work the time ratio control with constant frequency (This type also called pulse width modulation) control is used.

Theory of operation.

The chopper is now widely used for the control of d.c series motor[Lander,1987]. The output voltage of the chopper is controlled by using PWM control. A chopper with square-wave output voltage normally operates in two modes; namely, the duty interval and the freewheeling interval, during chopping cycle. The performance of d.c series motor is described by the following differential equations[Lander,1987], referring to **Fig.(2).**

Duty interval $(0 < t < \delta t)$.

$$L\frac{d_{id}}{dt} = v - R_{id} - K(_{id})w \quad (2)$$

Also from dynamic of motor pulse load

$$J\frac{dw}{dt} - k(_{id})_{id} - \beta w \qquad (3)$$

Free wheeling interval $(\delta T \leq t < T)$

$$L\frac{d_{if}}{dt} = -R_{if} - k(_{if})w \qquad (4)$$

$$j\frac{dw}{dt} = -k(_{if})if - \beta w \qquad (5)$$

In equations (2-5) , the terminology k($_{id}$) and k($_{if}$) denotes that k is a function of the instantaneous values of the motor current, so that the equation represent a set of simultaneous, nonlinear differential equation . For calculation of the transient response of current and speed the above equations are solved numerically for each interval of the chopping cycle by using the final conditions of the pervious interval as the initial condition for each successive chopping interval. This method has the advantages that it permits the calculation of transient response exactly for the assumed model. The necessary computation time is, however quite large, particularly for system with slow transient response.

System implementation.

Fig.(3) shows the block diagram of the implemented closed loop chopper –fed d.c series motor. The speed of the d.c series motor change with the load torque. To maintain a constant speed, the armature (and/or) field voltage should be varied continuously by varying the duty cycle of d.c. chopper. A closed loop control system has the advantages of improved accuracy; fast dynamic response and reduce effect of load disturbance and system nonlinearities. the block diagram of the closed- loop chopper-fed d.c. series is shown in **Fig.(3).** If the speed of the motor decreases due to the application of additional load torque, the speed error increases. The speed controller signal u , changes the duty cycle of the chopper, and increases the armature voltage of the motor. An increased armature voltage develops more torque to restore the motor speed to the original value, the drive normally passes through transient period until the developed torque is equal to the load torque [Rashid,1988].

Power MOSFET driving circuit

Fig.(4) shows the total power needed to drive power MOSFET is very small, all that must be provided is the capability to charge and discharge the gate to-source capacities (typically 8.0 nf) in short time. This ensures that the switching losses are minimized. The output of the protection circuit is coupled to power MOSFET gate drive stage via opto -coupler ,the output side opto -coupler is powered from an isolated power supply (+5v).

Digital PWM circuit.

It consists of a binary switch which contains eight micro switches ,one side of each is connected to 5v through a resistance of 1 k Ω value and then applied to latch IC1 type (74HCT273E),. The other side is connected to the common point of the power supply.

Current measurement circuit.

A D.C current transfoffi1er of type RDCT50/B is used .Armature current flow in the direction of arrow produces a positive voltage across the load with respect to the common line .The d.c current transformer is a constant current device. It is only used with the load connected.

Speed measurement circuit.

Optical tachometer is used to measure the speed of the machine. The speed encoder produces a train of pulses whose frequency is linearly depended upon the motor speed.

Overcurrent and over speed protection circuit.

D.C motor has low resistance and at starting the back e.m.f is zero, therefore, high current passes through the chopper and the motor .Also if the load of d.c series motor is not coupled the speed becomes very high therefore protection from over current and over speed is necessary. The current signal and speed signal are compared with reference values for current and speed respectively. Two comparators inside one chip (ICI type LM139) are used one for current and another for speed.

Control system using Microprocessor.

The advantages of microprocessor controllers for a variable speed drives are reducing the size and cost of the hardware electronics, and having more precision and stability. **Fig.(5)** shows the flowchart of the software.

Results and Conclusion.

The purpose of the present. work is to construct d.c power MOSFET chopper driving for driving d.c series motor. The power MOSFET devices are now available in production quantities and are already being utilized for switched power applications including motor control.The use of power MOSFET eliminate the need for a commutation circuit that is used with the thyristor choppers to turn the thyristor off and allows the chopping frequency to be raised, the switching and snubber losses associated with power MOSFET sets an upper bound on the chopping frequency from an efficiency point of view . The chopping frequency is chosen to be equal to (3.92 KHZ) , the inductance of the motor (48 mH) is sufficient to smooth the armature current , no need to add external inductance.The maximum peak – to - peak ripple in armature current is 3% . The supply d.c voltage =180 v .The experimental results for maximum peak -to-peak ripple is equal to 150mA . For duty cycle 0.75.The experimental value of peak -to -peak ripple is equal to 100mA. The parameters of speed controller that gives good response with no over shoot are k_P=0.5 and k_i=0.1 The closed loop system is tested for step change in load resistance from 100Ω to 50Ω as shown in **Fig. (6). Fig.(7)** shown the experimental response is compared with the theoretical response of the speed for step change in load resistance RL from 50Ω to 100Ω. Reference speed is changed from 46 rad/sec to 59.3 rad/sec, the system is tested for this step change , the steady state operating point (w_{avo}=46rad/sec and i_{avo}=3.05A).comparison between experimental and theoretical response is in **Fig.(8). Fig.(9)** shows the experimental and theoretical transient response of the speed for step change in reference speed from 68 rad/sec to 44.7 rad/sec. The following points are deduced tram the tests:

1) High gain and transcoductance which are variant with increasing current : MOSFET are voltage -driven devices requiring simple drive circuits with low energy sources such as MOS logic or opto devices.
2) Raggedness, with no secondary breakdown turn- off.
3) A positive temperature coefficient, and hence ease of parallel connection.
4) An integral reverse body – drain diode with a similar current – handling ability to that of transistor itself .

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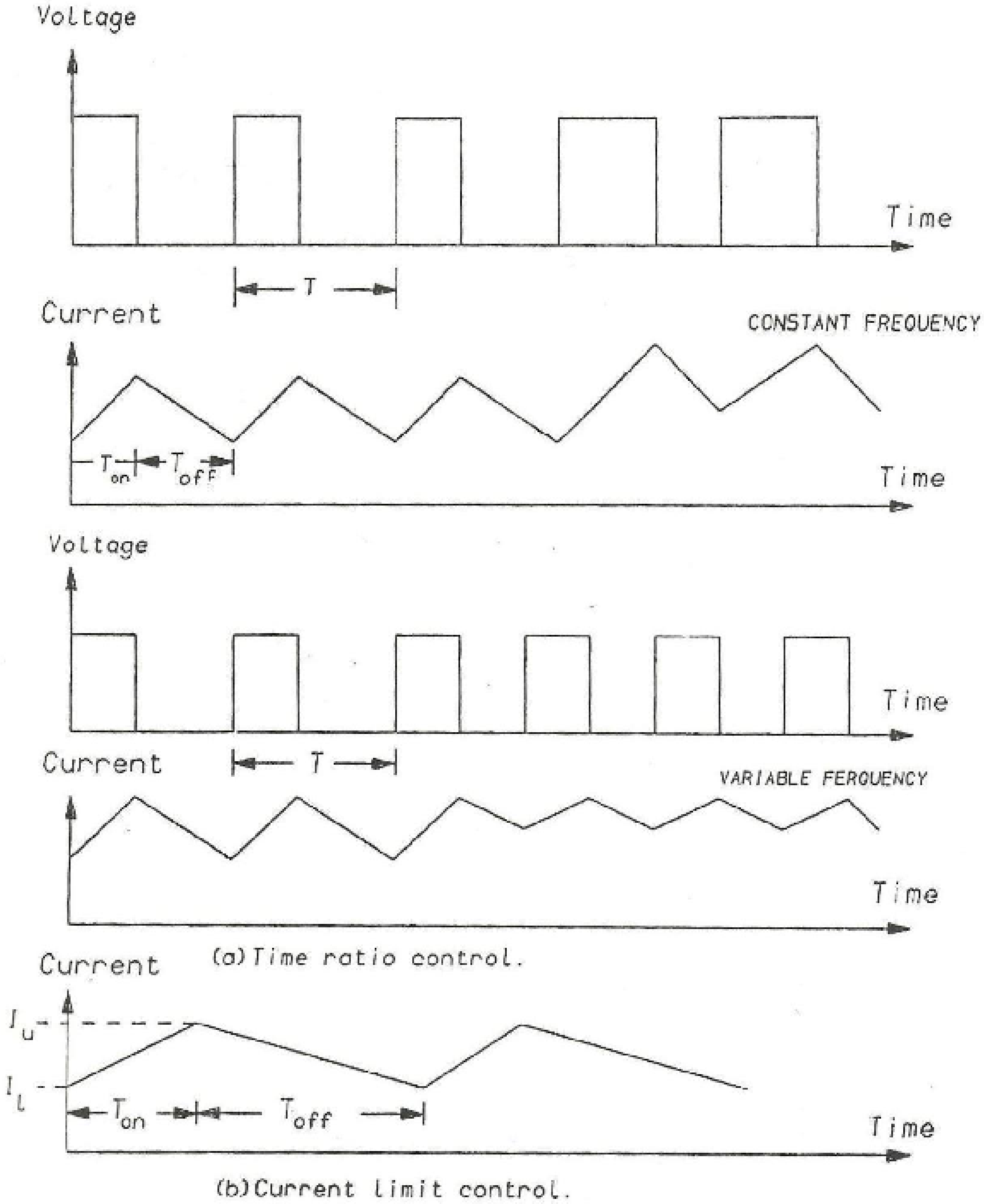

Fig.(1) Control strategies of a chopper.

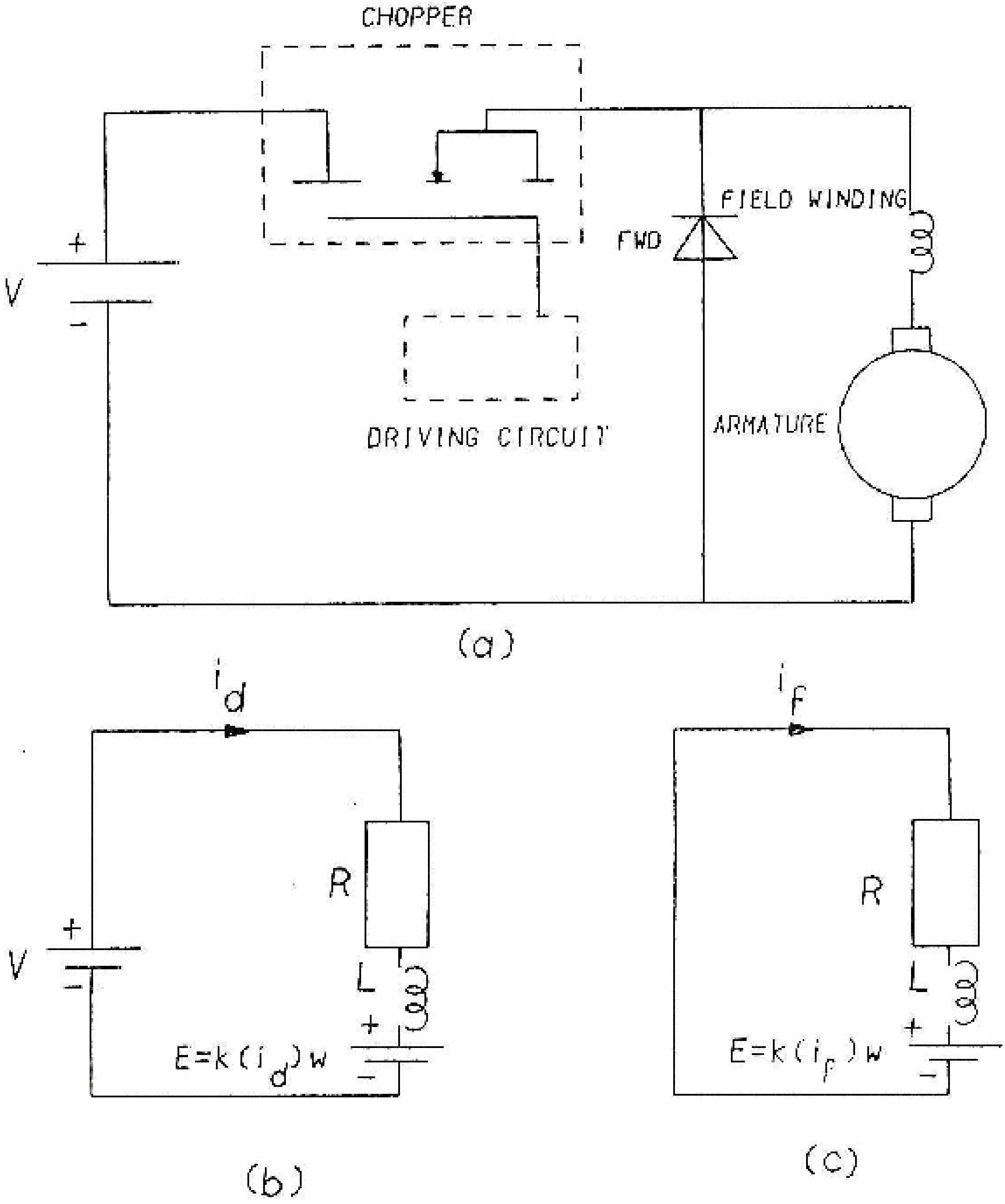

Fig.(2) Representation of a chopper – controlled dc series motor.
(a) Basic schematic diagram .
(b) Equivalent circuit of duty interval .
(c) Equivalent circuit of freewheeling interval .

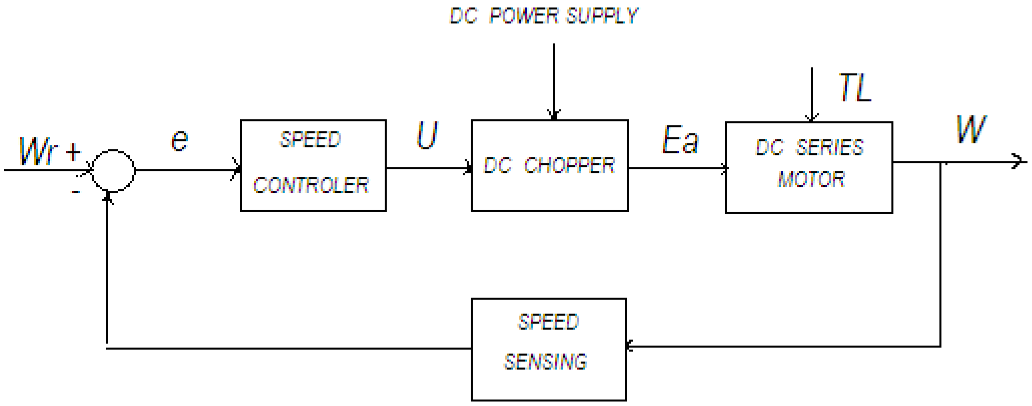

Fig.(3) Block diagram of a closed – loop fed dc series motor .

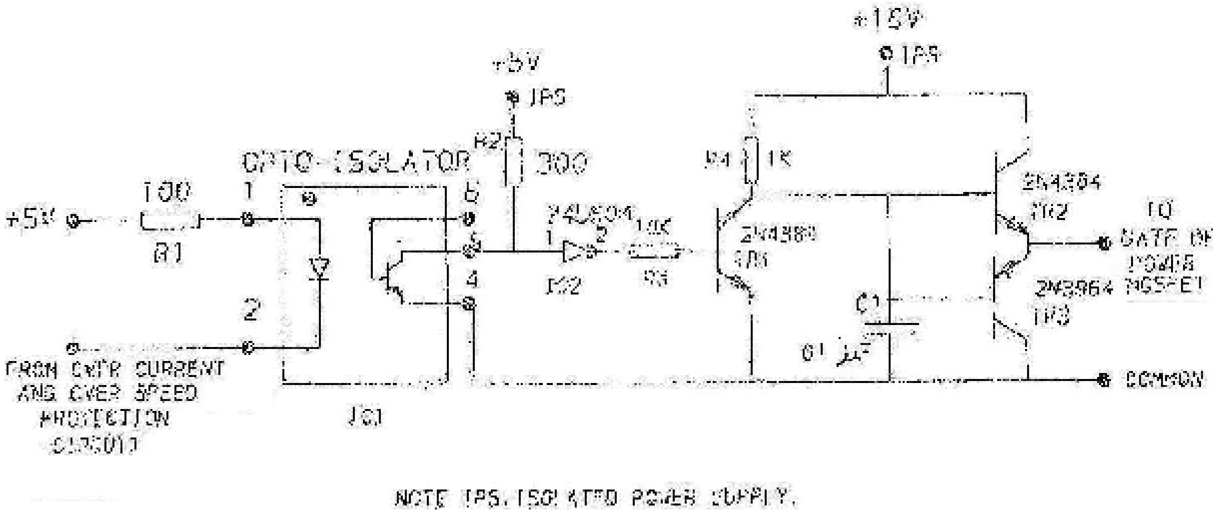

Fig.(4) Driving circuit for dc chopper.

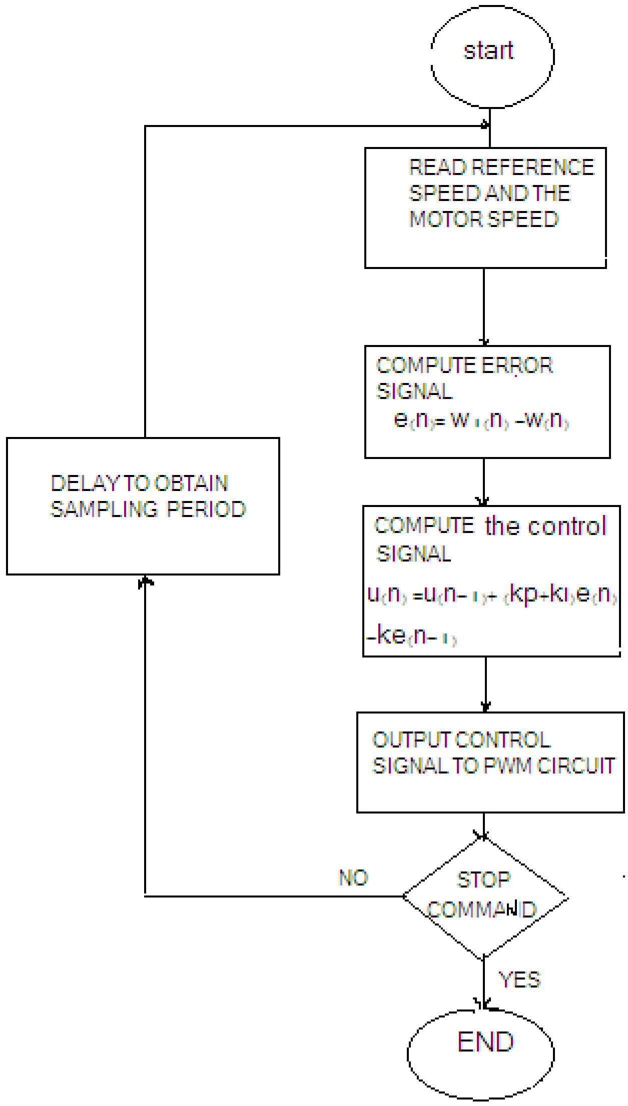

Fig.(5) The software flowchart of speed control.

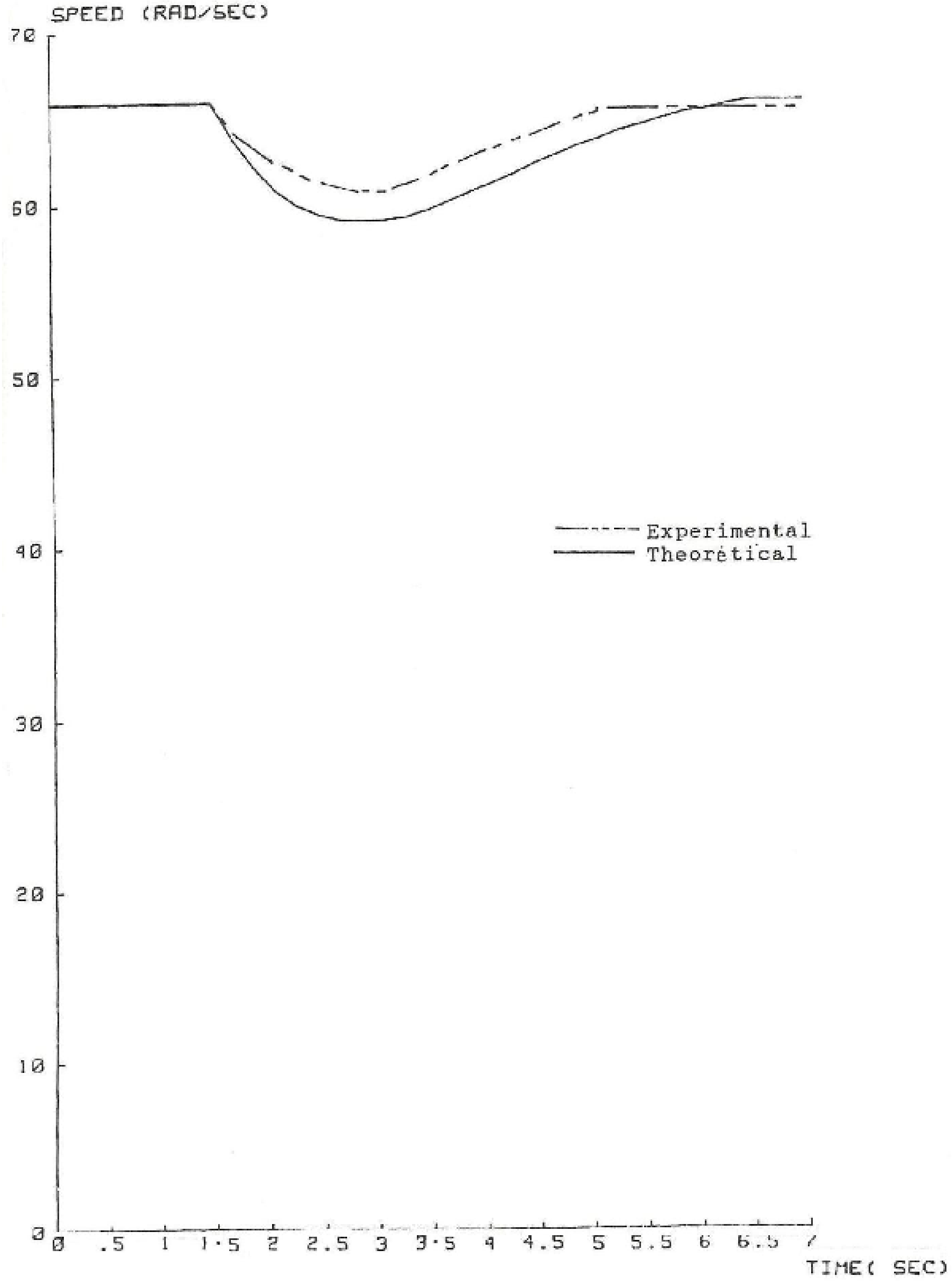

Fig.(6) Experimental and theoretical closed loop transient response of the speed for step change in load resistance RL from 100Ω to 50Ω , w_{avo} = 66.6 rad/sec., i_{avo} = 2.7A .

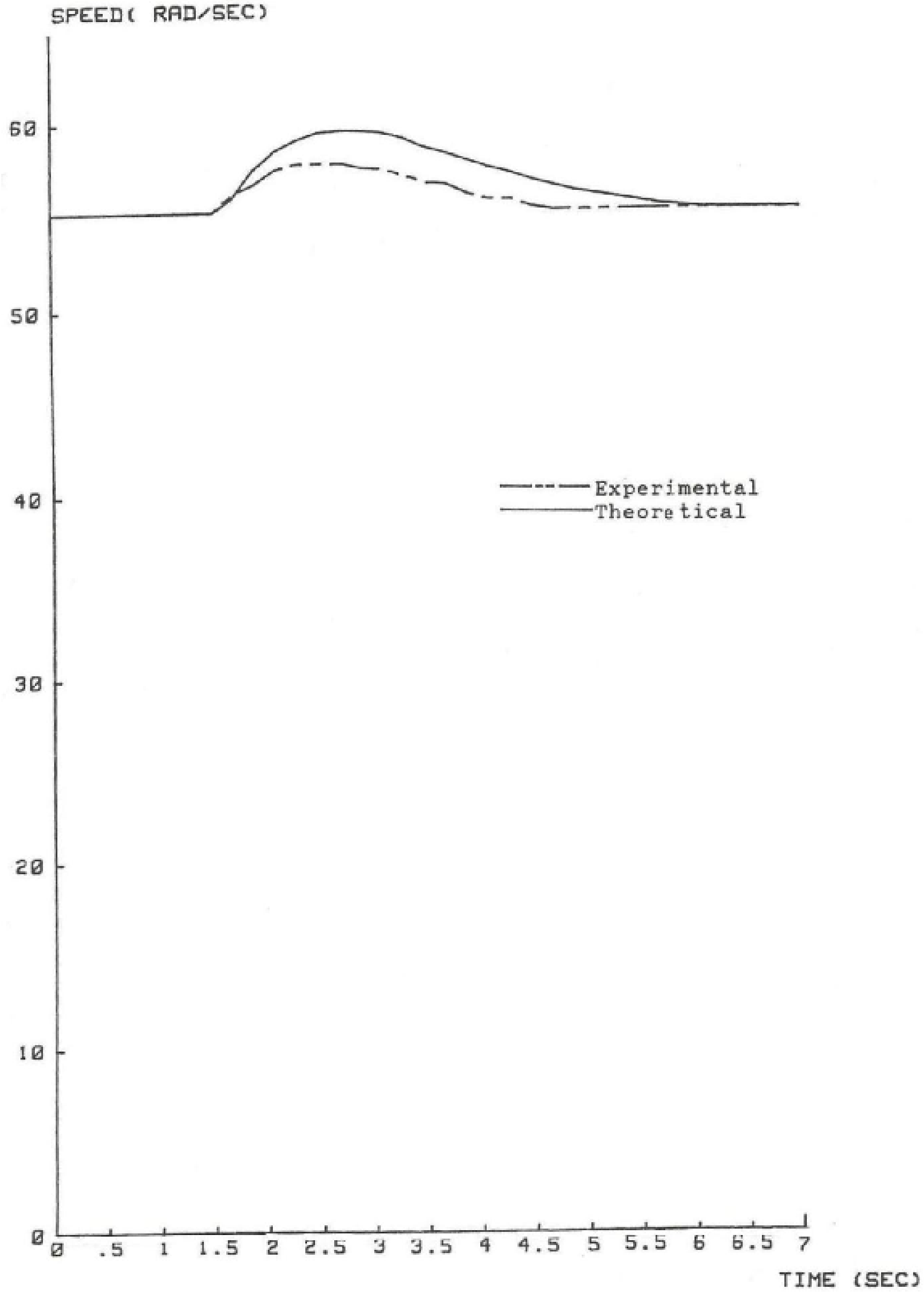

Fig.(7) Experimental and theoretical closed loop transient response of the speed for step change in load resistance RL from 50 Ω to 100 Ω , W_{avo} = 55.2 rad/sec. , i_{av0}= 3.38A .

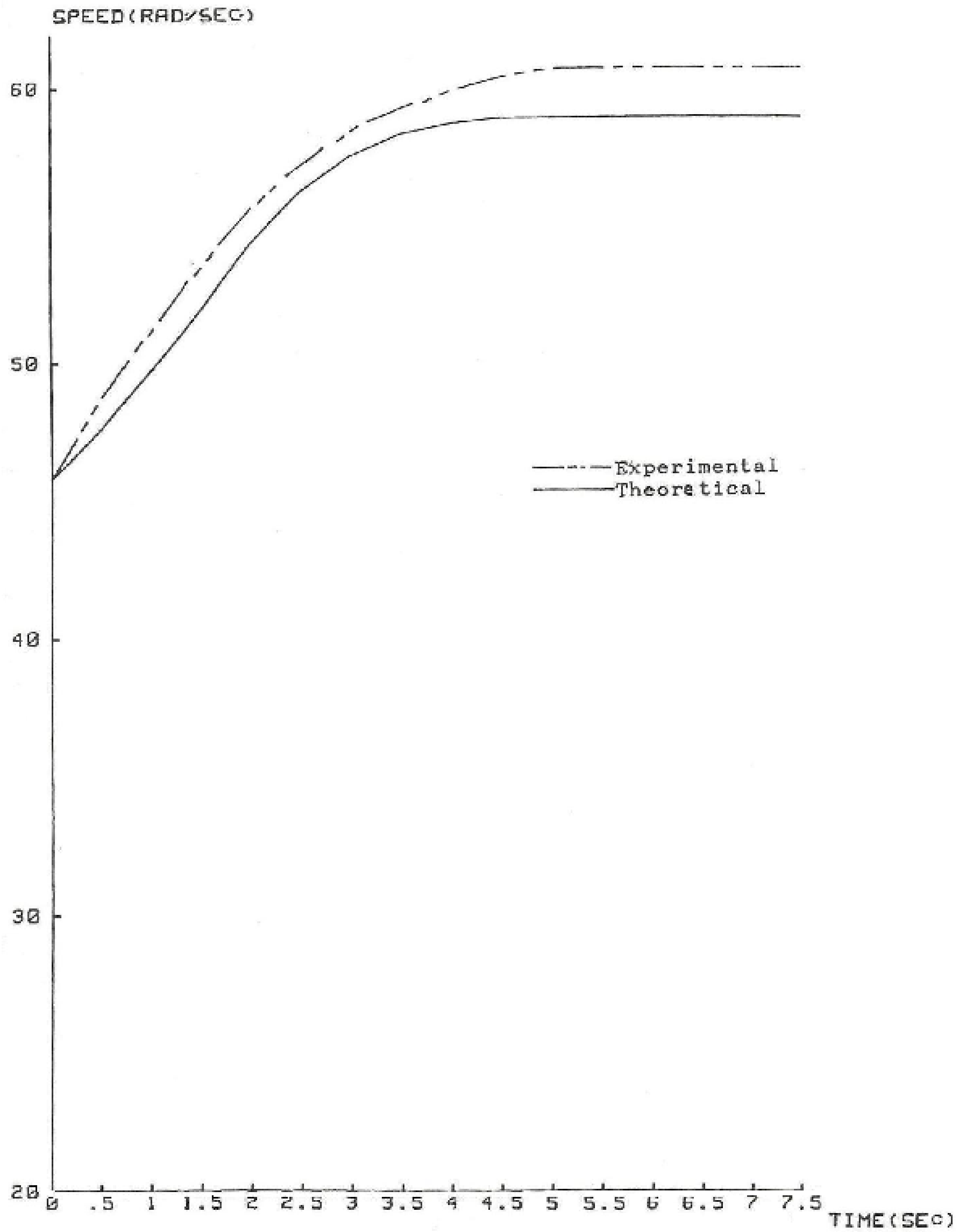

Fig.(8) Experimental and theoretical closed loop transient response of the speed for step change in reference speed Wr from 46.0 rad/sec to 59.3 rad/sec , W_{avo} = 46.0 rad/sec , i_{vao} = 3.05A .

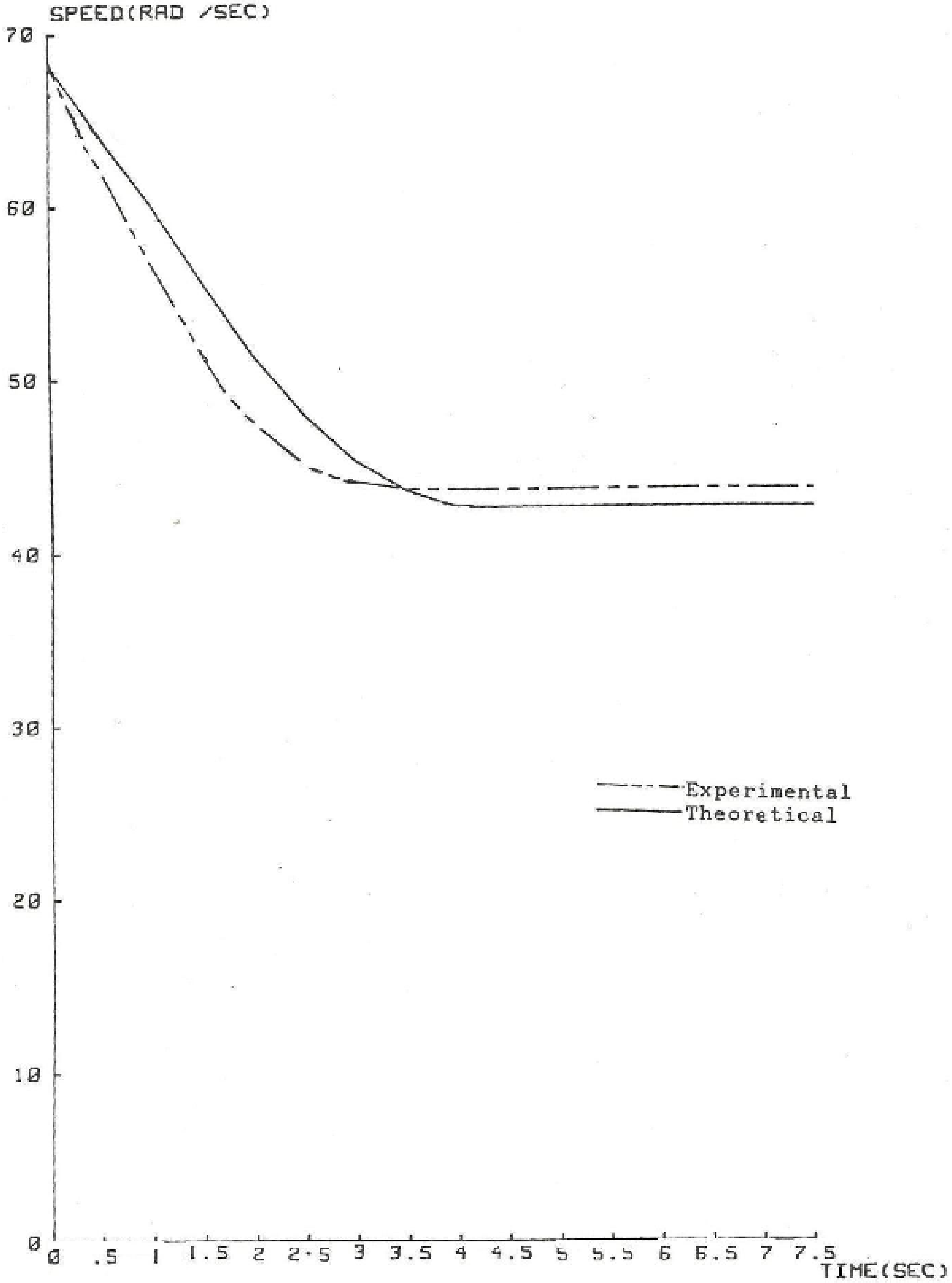

Fig.(9) Experimental and theoretical closed loop transient response of the speed for step change in reference speed Wr from 68.0 rad/sec to 44.7 rad/sec, W_{avo}=68.0 rad/sec , i_{avo}=3.16A.