Chapter-4

Design and Development of C2ISO and 3ISO FLC/AIFLC controllers

The design and development of C2ISO/3ISO FLCs/AIFLCs for the speed control of BLDC motor is discussed. The parameter variations in speed control of BLDC motors like desired speed, brake application and load variations using MISO FLCs and AIFLCs are reported in this Chapter. The said controllers are further analysed for the effect of noise and its suppression using IIR filter. The IIR filter is used from LABVIEW software.

4.1 Design and development of C2ISO FLC:

The design and development of PID and auto tune PID controller are discussed in detail in chapter 3. VI diagram of 2ISO FLC may also be designed similar to the PID controller with a few differences. The VI diagram of 2ISO FLC has two inputs e(k) and ce(k) and one output. The o/p of the FLC icon is added to the previous error by means of an adder ikon. An offset voltage of 2.6 V is added to this o/p cu(k) as shown in fig 4.1 which is given to the motor through the driver circuit. The details of selection of number of triangular membership functions for fuzzification, selection of defuzzification methods and sampling time for this controller is highlighted in this section.

4.1.1 Selection of number of triangular membership functions:

C2ISO FLC is designed for various number of triangular membership functions for fuzzification. The selection of number of membership functions, their shapes and their appropriate ranges for optimized output has been discussed in the fuzzy set editor of fuzzy logic tool kit in LabVIEW. e(k) and ce(k), the two input for C2ISO FLC are fuzzified by using three-number, five-number and seven-number triangular membership functions separately. Control output is also fuzzified by using three-number, five-number and seven-number triangular membership functions. Rule base editors are designed as discussed earlier corresponding to the three-number, five-numbers and seven-number triangular membership functions. Fig. 4.1 (a),(b),(c), shows rule base editors. Figure 4.2 shows the seven number triangular membership functions for fuzzification. Fuzzification procedure is carried out according to the number of membership functions. The number of rules in rule base editor

ce(k) / e(k)	NL	ZE	PL
NL	NL	NL	ZE
ZE	NL	ZE	PL
PL	ZE	PL	PL

(a)

ce(k) / e(k)	NL	NM	ZE	PM	PL
NL	NL	NL	NL	NM	ZE
NM	NL	NL	PM	ZE	PM
ZE	NL	NM	ZE	PM	PL
PM	NM	ZE	PM	PL	PL
PL	ZE	PM	PL	PL	PL

(b)

ce(k) / e(k)	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NM	NM	NS	ZE	PS
NS	NL	NM	NS	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PS	PM	PL
PM	NS	ZE	PS	PM	PM	PL	PL
PL	ZE	PS	PM	PL	PL	PL	PL

(c)

Fig. 4.1 (a), (b), (c) shows rule base editors for 3-,5-,7-membership functions for FLC/AIFLC .

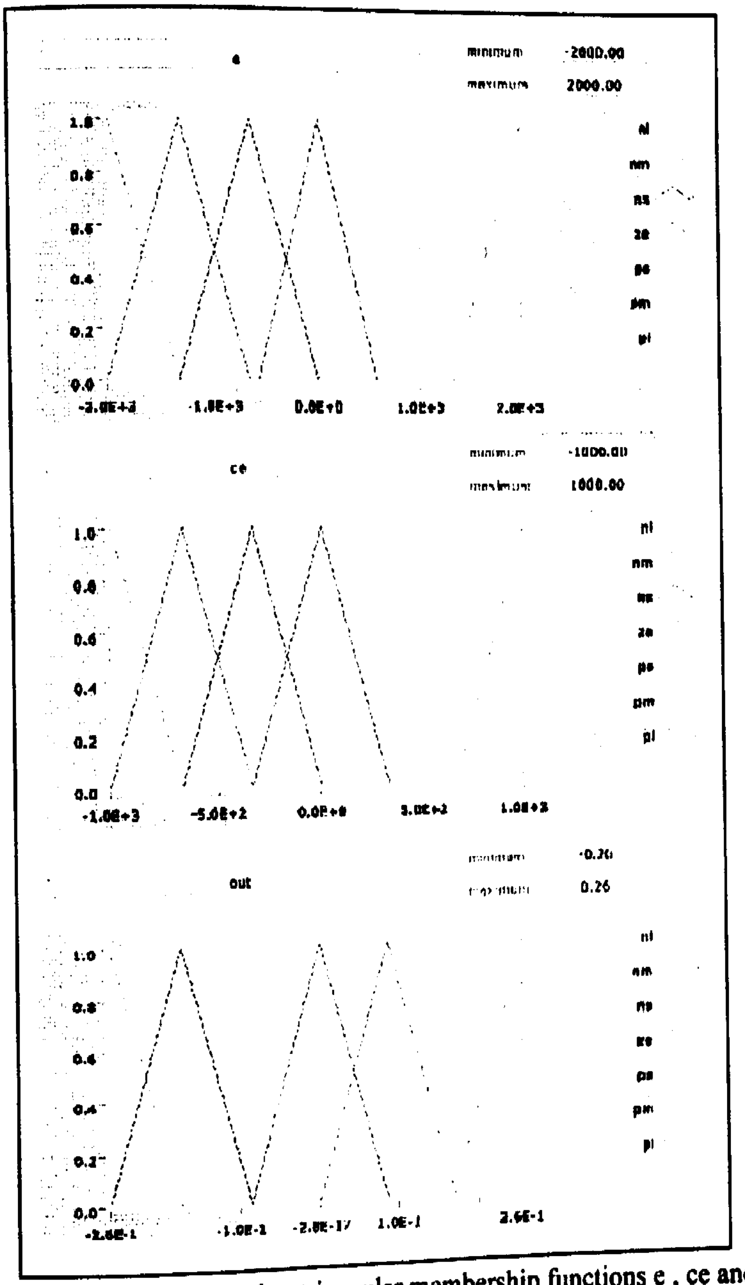

Figure:4-2-Seven number triangular membership functions e , ce and cu

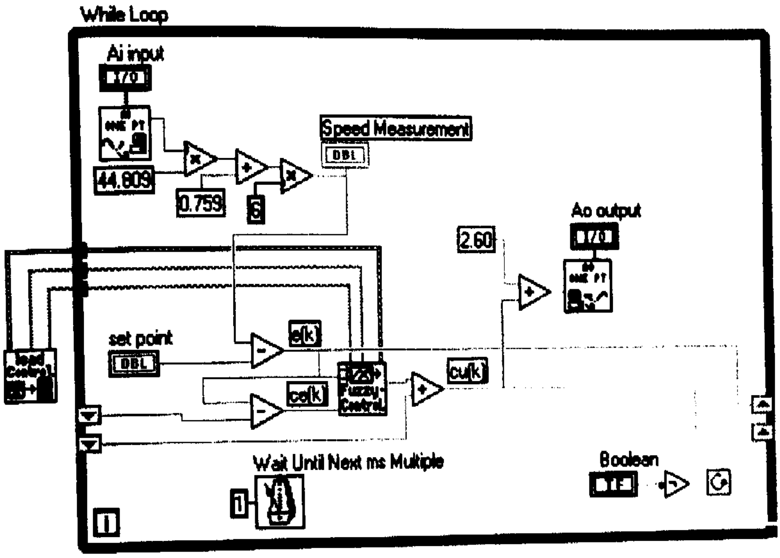

Figure4.3 : VI block diagram of C2ISO FLC for the speed control of BLDC motor

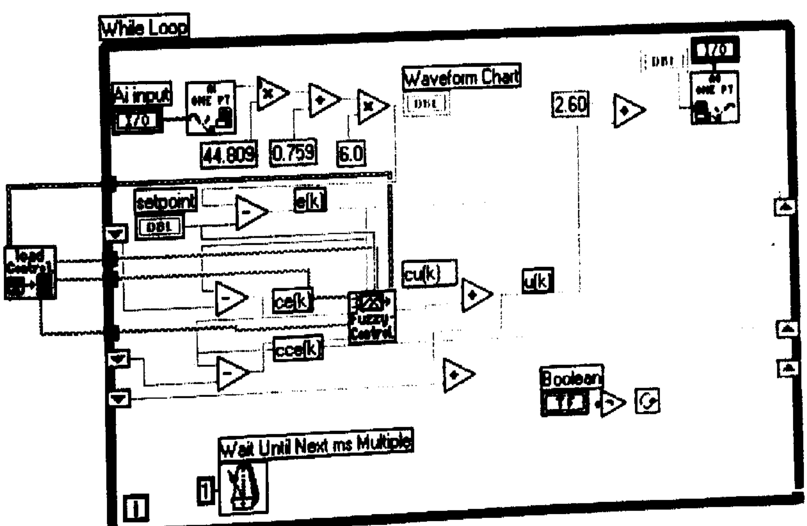

Figure 4.4: VI block diagram of C3ISO FLC for the speed control of BLDC motor

depends on number of inputs and number of membership functions for inputs .For example, for two inputs and three-number triangular membership functions, we have 3 x 3 = 9 rules. Similarly, for two input five-number membership functions, we have 5x5 = 25 rules and for two input seven -number membership functions we have 7 x 7 = 4 9. Similarly for three input, three membership functions ,we have 3 x 3 x 3 = 27 rules , for five- number membership functions we have 5 x 5 x 5 = 125 rules and for seven- number membership functions we have we have 7 x 7 x 7 = 343 rules.

4.1.2 Selection of defuzzification method:

There are various defuzzification methods as discussed earlier Center of gravity (COG), center of maximum (COM) and mean of maximum (MOM) are very popular among them. These three methods are implemented separately, while designing FLC for the speed control of BLDC motor. Output response is obtained for all the three methods.

4.1.3 Sampling Rate:

C2ISO FLC has been implemented with different sampling rates with 1 m sec, 0.1 sec and 1 sec and settling time of the response has been observed.

4.1.4 Experimental Results:

The C2ISO FLC has been successfully implemented for the real time speed control of BLDC motor for a rated speed of 1500 rpm. First three-number triangular membership functions are chosen for fuzzification of input variables e(k) and ce(k) and control output cu(k). The speed control of BLDC motor is carried out using three-number triangular membership functions. The transient response i.e., speed versus time is obtained. Similarly five-number and seven-number triangular membership functions are selected for the next two cases. Experimental transient responses for fuzzification are shown in figure 4.4. It is observed that for three-number triangular membership functions settling time of 2.2 sec with zero steady state error for set point speed of 1500 rpm. For five-number triangular membership functions, a settling time of 2.1 sec is observed. The response of seven-number triangular membership functions is found to be 1.9 sec. Above results show that seven-number triangular membership functions is the best choice for fuzzification for the speed control of the BLDC motor.

The COG, COM and MOM defuzzification methods are applied to get crisp control signal for the speed control of the BLDC motor. First, the experimental transient response is obtained for speed control of the BLDC motor using COG defuzzification method. Similarly, COM and MOM defuzzification methods are also applied separately for the speed control of the BLDC motor. The experimental transient responses for these three defuzzification methods for the set point speed of 1500 rpm are as shown in figure 4.5. For MOM defuzzification method, the settling time is 2.15 sec, with COM defuzzification method the settling time of 2.0 sec was obtained. In the case of COG defuzzification method, the settling time is 1.9 sec, with no overshoots/undershoots and zero steady state error. Hence, the COG defuzzification method gives the best result as compared with MOM and COM.

Figure 4.6 shows the experimental transient response of speed control of BLDC motor using C2ISO FLC for sampling time of 1 msec, 0.1 sec and 1 sec. From the transient response, it is observed that for 1 msec, the settling time is 2 sec with no overshoots/undershoots and zero steady state error. For 0.1 sec of sampling time, the oscillations of ±12 rpm and for 1 sec of sampling time, the oscillations of ±25 rpm are observed respectively. From this work, it is observed that as the sampling time increases, the response of the BLDC motor becomes sluggish, unstable and oscillatory at the set point (desired) speed of 1500 rpm. Hence, it is concluded that a sampling time of 1 m sec gives the optimum response for the real time speed control of BLDC motor.

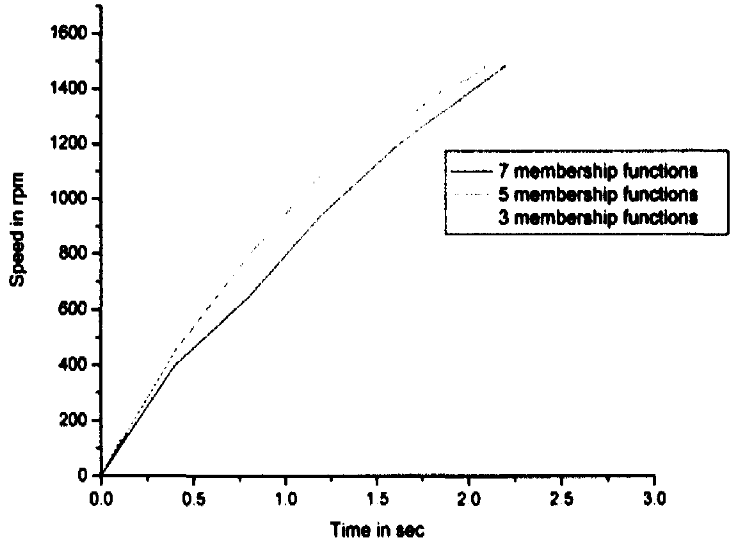

Figure 4.4: Experimental transient response for 3, 5 and 7 number Triangular membership function.

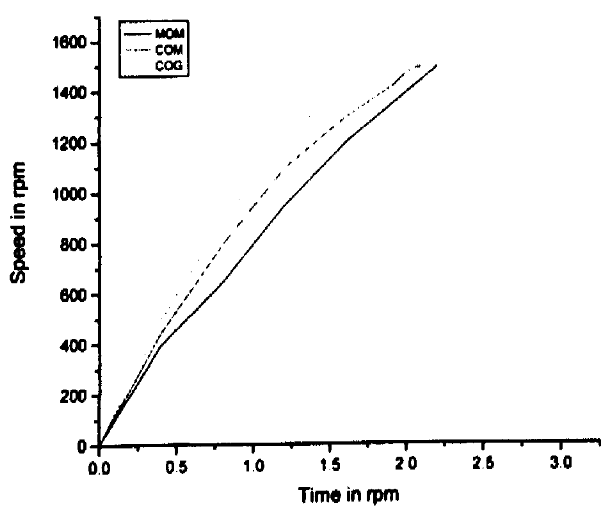

Figure 4.5: Experimental transient response for COG, COM and MOM defuzzification methods

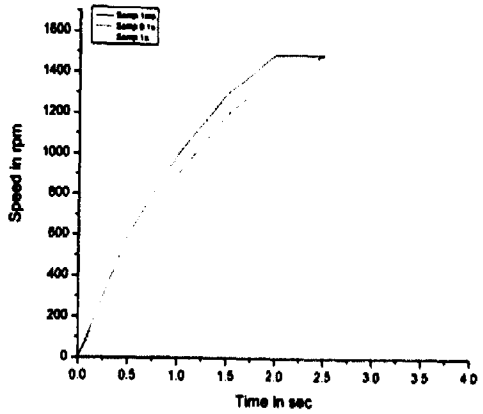

Figure 4.6: Experimental transient response for sampling rates of 1msec, 0.1sec and 1sec

4.1.5 Conclusions:

The C2ISO FLC has been successfully designed and implemented for the real time speed control of BLDC motor for a desired speed of 1500 rpm. The results for the number of triangular membership functions for fuzzification, defuzzification methods and different sampling rates were obtained. From the experimental transient responses, it was concluded that for robust, flexible, faster and real time speed control of BLDC motor using C2ISO FLC technique, seven-number triangular membership functions for fuzzification, COG method for defuzzification and sampling time of 1 m sec are the best choices for the speed control of BLDC motor.

Hence, for the design and development of C2ISO AIFLC, 3ISO FLC and 3ISO AIFLC for the speed control of BLDC motor, seven-number triangular membership functions for fuzzification, COG defuzzification method and sampling rate of 1 m sec are used.

4.2 Design and development of 3ISO FLC:

For some applications the response of the system using C2ISO FLC may not reach/maintain at a constant level with in a short time. Hence, there is a need to improve the performance of the controller. The basic block diagram of 3ISO FLC is shown in fig 4.7. 3ISO FLC is improved version of C2ISO FLC. It not only decreases the rise and settling times, but also improves the over all performance of the system. The VI block diagram for 3ISO FLC is shown in fig 4.8. With addition of 3rd input, there is a remarkable improvement in the performance of the controller. The system response is observed; the tuning is done by keeping the range of error as -2000 to + 2000,change in error as -1500to to +1500 and change in error as -1000 to +1000.

Control action 'cu' has been tuned for the best response of the system i.e. minimum settling time with no overshoots/undershoots and zero steady state error.

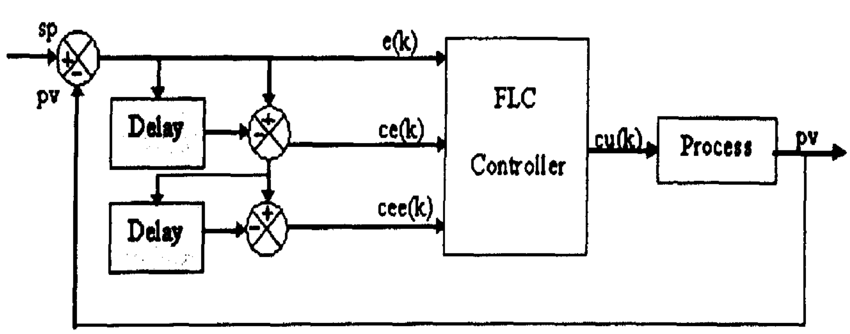

Fig 4.7: Block diagram of 3ISO FLC.

4.2.1 VI diagram of 3ISO FLC:

Fig 4.8 shows the VI block diagram for 3 inputs FLC. 3ISO FLC is similar to C2ISO FLC. In case of C2ISO FLC, error and change in error are the two inputs whereas the case of 3ISO FLC error, change in error and change in change in error (i.e., e, ce and cce) are the three inputs.

4.3 Design and development of 2 input AIFLC:

Design and development of FLC for the speed control of a BLDC motor was discussed in previous section. Integrated FLC is discussed here. Basic configuration of IFLC is shown in figure 4.9 where AIFLC is combination of PID and FLC. The PID output control is the final control, but it is initially controlled by FLC.

AIFLC is cascaded controller of tuned PID and optimal FLC. As tuned PID is used instead of conventional PID, it is auto tuned integrated fuzzy logic controller (AIFLC). The output of FLC is given as set point for PID controller. IFLC system controls and upgrades the FLC system by using fuzzy decision making logic. The main advantage of IFLC is that one does not have to redesign the existing control system.

AIFLC has been implemented for the speed control of the BLDC motor discussed above using LabVIEW, SCXI cards, DAQ board fuzzy logic took kit, PID control tool kit, all procured from National Instruments, USA. The performance of IFLC is observed for a desired speed, set point variations, load variations and the effect of external Gaussian white noise. Such parameter variations are useful in robotic application, biomedical and industrial instrumentation etc. The experimental results have shown remarkable improvement over either ordinary FLC or tuned PID controller for real time speed control of BLDC motor.

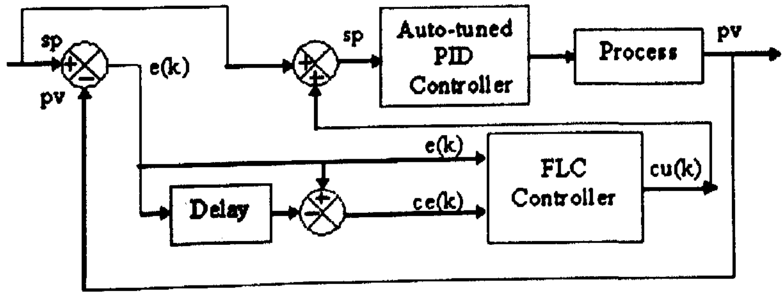

Fig 4.9 Block Diagram for C2ISO AIFLC

4.3.1 VI Block diagram for 2ISO AIFLC:

This block diagram is developed by using both PID and fuzzy logic tool kit (fig 4.10). The Hall sensor signals are combined and is accessed by Analog input (AI) channel. This is converted into speed by using adders and multipliers in the LabVIEW.

First DBL represents the speed 1500 rpm. Error and change in error are found by using subtractors. These two signals are fed to the FLC. FLC control action is added to set point and is fed to PID. This is the set point for PID. The PID controller gives final control voltage to be applied to the BLDC motor through Analog output. (AO) channel, which in turn controls the speed. The measured speed is displayed on the waveform chart in the monitor. All these events are carried out in a feed back loop, which is shown with a thick line shown in figure 4.9. Settling time of the response is obtained as 1.8 sec.

4.4 Design and Development of 3ISO AIFLC:

3ISO AIFLC.VI diagram for 3ISO AIFLC is similar to the 2ISO AIFLC. In a 2ISO AIFLC, there are two inputs to FLC (error and change in error) where as, a 3ISO AIFLC has three inputs e, ce and cce applied to FLC. Control output of FLC is the set point to auto PID. An offset voltage of 2.6V is added to the control output of PID. This in turn is applied to the controller IC UCC 3626. Basic block diagram for 3ISO AIFLC is shown in fig 4.11

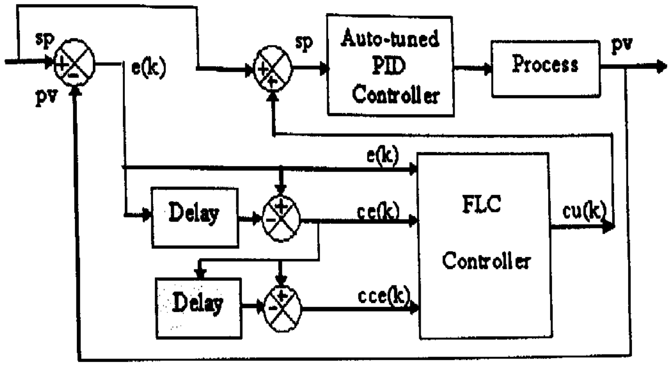

Fig 4.11 Block Diagram for C3ISO AIFLC

VI Block diagram of 3input (3ISO) AIFLC:

The VI block diagram for 3ISO AIFLC is shown in fig 4.12. the design and operation of this VI block diagram is similar to that of C2ISO AIFLC.

4.5 Desired speed:

The set point speed of the BLDC motor is fixed at 1500 rpm. The given BLDC motor is controlled by MISO FLCs and IFLC {i.e., (i) C2ISO FLC and AIFLC and (ii) 3ISO FLC and AIFLCs. Figure 4.13 shows the experimental transient response of C2ISO FLC, 3ISO FLC, C2ISO AIFLC and 3ISO AIFLC. The settling times of C2ISO FLC is 2 sec, 3ISO FLC is 1.8 sec, C2ISO AIFLC is 1.75 sec and 3ISO AIFLC is 1.6 sec. All the responses exhibited no overshoots/undershoots and zero steady state error. The response of 3ISO AIFLC is found to be the fastest as compared to all the rest.

4.6 Load variations:

The BLDC motor is loaded. Three different loads of weights 2.3 gms, 2.6 gms and 3.5 gms are used for loading. Intitially, the BLDC motor is loaded with 2.3 gms and system response is observed. There are overshoots and undershoots with larger settling time.

However these oscillations, overshoots/undershoots and settling time are in descending order from 2ISO FLC ,3ISO FLC, 2ISO AIFLC to 3ISO AIFLC. The loading is repeated with other two loads also. It was observed that, the settling time is increasing with increasing load for any one method (say either FLC or AIFLC) and the results are tabulated. Experimental transient response of the speed control of BLDC motor is shown in figs 4.

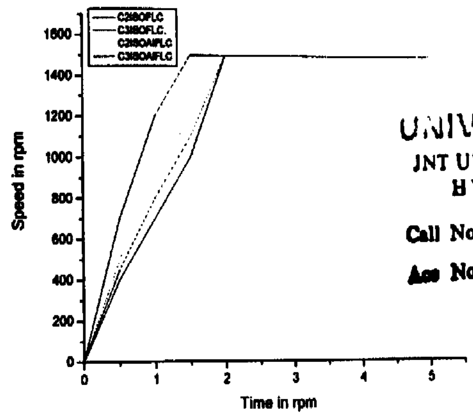

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Figure 4.13: Experimental transient response for C2ISO FLC, C3ISO FLC, C2ISO A IFLC and C3ISO AIFLC

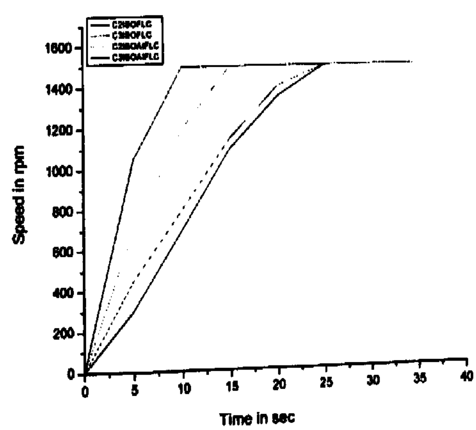

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Figure 4.14 (a): Experimental transient response for C2ISO FLC, C3ISO FLC, C2ISO AIFLC and C3ISO AIFLC with a load of disc of 2.3cm diameter.

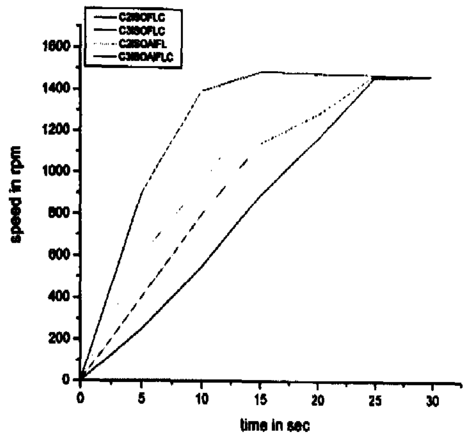


Figure 4.14 (b): Experimental transient response for C2ISO FLC, C3ISO FLC, C2ISO AIFLC and C3ISO AIFLC with a load of disc of 2.6cm diameter.

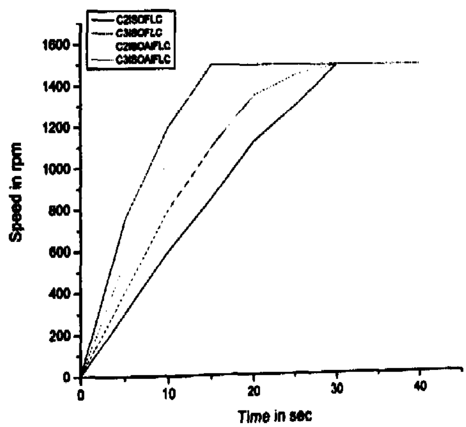


Figure 4.14 (c): Experimental transient response for C2ISO FLC, C3ISO FLC, C2ISO AIFLC and C3ISO AIFLC with a load of disc of 3.5cm diameter.

4.7 Brake Application:

In the present case, there exists a pin in the controller IC (UCC3626) and shorting this pin with ground, braking of the BLDC motor occurs.

This braking is applied for 1 sec and released in all the four methods. The time taken by the response to reach the set point after the brake is released is observed and shown in figure 4.15

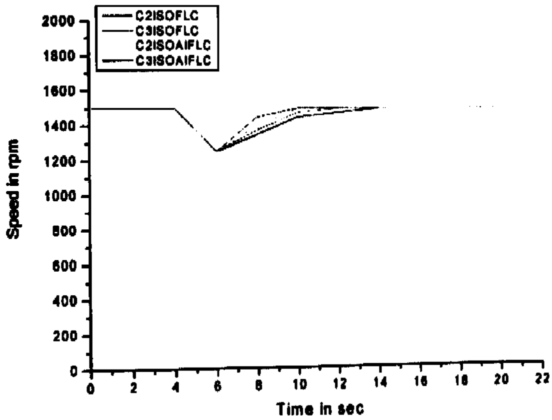


Figure 4.15 Experimental transient response of BLDC motor using C2ISO/C3ISO (FLC and AIFLC) with the release of applied brake.

Results:

After the release of brake, in the case of 2ISO FLC the speed reaches the set point in 8.5 sec with an undershoot of 20 rpm, in the case of 3ISO FLC the speed reaches the set point in 7 sec, in the case of 2ISO AIFLC the speed reaches the set point in 5.5 sec and in the case of 3ISO AIFLC the speed reaches the set point in 4 sec.

4.8 Effect of Noise on FLC/AIFLC (C2ISO and 3ISO):

The term noise is used to designate unwanted signals that tend to disturb the parameters in control system. There are many potential sources of noise. they may be external to the system or internal to the system. The internal noise may be due to the spontaneous fluctuations of current or voltage in electrical circuits. In the present work, we used Gaussian white noise for observing the effect of noise on the proposed controllers.

The term Gaussian white noise refers to probability density function (PDF) of the amplitude of the time domain samples of the noise. For Gaussian white noise the PDF of the amplitudes of the time domain samples is Gaussian. In the present work, Gaussian white noise is generated using LabVIEW software.

Gaussian white noise of various amplitudes is deliberately introduced in the system and its effect is observed. The Gaussian white noise of 10 mV to 50 mV is used in the present work.

4.8.1 Design and Development Of FLC and AIFLC (C2ISO And 3ISO) for Studying The Effect Of Noise On Speed Control Of BLDC Motor:

The block diagram for observing the effect of noise on FLC and AIFLC (C2ISO and 3ISO) for the speed control of BLDC motor is shown in the figure 4.6 The VI block diagram of C2ISO and 3ISO FLC/AIFLC with Gaussian white noise are shown in figures 4.16 to 4.19 respectively.

VI diagram for observing the effect of noise on 2ISO/3ISO (FLC and AIFLC):

This VI is similar to that of FLC up to some extent. There exists an icon of Gaussian white noise in LabVIEW software. Gaussian white noise is introduced in the controller using this icon. Gaussian white noise is added to the control output using an adder icon. The output is added to an offset voltage of 2.6V by using another adder icon. This is applied to the motor through analog output AO channel as discussed. earlier. The VI block diagram of

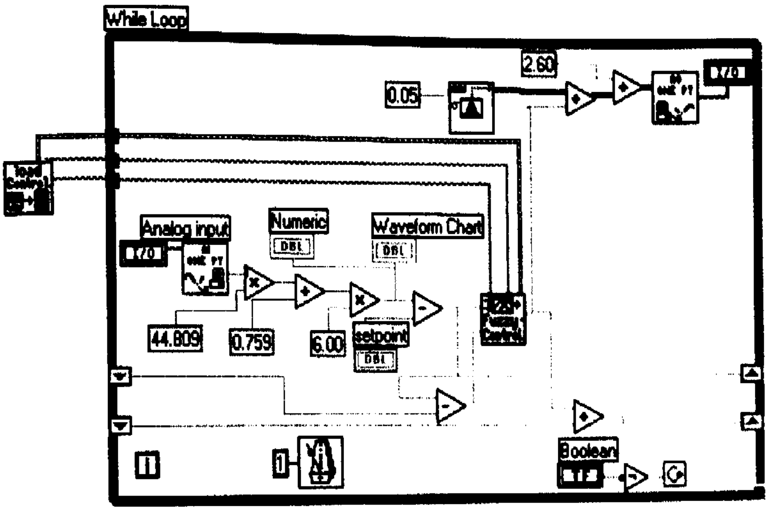


Figure4-16 : VI block diagram for observing the effect of Gaussian white noise using C2ISO FLC

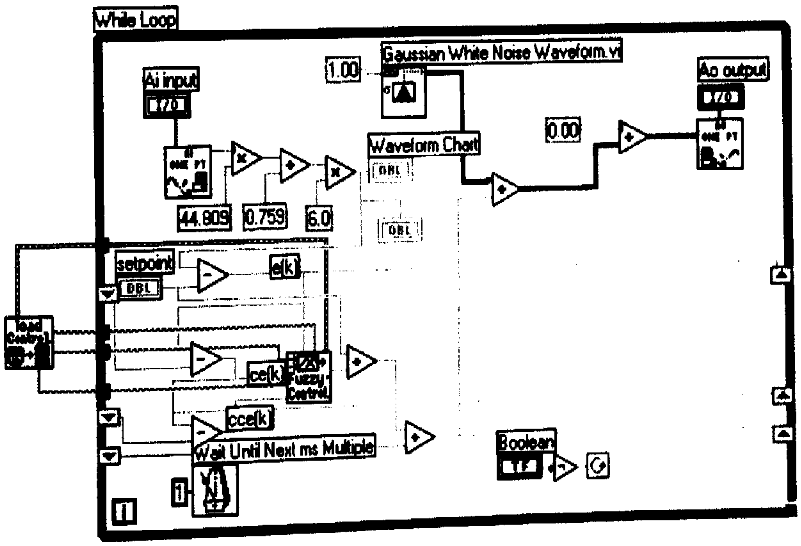


Figure4-17: VI block diagram for observing the effect of Gaussian white noise using C3ISO FLC

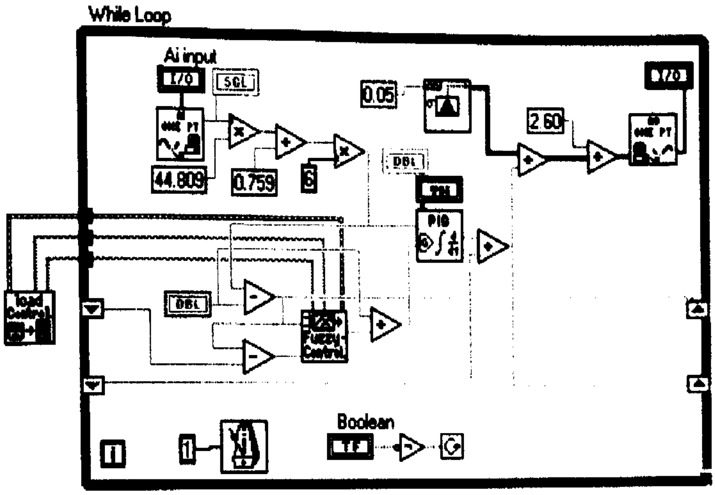


Figure4.۱۸ : VI block diagram for observing the effect of Uniform white noise and IIR filter using C2ISO AIFLC

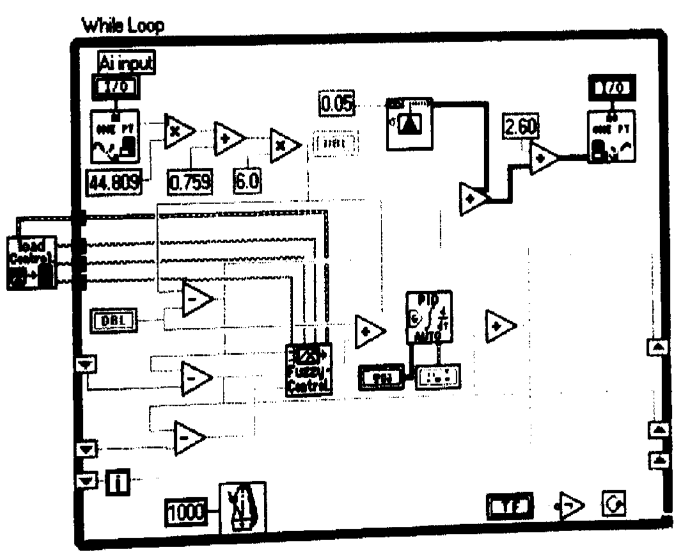


Figure4.۱۹ : VI block diagram for observing the effect of Uniform white noise and IIR filter using C3ISO AIFLC

C2ISO and 3ISO FLC/AIFLC with Gaussian white noise are shown in figures 4.16 to 4.19 respectively.

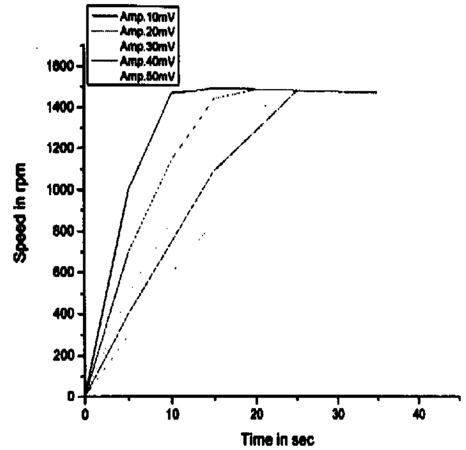


Figure 4.20: Experimental transient response for C3ISO FLC with Gaussian white noise of various amplitudes

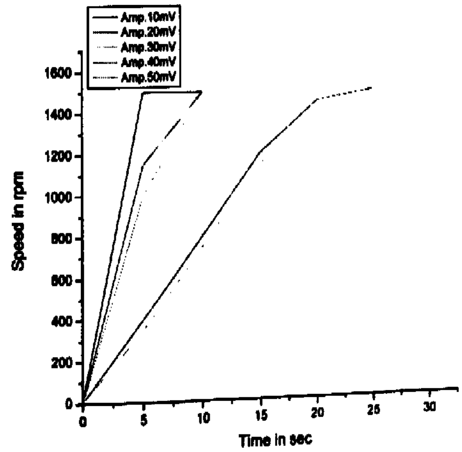


Figure 4.21: Experimental transient response for C2ISO AIFLC with Gaussian white noise of various amplitudes

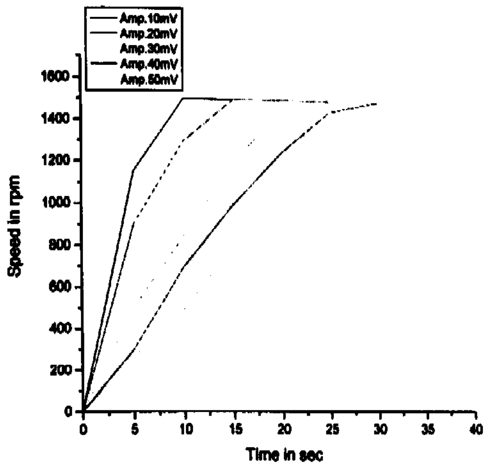


Figure 4.22: Experimental transient response for C3ISO AIFLC with Gaussian white noise of various amplitudes

Results:

The settling time of the response of the speed control system of the BLDC motor with the introduction of Gaussian white noise of various amplitudes is observed and shown in figures 4.20-4.22. With all the proposed controllers. The readings are tabulated in table no. 4.1

4.8.2 Suppression of Gaussian White noise using IIR Filter:

A filter is frequency selective device that is used to limit the spectrum of a signal to some specified band of frequencies. In the present study infinite impulse response (IIR) low pass Chebyshev filter is used. IIR filter is faster and more efficient than the finite impulse response (FIR) filter therefore we have used IIR filter in the present work. Low pass Chebyshev IIR filter of 30t^h order is used in the present work. This IIR filter is used from LabVIEW software.

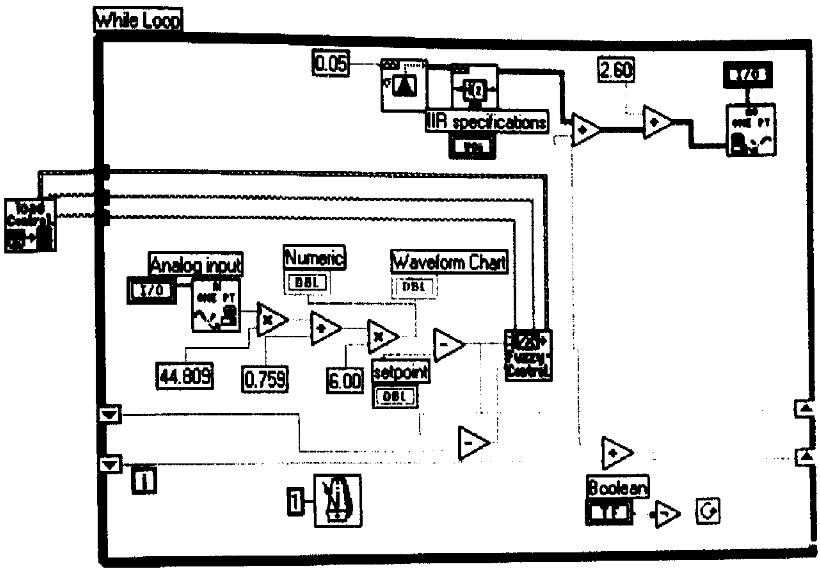


Figure4·23 VI block diagram for observing the effect of Gassuian white noise and IIR filter using C2ISO FLC

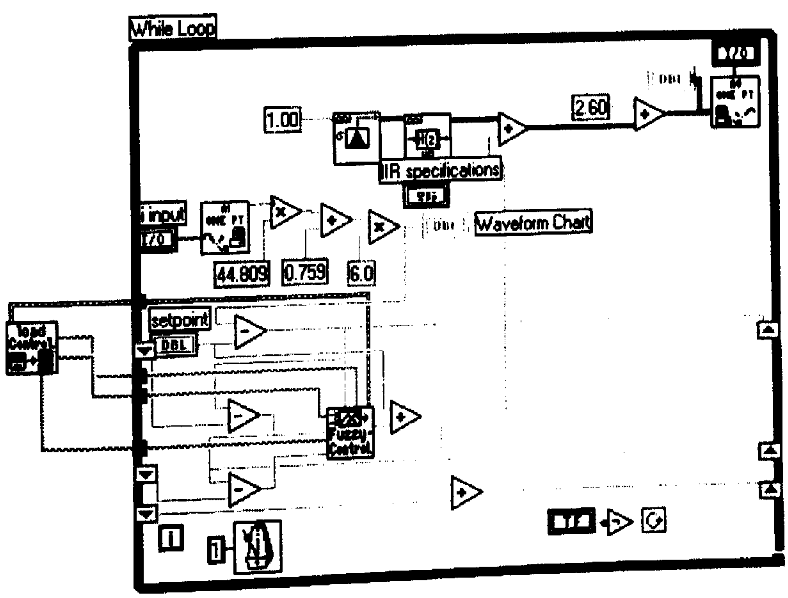


Figure4·24 VI block diagram for observing the effect of Gassuian white noise and IIR filter using C3ISO FLC

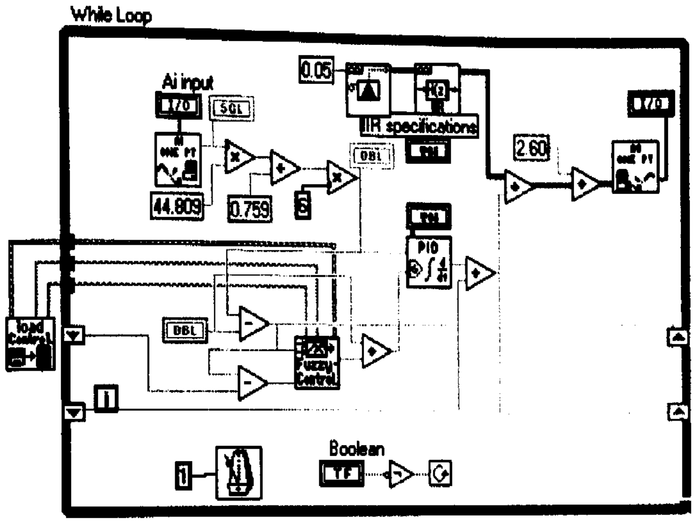


Figure4-25: VI block diagram for observing the effect of Gaussian white noise and IIR filter using C2ISO AIFLC

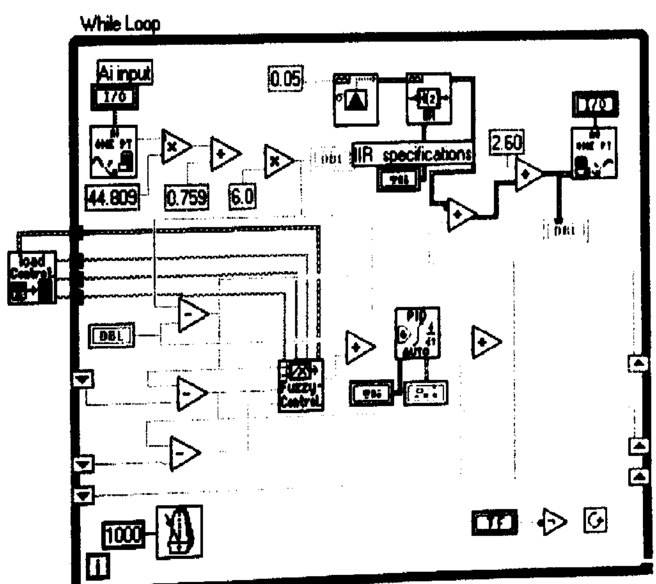


Figure4-26: VI block diagram for observing the effect of Gaussian white noise and IIR filter using C3ISO AIFLC

4.9 Design and development of controllers for suppressing Gaussian white noise introduced in FLC and AIFLC (C2ISO and AIFLC) using IIR filters:

In the above developed VI Gaussian white noise has been introduced for observing its effect. In the present case an IIR Chebyshev filter of 30 th order has been employed for suppressing above noise in all the above said controllers. The filter icon is connected to the output of the noise. Similarly, VI Block diagrams of 2ISO and 3ISO FLC/AIFLC with Gaussian white noise and IIR filter are shown in figures 4.23 to 4.26

Results:

The settling time of the response of the speed control system is observed and shown in figures 4.27 – 4.29 with all the above mentioned controllers ie.2ISO/3ISO FLC/AIFLC. The results are shown in table no. 4.1.

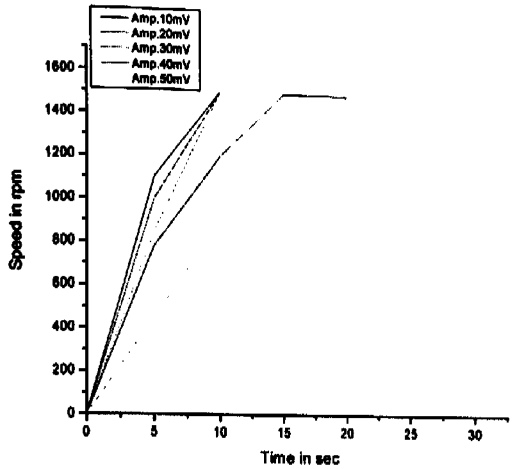
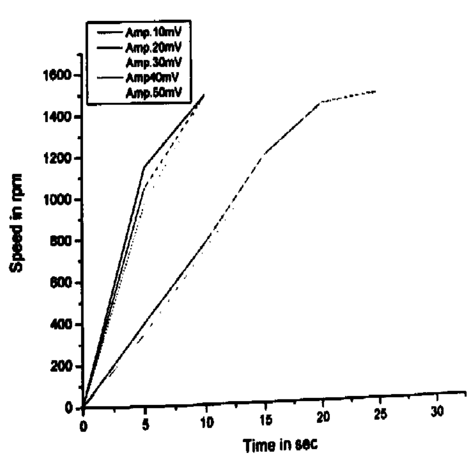
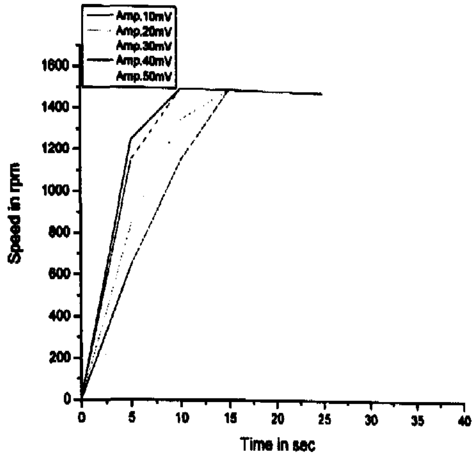


Figure 4.27 Experimental transient response of C3ISO FLC with Gaussian white noise and IIR Chebyshev filter



4.28 Experimental transient response of C2ISO AIFLC with Gaussian white noise and IIR Chebyshev filter



4.29 Experimental transient response of C3ISO AIFLC with Gaussian white noise and IIR Chebyshev filter

Table No. 4.1

Noise Amp	2ISO FLC		3ISO FLC		2ISO IFLC		3ISOIFLC	
	With noise	With noise & filter	With noise	With noise & filter	With noise	With noise & filter	With noise	With noise & filter
10 mV	overshoot oscillations no settlement	Undershoot $T_s = 31$ sec with ± 15 rpm	10.5sec slight overshoots & undershoots	3.5 sec slight oscillations	9.5 sec	5.6 sec	5 sec	4.4 sec
20 mV	Undershootoscillations ± 50 rpm no settlement	Undershoot of 60 with – 15 rpm oscillation	17.5 sec slight oscillation	9.5 sec no oscillations	13.5 sec	7.5sec	7.5sec	6.5 sec
30 mV	Undershootoscillations of ± 60 rpm	Slight oscillations T_s=31 sec	21.5 sec slight	9.5 sec no	24 sec with slight oscillations	17.5 sec no oscillations	9.5 sec with slight	7.5 sec no oscillation
40 mV	Undershoot of 100 rpm oscillation of ± 50 rpm		25 sec slight	18.5 sec no	26 sec with slight scillation	18 sec no oscillation	21sec with slight	9.5 sec
50 mV	Undershoot of 100 rpm oscillation of ± 70 rpm		35 sec slight over & undershoots	21.5 sec no	33sec with slight oscillations	24.5 sec no oscillation	22 sec with slight oscillation & 5.5 error±10 rpm	14.5 sec no oscillation