Intelligent Control of Parallel Loaded Resonant Converter fed PMDC Motor

T.S. Sivakumaran. S.P. Natarajan.

Abstract – The Permanent Magnet DC (PMDC) motor has been widely used in industrial applications because of its low inertia, fast response, high power density, high reliability and maintenance free operation. A Parallel loaded Resonant Converter (PRC) which is a subset of DC-DC converters can be operated with either zero-voltage turn – on (above resonant frequency) or zero-current turn-off (below resonant frequency) to eliminate the turn-on or turn-off losses of the semiconductor devices. This paper presents simulation and real time implementation of PI and Fuzzy Logic Controllers (FLC) for speed control of a PRC fed PMDC motor on light load. The control algorithm developed ensures tracking of the reference speed and rejection of system disturbances by successive measurements of the motor speed. The results from (i) simulation of PI and fuzzy logic controls using MATLAB software and (ii) TMS320F2407 DSP based hardware implementation show that FLC performs effectively for the chosen PMDC motor system.

Keywords - PI control, fuzzy logic control, parallel loaded resonant converter (PRC).

I. INTRODUCTION

Load resonant converters [1-6] are soft-switched DC-DC converters. A Parallel loaded Resonant Converter (PRC)[1-4] which is a subset of load resonant converters can be operated with either zero-voltage turn – on (above resonant frequency) or zero-current turn-off (below resonant frequency) to eliminate the turn-on or turn- off losses of the semiconductor devices. Due to the reduced switching losses, this converter is particularly suited for high power and high frequency operation. The operating frequency of a PRC usually varies over a wide range to regulate the output. This results in a penalty in filter design and poor utilization of magnetic components. Instead of frequency modulation control, the resonant converters can also be regulated by phase shift control where the duty ratio D is modulated and the switching frequency is kept constant. Power electronic systems like PRC have non-linear characteristics. Considerable research work reported very recently in [3-6] discuss about control of load resonant converters operated only as power supplies.

Since soft-switching techniques can also be applied for DC motor drives, the performances of PI control and Fuzzy Logic Control (FLC) for a PRC fed PMDC motor are compared in this work using MATLAB based simulation as well as TMS320F2407 DSP based implementation [7].The results are presented and analyzed.

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II. PARALLEL LOADED RESONANT CONVERTER FED PMDC MOTOR

The system comprises a full-bridge inverter, resonant tank circuit, bridge rectifier, filter circuit, PMDC motor and eddy current type mechanical load as shown in Fig. 1 The resonant circuit consist of series inductance L_s and parallel capacitor C_p. Q_1-Q_4 are switching devices having base /gate turn-on and turn-off capability. D_1 to D_4 are anti-parallel diodes across these switching devices. The MOSFET (say Q_1) and its anti-parallel diode (D_1) act as a bidirectional switch. The gate pulses for Q_1 and Q_2 are in phase but 180 degree out of phase with the gate pulses for Q_3 and Q_4. The positive portion of switch current flows through the MOSFET and negative portion flows through the anti-parallel diode. The voltage across the points AB is rectified and fed to motor load through low pass filter L_f - C_f. In the analysis that follows, it is assumed that the converter operates in the continuous conduction mode and the semiconductors have ideal characteristics. The parameters of the chosen DC motor are: 12V, 1500 rpm, 18Watts, R_a=160Ω, L_a=1.6mH, J=1Nm^2, B=0.5 Nm/rads^{-1}.

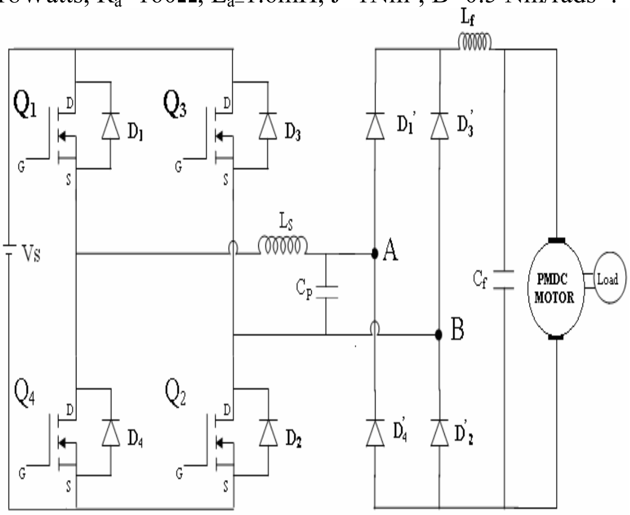

Fig. 1: Schematic diagram of full-bridge PRC fed PMDC motor

III. OPEN- LOOP CONVERTER DYNAMICS

The open-loop converter system (Fig. 2) comprises the power stage modeled in the above section. The inputs to the power stage are supply voltage Vs and duty ratio D and the output is Vo. Generally, Vs is maintained at a constant value.

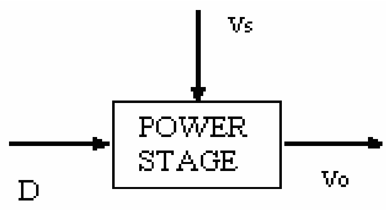

Fig. 2: Block diagram of open loop converter

IV. Design of Conventional Controller

Many industrial processes are non-linear and are thus complicated to be described mathematically. However, it is known that a good many non-linear processes can satisfactorily be controlled using PID controllers provided the controller parameters are tuned well. Practical experience shows that this type of control has a lot of sense since it is simple and based on three basic behavior types or modes: proportional (P), integrative (I) and derivative (D). Instead of using a small number of complex controllers, a larger number of simple PID controllers can be used to control complex processes in an industrial assembly in order to automate such processes. Controllers of different types such as P, PI and PD are today basic building blocks in control of various processes. In spite of simplicity, they can be used to solve even a very complex control problem, especially when combined with different functional blocks, filters (compensators or correction blocks), selectors etc. A continuous development of new control algorithms insure that the PID controller has not become obsolete and that this basic control algorithm will have its part to play in process control in foreseeable future. It can be expected that it will be a backbone of many complex control systems. While proportional and integrative modes are also used as single control modes, a derivative mode is rarely used in control systems.

PI controller forms the control signal in the following way:

$$U(t) = K_p[e(t) + 1/T_i \int e(\tau)d\tau] \qquad (1)$$

The tuning of this controller is done by the reaction curve method. Controller tuning involves the selection of the best values of K_p and T_i. This is often a subjective procedure and is certainly process dependent. In this work K_P=2.5 and T_i=5 are the values of the controller settings tuned to provide satisfactory response of the converter.

V. Design of Fuzzy Logic Controller

The derivation of fuzzy control rules is heuristic in nature (Table 1) and based on the following criteria:

- When the output of the converter is far from the set point, the change of duty cycle must be large so as to bring the output to the set point quickly.
- When the output of the converter is approaching the set point, a small change of duty cycle is necessary.
- When the output of the converter is near the set point and is approaching it rapidly, the duty cycle must be kept constant so as to prevent overshoot.
- When the set point is reached and the output is still changing, the duty cycle must be changed a little bit to prevent the output from moving away.
- When the set point is reached and the output is steady, the duty cycle remains unchanged.
- When the output is above the set point, the sign of change of duty cycle must be negative and vice versa.

Fuzzy memberships NL, NM, NS, ZE, PS, PM, PL are defined as negative large, negative medium, negative small, zero, positive small, positive medium and positive large.

VI. Simulation Results

The regulatory responses obtained by simulation using Matlab software with PI and fuzzy controls under supply and load disturbances are presented in this section. The simulated speed and armature current of PRC (Table 2) fed PMDC motor with PI control and set speed =750 rpm under sudden (10%) line disturbances (27V-30V-27V) on no load are shown in Fig. 3. The corresponding results with PI control and sudden load torque changes from 0.0981Nm to 0.10791Nm are shown in Fig. 4. Fig. 5 shows results on no load with fuzzy control for set speed =750 rpm and sudden (10%) line disturbances (27V-30V-27V). Corresponding responses for sudden load torque changes from 0.0981Nm to 0.10791Nm at t=0.02sec with 750 rpm set speed are shown in Fig. 6. Triangular memberships functions (Table 1) and centroid method of defuzzification are used in the FLC of this work.

Table 1: Fuzzy rule base

e \ ce	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	Z
NM	NL	NL	NL	NM	NS	Z	PS
NS	NL	NL	NM	NS	Z	PS	PM
ZE	NL	NM	NS	Z	PS	PM	PL
PS	NM	NS	Z	PS	PM	PL	PL
PM	NS	Z	PS	PM	PL	PL	PL
PL	Z	PS	PM	PL	PL	PL	PL

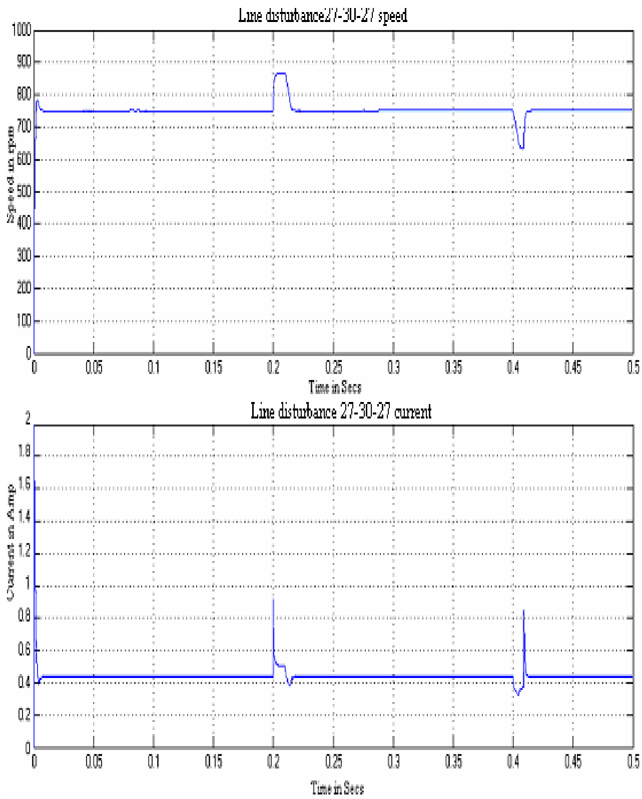

Fig. 3: Simulated transients in speed and current of PMDC motor on no load with sudden line disturbances (27V-30V-27V) at t=0.2sec and t=0.4sec with set speed 750 rpm

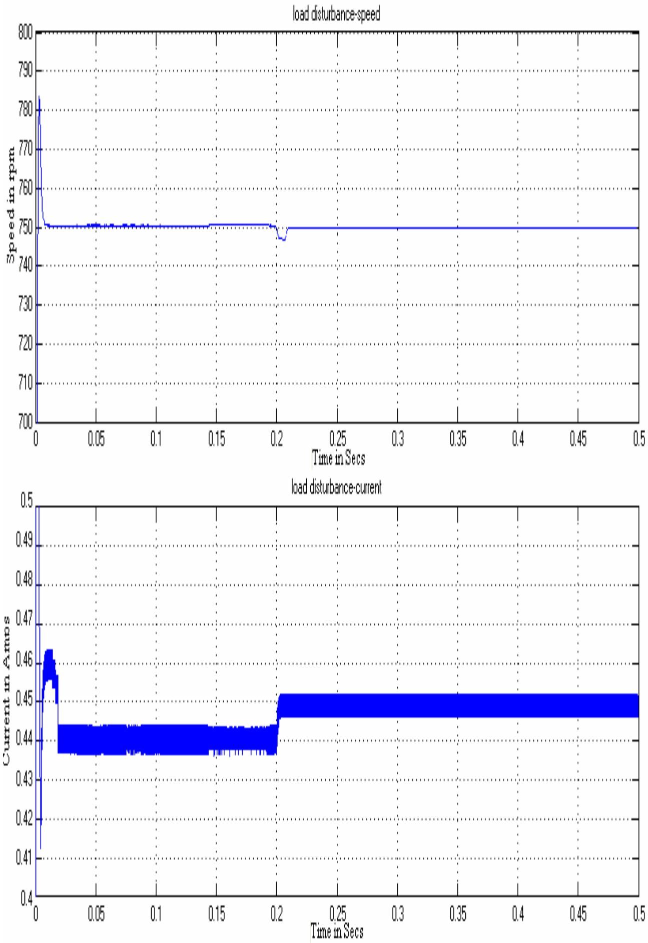

Fig. 4: Simulated speed and current of motor for sudden load torque changes from 0.0981Nm to 0.10791Nm at t=0.2sec with set speed 750 rpm

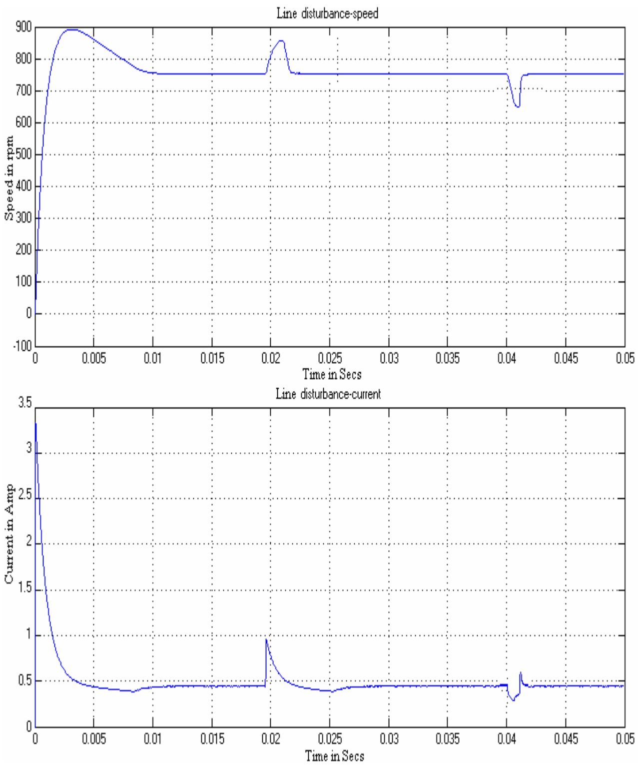

Fig. 5: Simulated transients in speed and current of PMDC motor on no load with sudden line disturbances (27V-30V-27V) at t=0.02sec and t=0.04sec with set speed 750 rpm

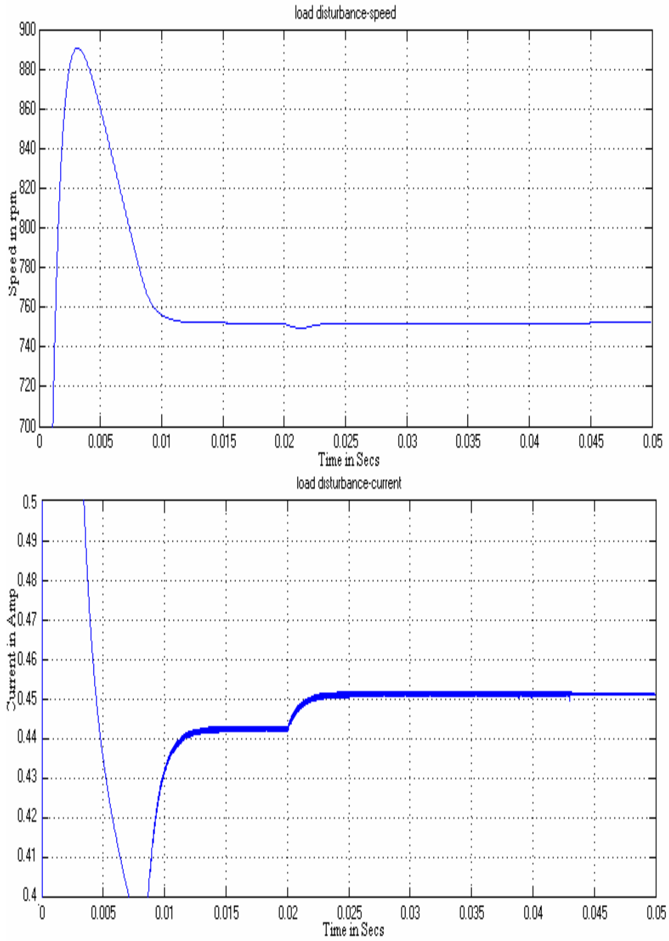

Fig. 6: Simulated speed and current transients for sudden load torque changes from 0.0981Nm to 0.10791Nm at t=0.02sec with set speed 750 rpm

VII. DSP Based Controllers

Hardware implementation of the PI and fuzzy controls for PRC fed PMDC motor carried out in this work using TMS320F2407 DSP is shown in Fig. 7. The PI and fuzzy controllers are designed to detect the speed variation (ω_e) using the ADC of the TMS320F2407 DSP. A drop in the actual speed (ω) triggers the controllers to increase the duty ratio of the converter thereby increasing the speed of the motor to reach the set point (ω^*). The actual speed after suitable signal conditioning is fed to the on-chip ADC of DSP. The signal conditioning circuit converts the actual speed to (0-3V) range to be fed as input to ADC. The error (ω_e) between the required speed (ω^*) and actual speed (ω) are manipulated by the TMS320F2407 DSP based controller to provide an appropriate change in duty ratio of the firing pulses to the MOSFETs so as to maintain the speed constant in spite of line and load variations.

The event manager module of the TMS320F2407 DSP generates the firing pulses. Optocouplers HCPL 4506 provides isolation between the event manager module of DSP and gates of MOSFETs. The PWM signal from the DSP is not capable of driving MOSFET. In order to strengthen the pulses, IR 2110 driver is used for each firing pulse. Fig. 8 shows the PWM pulses for Q_1 and Q_2 of PRC. Fig. 9 shows the experimental start up transient of the speed and current of parallel loaded resonant converter fed PMDC motor. Fig. 10 shows the experimental responses for speed and current of the PRC fed PMDC motor on no load with PI control for step changes in supply voltage from 27V to 30V and vice versa. The next figure shows the corresponding transients for step load changes from 0.0981Nm to 0.10791Nm. The experimental regulatory responses for speed and current of PRC fed motor on no load with FLC for step changes in supply voltage from 27V to 30V and vice versa are displayed in Fig. 12. The corresponding regulatory responses for step load torque changes from 0.0981Nm to 0.10791Nm are portrayed in Fig. 13. The experimental waveforms after appropriate signal conditioning are obtained using 100MHz digital storage oscilloscope through software SW205-2 (Ver 1.4) with settings as in Figs. 8-13. The reference is marked with arrow at the right side. A 0.22 Ω, 5W current sensing resistor has been used.

Table 2: Circuit parameters of the test converter

PARAMETER	VALUE
Inductor L_s	101.7μH
Capacitor C_p	98.4nF
Capacitor C_f	45.4μF
Inductor L_f	1.44mH
Input voltage V_s	(0-30)V
Switching frequency f_s	60kHz
Duty ratio D	0.25-0.99
MOSFETs	IRFP9240
DIODEs	UF5042

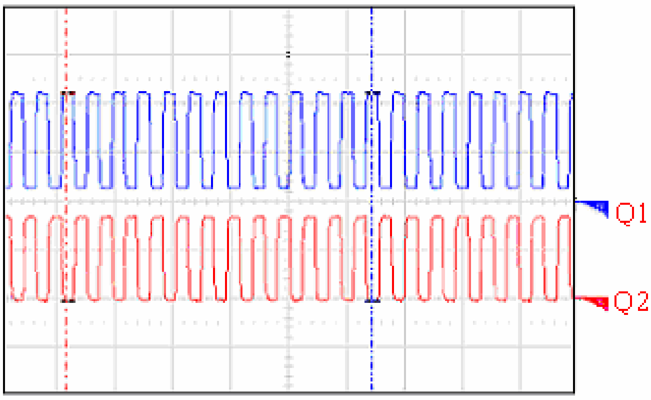

Fig. 8: PWM pulses for Q_1 (upper trace) and Q_2 (lower trace) of parallel loaded resonant converter feeding PMDC motor

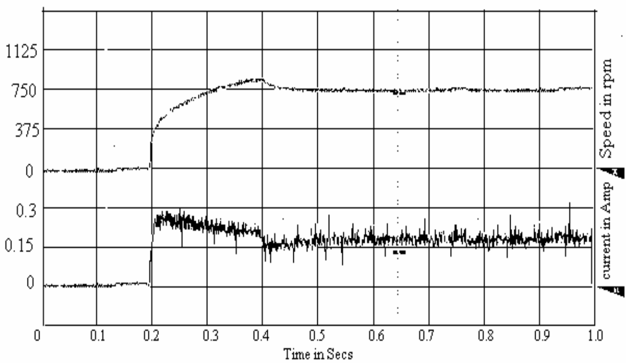

Fig. 9: Experimental start up transients of the speed and current of parallel loaded resonant converter fed PMDC motor

PI Controller

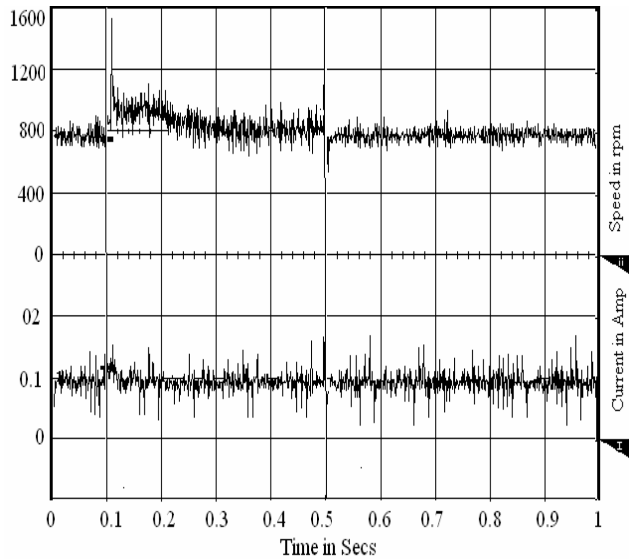

Fig. 10: Experimental transients in speed and current of motor on no load for step changes in supply voltage from 27V to 30V and vice versa

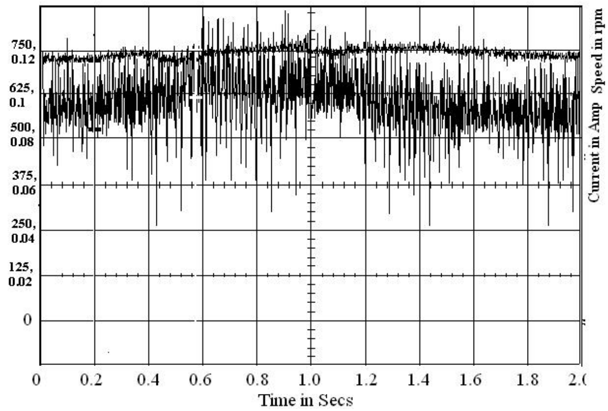

Fig. 11: Experimental transient responses of the speed and current of motor for step load changes from 0.0981Nm to 0.10791Nm

VIII. CONCLUSION

Armature current and peak overshot in speed are found to be larger in the simulated start-up of the PMDC motor on no load under sudden supply disturbances and sudden load disturbances with FLC than with the PI controller (Figs. 3-6). Such behaviors are not found to be present in the experimental responses (Figs. 10-13). Considerable noises due to switching are found to be superimposed only on experimental responses. The simulation and experimental results closely match and show that the proposed PI and fuzzy controllers regulate satisfactorily the speed of PRC fed PMDC motor irrespective of line and load disturbances. These establish the validity of the developed controllers that effectively reject disturbances in speed and load while achieving fast tracking of the speed. Performance evaluation of simulated controllers is carried out using speed related performance indices as reported in Table 3. It is found that FLC performs better for the chosen PMDC motor system.

Table 3: Performance evaluation of controllers for PRC fed PMDC motor using MATLAB

Supply disturbances | Load disturbance

CONTROLLERS	Supply increase (10%)		Supply decrease (10%)		Load changes from 0.0981Nm to 0.10791Nm	
	Peak overshoot (%)	Settling time (msecs)	Peak overshoot (%)	Settling time (msecs)	Peak overshoot (%)	Settling time (msecs)
PI	20	20	20	16.67	0.4	10
FUZZY	16	2.7	16	1.92	1.3	3.85

Fuzzy Controller

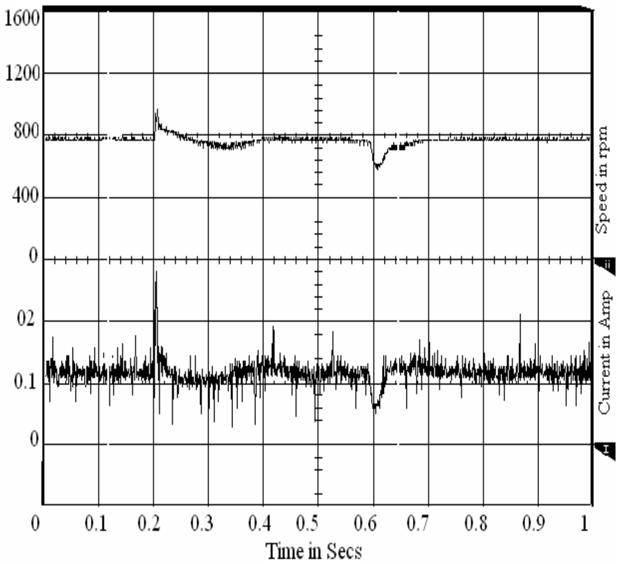

Fig. 12: Experimental transient responses of the speed and current of motor on no load for step changes in supply voltage from 27V to 30V and vice versa

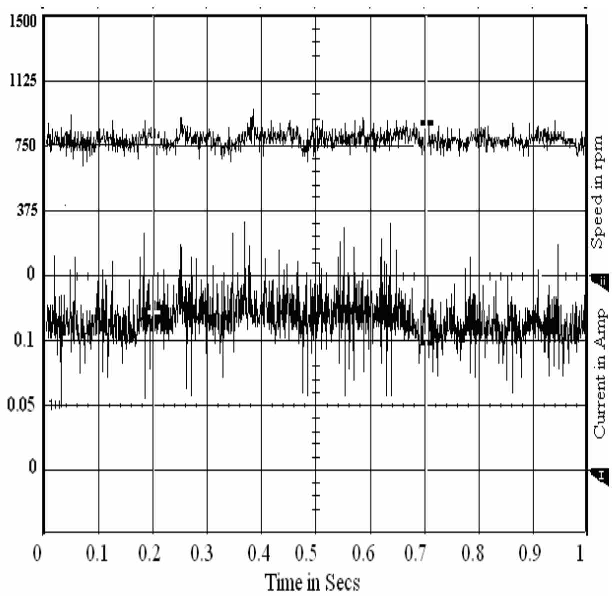

Fig. 13: Experimental transients in speed and current of motor for step load torque changes from 0.0981Nm to 0.10791Nm

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BIOGRAPHIES

S.P.Natarajan was born in 1955 in Chidambaram. He has obtained B.E (Electrical and Electronics) and M.E. (Power System) in 1978 and 1984 respectively from Annamalai University securing distinction and then Ph.D in Power Electronics from Anna University, Chennai in 2003. He is currently a Professor in the Instrumentation Engineering Department at Annamalai University where he has put in 26 years of service. He has produced one Ph.D and is presently guiding eight Ph.D scholars and so far guided sixty M.E students. His research papers have been presented at IEEE / International Conferences in Mexico, Virginia, Hong Kong, India, Singapore, Japan, SriLanka, Malaysia and Korea. He has six and two publications in national and International journals. His research interests are in modeling and control of DC-DC converters and multiple connected power electronic converters, control of Permanent Magnet Brushless DC motor, embedded control for multi level inverters and matrix converters etc. He is a life member of Instrument Society of India and Indian Society for Technical Education. He has completed an AICTE sponsored R & D project on “Investigations on Controllers for Permanent Magnet Brushless DC motor.

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