Speed Regulation of Dc Drive Using Variable Structure Controller

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ABSTRACT

The idea orients to develop a nonlinear theory based control scheme to effectively regulate the speed of the chosen separately excited DC motor. The presence of power converter interfaces along with the combined characteristic of the drive motor and the load accrue to the nonlinear nature of the system. It augurs the need to implement a nonlinear control technique with a view to prevail over the annoyance of the unbounded operating regions. The conventional controllers employing a linearised model of the system appear to be unsuccessful over a wide bandwidth in practical systems owing to the drift in the plant operating conditions beyond which the system exhibits a complex behaviour. A Variable Structure Controller is identified to serve the purpose by intentionally allowing the control law to follow a predefined algorithm and thereby elicit a structural change. It echoes to steal the artefacts of the trajectory based philosophy to arrive at a stable regulatory mechanism. The performance investigated through the entire operating range illustrates its supremacy over a traditional PI controller to demonstrate its suitability for practical applications.

KEYWORDS: Buck converter, Variable Structure Controller (VSC), Non Linear control scheme

INTRODUCTION

DC Motor finds a wide range of applications owing to its ease of operation and exhibits favourable mechanical characteristic. It is widely used in industries even though its maintenance costs are higher than the induction motor. It continues to play a major role in variable speed drives, in view of its ability to run both above and below the base speed. Besides the mechanism involving the philosophy of speed control can be easily implemented in spite of the commutational problems. Speed regulation assumes considerable significance to meet the emerging requirements of the present day applications.

Power Electronic Converter interfaces acclaim their predominant role in the perspective of extracting the desired performance of drive utilities. It appears to be an erudite need to sandwich the supply through an appropriate choice of power modulator to suit the contrasting dictates of the industrial comforts. The switching action of the converter adds to the nonlinear fold and further emphasises to unfold mechanisms to arrive at the preferred trajectory for the characteristics.

LITERATURE REVIEW

A novel strategy for regulating the speed of separately excited dc motor drive using Fuzzy Logic principles has been suggested [1]. A simple sliding mode like control (SMLC) technique suitable for the steady state error in its attempt to regulate the load voltage of a buck converter has been proposed [2]. The stability of an adaptive observer used to estimate the speed of the separately excited dc motor drive has been analysed [3]. The control of speed of a separately excited DC motors has been investigated through automatically regulated armature and field voltages [4]. The generalized predictive controller (GPC) applications to speed control of a separately excited DC motor using single phase single way rectifier has been presented [5]. A speed controller has been designed successfully for the closed loop operation of the BLDC motor to enable the motor to run close to the reference speed [6].

The fact that the drive motor by itself is a nonlinear load and in addition it can be subjected to sudden changes both in the supply voltage and load torque expands the scope of a non-linear control strategy. Despite the fact that a linear design of a control is frequently used, it still necessitates viable alternatives to meet the emerging challenges. It is in this direction that a nonlinear design is explored to attract a greater domain of applications for DC drives.

PROBLEM FORMULATION

The central theme echoes to develop a nonlinear theory based control scheme with a view to regulate the speed of the separately excited DC motor. It involves modelling of the drive apparatus and arbitrates the theory of the control law to arrive at a stable regulatory mechanism. The performance is to be investigated through the entire operating range to demonstrate its suitability for practical applications.

MODELLING OF BUCK CONVERTER

The power module in Fig.1 is constituted of a buck converter that uses a pair of switches, usually one controlled (IGBT) and one uncontrolled (Diode), to achieve unidirectional power flow from input to output. The converters also use one capacitor and one inductor to store and transfer energy from input to output, along with a filter to smoothen the voltage and current waveforms. The circuit is assumed to be operating in the steady state continuous conduction mode (CCM). This process of energy transfer results in an output voltage that is related to the input voltage by the duty ratios of the switches.

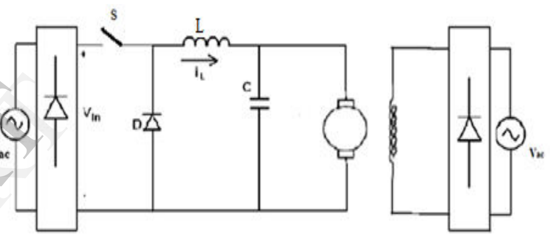

Fig 1: Power Module

The relation between output and input voltage can be given as $V_o/V_{in} = D$. Where D is the duty cycle of the pulse to the switch $D = T_{on}/T$. The voltage ratio of the buck converter shows a linear relationship between the duty ratio and output voltage. Thus, the switch is ON for time duration of DT and is OFF for time duration of (1-D) T. The D can take values from 0 to 1, thus the output voltage is a portion of the input voltage.

The matrix representation of the state space equations are in the form

When S is ON:

$$\frac{d}{dt}\begin{bmatrix} i_{La} \\ V_o \end{bmatrix} = \begin{bmatrix} 0 & \frac{-1}{L_a} \\ \frac{1}{C} & \frac{-1}{R_a C} \end{bmatrix} \begin{bmatrix} i_{La} \\ V_o \end{bmatrix} + \begin{bmatrix} \frac{1}{L_a} \\ 0 \end{bmatrix} V_{in} \quad (1)$$

When S is OFF:

$$\frac{d}{dt}\begin{bmatrix} i_{La} \\ V_o \end{bmatrix} = \begin{bmatrix} 0 & \frac{-1}{L_a} \\ \frac{1}{C} & \frac{-1}{R_a C} \end{bmatrix} \begin{bmatrix} i_{La} \\ V_o \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} V_{in} \quad (2)$$

PROPOSED METHODOLOGY

The basic philosophy explaining the mechanism of control is explained through the schematic shown in Fig 2. It forges to canotate the nonlinear behaviour of the drive powered through a power converter from the available supply. The presence of circuit parasitic and their dependence on the rate of change of current necessitate creating a structural change in the system and thereby facilitate the regulatory phenomenon.

The Variable Structure Controller (VSC) inherits a method to design the system in such a way that it is insensitive to parameter variations and external load disturbances. The approach is realised by the use of high speed switching control law which creates modifications in the system to allow it to move in the predetermined path in a state variable space and remain in that surface thereafter.

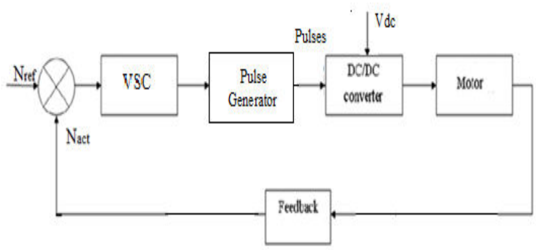

Fig 2: Block schematic of a proposed methodology

DESIGN OF VARIABLE STRUCTURE CONTROLLER

The principle of Variable Structure Control system is to forcibly constrain the system, by a suitable mechanism, to project the desired objectives. It is pivoted by designing a switching surface through a switching function. The converter is forced to switch across this switching surface by constructing a control law, which satisfies a set of necessary conditions for the existence and stability of VSC.

The switching function proposed for this control scheme is given by the Equation

$$\sigma(X) = G \cdot X \pm K \quad (3)$$

Where σ is switching function, G is gain vector, X is state vector and K is constant.

A Typical variable structure control law is expressed through Equation (4)

$$\begin{aligned} m &= m+ \ for \sigma(X) > 0 \\ m &= m- \ for \sigma(X) < 0 \end{aligned} \quad (4)$$

The stable surface exists if all the state trajectories are directed towards the surface. The mathematical form for such a condition is given by

$$\begin{aligned} \lim_{\sigma \to 0+} \frac{\partial \sigma(X)}{\partial X} < 0 \\ \lim_{\sigma \to 0-} \frac{\partial \sigma(X)}{\partial X} > 0 \end{aligned} \quad (5)$$

The above two equations can be alternatively stated as

$$\sigma \dot{\sigma} < 0 \quad (6)$$

In order to obtain a continuous system, the above discontinuity may be replaced by a smooth continuous control law, which is given by

$$\sigma(X) = \dot{\sigma}(X) = 0 \qquad (7)$$

SIMULATION RESULTS

The parameters of the Buck converter that feeds the separately excited DC motor are chosen as L = 250µH, C = 60µF, switching frequency = 20 KHZ. The capacity of the drive motor is 5HP, 240 V, 1750 rpm. A DC output of 230 V obtained using an uncontrolled bridge rectifier from an available AC supply serves as the input on no load. The methodology is tested on a MATLAB Simulink platform over a preferred operating range. It is observed from Table 1 that the action of VSC facilitates a relatively superior performance over a PI controller.

Torque (Nm)	Armature current(Ia)		Speed (rpm)	
	PI	VSC	PI	VSC
12	9.3	9.5	782	800
10	7.8	7.9	788	800
8	6.3	6.3	792	800
7	5.4	5.6	795	800
6	4.5	4.7	796	800

Table 1: performance comparison

The Fig 3 depicts the steady state time variation of speed, motor armature current, field current and the torque corresponding to a load torque of 10 Nm. A sudden change in load torque from 10 to 12 Nm is introduced at 2 secs and thereafter a similar change in reference speed from 800 to 600 rpm at 4 secs. The VSC initiates the appropriate adjustment in duty cycle and restores the speed to 800 and 600 rpm respectively as observed from Fig 4 thus projecting the ability of the Non linear controller to reject regulatory and servo disturbances.

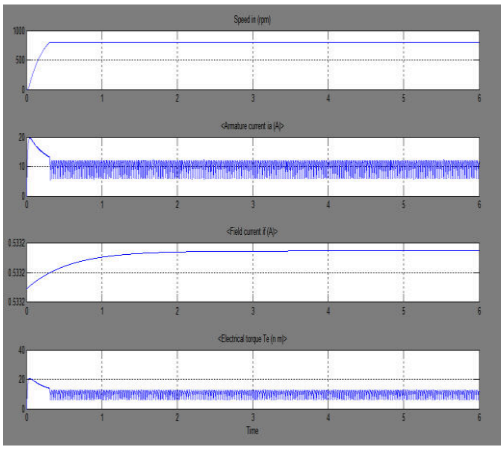

Fig 3: Closed loop steady state response

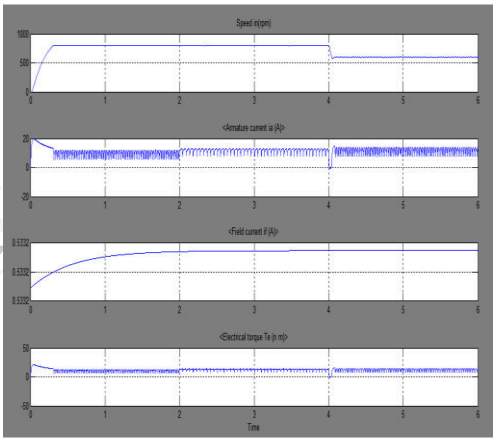

Fig 4: Closed loop transient response

The entries in Table 2 relate to the time response specifications of the system when the step change in load torque is inserted obtained using PI and VSC control actions. It reveals the superior performance of the non-linear theory based VSC controller and brings out its adaptability to practical operating status through a much lower over shoot, smaller peak, rise and settling times and an acceptable steady state error.

TIME RESPONSE PARAMETERS	PI	VSC
PEAK OVERSHOOT IN %	2.88%	0.125%
RISE TIME IN MS	110	35
PEAK TIME IN MS	170	38
SETTLING TIME IN MS	180	40
STEADY STATE ERROR IN SPEED IN RPM	48	9

Table 2: Comparison of Time response Specifications

CONCLUSION

A Non linear control methodology has been developed to regulate the speed of the drive motor. The controller has been programmed to generate a value for the duty cycle that serves to regulate the speed. It has been designed to epitomise a perfect speed tracking mechanism to corner the formulations of the objective.The scheme has been portrayed through a closed loop action that facilitates to accord the desired performance. The procedure has been formulated so as to generate the firing pulse to the power switch in a DC-DC converter such that it minimizes the error and guarantees the stable regulatory region for the separately excited DC motor.

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BIOGRAPHY

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