DC MOTOR SPEED CONTROL USING PWM METHOD

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***Abstract**: DC motor controllers using Power MOS devices can be used in many speed control and servo applications giving excellent drive performance. Basic principles relating to DC motor specifications and drive frequency are presented. The pulse width modulated (PWM) method of switched-mode voltage control is discussed with reference to armature current control, and hence output torque control of DC motors. The paper presents the functional units designing, which compose the controller.*

Keywords: *DC Motor, half bridge converter, controller.*

1. INTRODUCTION

DC motor controllers using Power MOS devices have a series of advantages, and the most important are the next:

- Power MOS choppers can operate at a higher switching frequency, giving reduced noise, interference, and current ripple. These devices allow the obtaining a good dynamic system response.
- The principle control variable in the PWM motor control system is "duty cycle", δ. Motor torque and velocity can be tightly controlled, by controlling the PWM duty cycle and motor current.

Figure 1 presents the torque speed characteristics for motoring and regenerating operation of a DC motor (two quadrant operation).

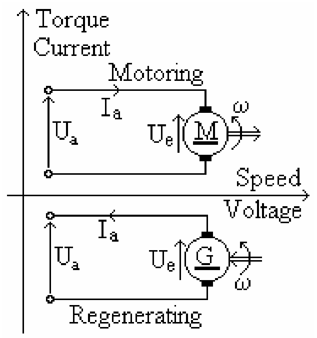

Fig. 1 Torque and speed characteristics for two quadrant operation

The braking with recovery (for regenerative operation) is used when the motor is engaged to a higher rotational speed than the rotational speed at the operation without load, n_0.

When the DC machine operates as a motor, this one is supplied from the supply network with a U_a voltage, the current coming in the armature winding through the positive brush. If the rotational speed becomes higher than n_0, the back voltage induced across the armature conductors exceeds the supply voltage value, as consequence in the armature winding is induced a current I_a, opposite to the initially current. The electromagnetic torque changes the sense and the DC motor becomes a generator which transforms the mechanical energy into electrical one which is returned to the supply network achieving a recovery of energy.

The armature induced emf, which is measured at brushes, is equal with the value of the induced voltage in a way of current because the ways of current are parallel connected [1]. Relation (01) describes the armature induced emf:

$$U_e = \frac{p}{a} N \frac{n}{60} \phi = K_e n \phi; \quad K_e = \frac{p}{a}\frac{N}{60} \quad (01)$$

Where: p is the number of poles pairs, a – the number of current way pairs, N – the number of actives conductors of the rotor, n – the rotational speed of the rotor which is measured in rotations per minute, ϕ – the inductor magnetic flux of a pole.

The steady state operation of the motor is described by the relation:

$$I_a = \frac{U_a - U_e}{R_a} = \frac{U_a - K_e\, n\, \phi}{R_a} \qquad (02)$$

Where: U_a represents the armature voltage supply, I_a – the armature current, R_a – the armature winding resistance, U_e – the armature induced emf.

For normal motor operation U_a and I_a are positive and the motor is operating in its "first quadrant". By reducing U_a below U_e such that I_a is negative, the motor will operate in its second quadrant that is regenerating or braking. The electromagnetic torque is described by the relation:

$$M = \frac{P}{\Omega} = \frac{U_e \cdot I_a}{\Omega} = \frac{p N \phi I_a}{2\pi a} = K_M\, \phi I_a \quad (03)$$

Where: P is the electromagnetic power of the motor and Ω is the angular rotational speed of the rotor.

Figure 2 presents the mechanical characteristics of a DC motor with parallel excitation for regenerative operation. In order to obtain different braking torque it is used a variable rheostat (R_v) serially connected to an external DC circuit which is connected to the armature coils. At a rotational speed, $n > n_0$, electromagnetic torque is negative and it becomes a braking torque, producing the braking of the motor until its rotational speed decreases at the n_0 value. If the rotational speed becomes lower than n_0 value, the motor will produce again a positive torque and it will operate in normal motor mode.

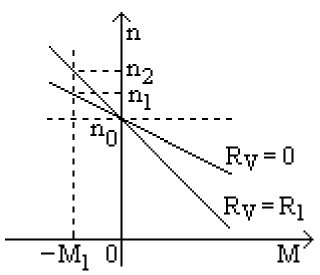

Fig. 2 Mechanical characteristics of a DC motor with parallel excitation for regenerative operation

2. TWO QUADRANT CONVERTER

Figure 3 shows a half bridge chopper circuit for motoring and regenerating operation [7].

The average voltage applied to the motor, and hence its rotational speed, is controlled by varying the duty cycle of the switch T_1. For regenerative operation the DC motor acts as the active power source, and the regenerating current is controlling by varying the duty cycle of the switch T_2.

The negative armature current increases through the switch T_2 and the armature inductance when T_2 is on.

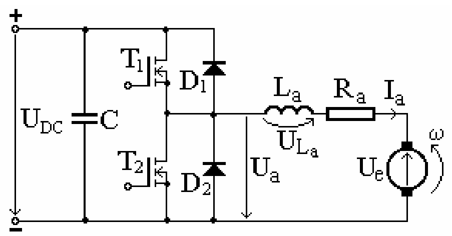

Fig. 3 Half bridge chopper circuit

The switching waveforms for the circuit, for motoring operation, are presented in figure 4.

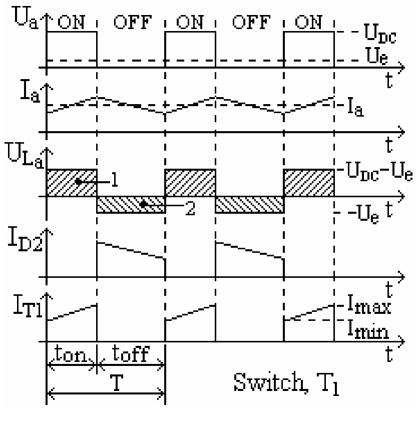

Fig. 4 Switching waveforms for motoring operation

During motoring operation the transfer function of the converter is given by the relation:

$$U_a = \frac{t_{on} \cdot U_{DC}}{T} \qquad (04)$$

The relevant circuit waveforms for regenerating operation are shown in figure 5, showing the equal areas of the inductor.

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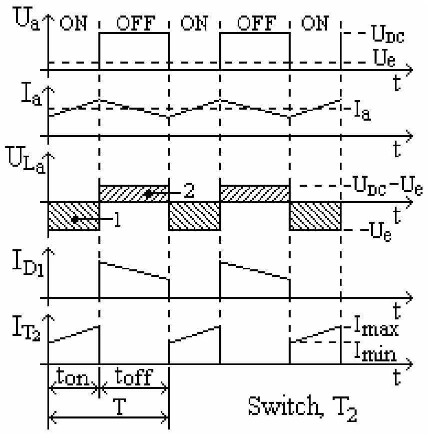

Fig. 5 Switching waveforms for regenerating operation

Figure 6 presents a schematic arrangement for two quadrants controller, showing the outer speed control loop and the inner current control loop [8].

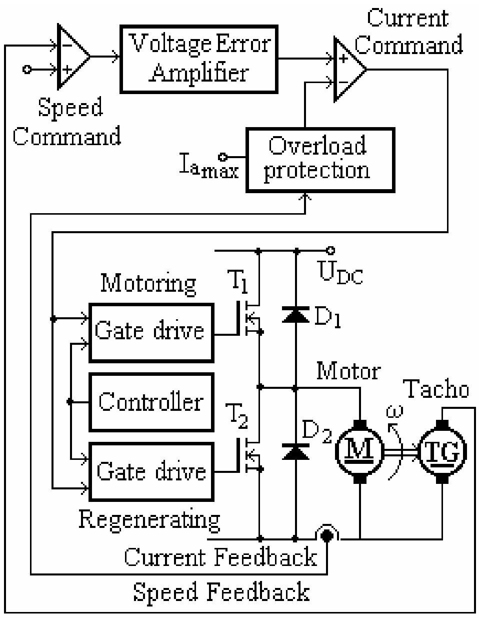

Fig. 6 Schematic arrangement for two quadrants controller

The voltage error signal gives the current reference command, and the current command signal is compared with the actual motor current in the inner control loop [3].

3. PWM CURRENT CONTROL

A way of controlling motor current it is to control the switching sequences to the main Power MOS devices.

The devices can be switched a constant frequency using a PWM method current control [6,7].

At start-up the duty cycle is adjusted to be long enough to give sufficient motor starting torque.

The initial motor current is given by the equation:

$$L_a \frac{di_a}{dt} + R_a \cdot i_a = U_{DC} \qquad (06)$$

Where: L_a is the armature winding inductance.

During the interval t_{on}, the rise of motor current prior to armature rotation is given by the equation:

$$i_a = \frac{U_{DC}}{R_a}\left[1 - \exp\left(-\frac{t}{\tau_a}\right)\right] \qquad (07)$$

Where: τ_a is the electrical time constant of the motor, $\tau_a = L_a/R_a$.

The current in the motor windings rises exponentially at a rate governed by average supply voltage and motor inductance.

During the interval t_{off} the switching element T_1 is off and motor current decays through the diode D_2 (Fig. 3) at a rate dependant upon the external circuit constants and internal motor leakage currents, according to the equation:

$$i_a = I_1 \exp - \left(\frac{t - \delta T}{\tau_a}\right) \qquad (08)$$

Where: I_1 is the current at the end of the first pulse and it is nearly 60% of i_a maximum value, $I_{amax} = U_{DC}/R_a$. For a PWM waveform with a period T the ratio of pulse width to switching period is denoted by δ.

The motor current at the end of the period, T, remains at a level I_2, which is then the starting current for the next cycle. As soon as rotation begins, back emf is generated, and the motor equation becomes:

$$L_a \frac{di_a}{dt} + R_a \cdot i_a = U_{DC} - U_e \qquad (09)$$

An approximate expression for the average motor current is given by the equation:

$$I_{ave} = \delta \frac{U_{DC} - U_e}{R_a} \quad (10)$$

Figure 8 presents the gate drive circuit to command the switching element (2 power MOSFET transistors BUK 438-800 A, parallel connected) [5].

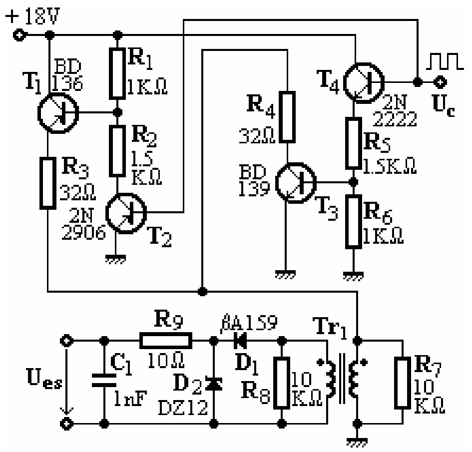

Fig. 8 Gate drive circuit

The power transistors are driven using the coupling transformer Tr_1. The respective circuit assures the necessary gate current for charging and respectively discharging the entry capacities gate-source (C_{gs}) of the MOSFET transistors, which were used, in a very short period. The switching elements command using the coupling transformers assures a controlled increase of the drain currents of the power transistors by applying a linear variable voltage on the gate.

4. CONCLUSION

DC motor speed control can be achieved using switch mod DC-DC chopper circuits.

For many applications the motor control system is operated at switching speeds in the range 1kHz to 100kHz.

Power MOS devices are ideally suited for this type of converter.

The advantages of power MOS devices include their simple gate drive requirements, rugged performance, easy of use in parallel configurations, switching performances.

Controlling the PWM duty cycle and motor current can tightly control motor torque and velocity.

By PSpice simulation [4] was tested in time and frequency domains the half bridge chopper circuit, and it was analyzed its stability. The obtained signal levels have a good concordance with calculated values [5].

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