CONTROL OF DC MOTORS BY CHOPPERS

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BY

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TO MY DEAR PARENTS, WIFE AND CHILDREN.

بسم الله الرحمن الرحيم

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A B S T R A C T

The dynamics of a separately-excited chopper-fed dc motor are investigated. Constant field-current dc motor is particularly chosen for this study. The input to the system is a chopped armature voltage and hence, a variable dc armature voltage is obtained and the speed can be changed in accordance.

Pulse-width modulation is employed owing to its advantages over the variable-frequency modulation. The mark/space ratio is varied assuming several constant rates, starting from a minimum value governed by the minimum time necessary for the commutating capacitor to ensure successful commutation, and up to a maximum value which is the continuous dc rated voltage. The motor electric equation and the equation of motion, assuming different loading conditions, are solved on a digital computer. A program simulating the system comprising the motor and chopper is completely described. Cayley-Hamilton's technique is considered for the mathematical analysis. A complete model of a dc chopper with commutating and firing circuits has been built, tested and used to supply the separately-excited dc motor used in the experimental work. Experimental results are obtained and compared with the theoretical results and conclusions are derived.

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CHAPTER I

INTRODUCTION

1.1 General

The direct current motors are being extensively used as variable speed drives in many industrial applications. The variation of dc motor speed is, in most cases, required. For example, printing machines, rolling mills, paper mills, traction systems and many other industrial applications are operating at variable speeds. This requires variable dc voltage levels to be applied across motor terminals in order to obtain a variable speed. The three classical methods being employed in varying the dc motor speed are; armature voltage control, rheostatic control and field-current control.

In armature voltage control, a motor-generator set is used, the output voltage can be varied by controlling the field-current of the dc generator. However, three electric machines of the same power raing have to be used. This, in turn, makes the system bulky, inefficient, costly and slow in response. In the rheostatic control method, a series variable resistance is inserted in the motor armature circuit. The disadvantages are; the large power-loss in the added resistance, which in some cases exceeds 40% of input power, besides the slowness of the system in response.
Finally, in field-current control method, although it is a simple way to change motor speed, but while changing speed, the motor torque also changes. Therefore,

this method is most suitable in constant power applications. The disadvantage is the slow response due to field circuit time delay.

1.2 Solid-State dc Power Converters

A reliable thyristorized dc voltage controller has been developed since the last two decades. The evolution of integrated circuits and digital electronics made the solid-state dc power converters more accurate and reliable. As it will be seen later, these types of converters have overcome all disadvantages of armature voltage control using motor-generator sets, rheostatic control and field-current control methods mentioned above. In other words, the solid-state dc power converters are now being used widely in industry and traction systems since they are economical (due to their greater efficiency), faster in response, reliable, offering accurate control, need minimal maintenance, have lower size and weight and noise-free. In addition, these converters can be used in controlling a considerably large number of dc motors from a common dc bus.

1.3 Types of Static dc Voltage Controller

1.3.a Controlled-voltage dc bridge

It can be either of the single or three phase type.

i) Single Phase Bridge

It is used with small dc motors and can be either of the fully-controlled or half-controlled type.

Fully-controlled bridge is chosen and shown in Fig. (1.1). Thyristors TH1, TH2 are fired simultaneously in one-half cycle, while TH3, TH4 are fired simultaneously in the other half-cycle. If α is the firing angle, thus the mean output voltage, assuming a continuous current mode, is:

$$V_o = v_{mean} = \frac{2\ v_{max}}{\pi} \cdot \cos\alpha \qquad (1.1)$$

Provided that the thyristor voltage drop is neglected.

ii) <u>Three-Phase Bridge</u>

It is used with large dc motors, Fig. (1.2).

The mean output voltage across the load, assuming continuous current mode, is:

$$V_o = v_{mean} = \frac{3\ V_{L(max)}}{\pi} \cdot \cos\alpha \qquad (1.2)$$

If a commutating diode is connected across the motor,

$$V_o = \frac{3\ V_L\ (max)}{2\ \pi}\ (1 + \cos\alpha) \qquad (1.3)$$

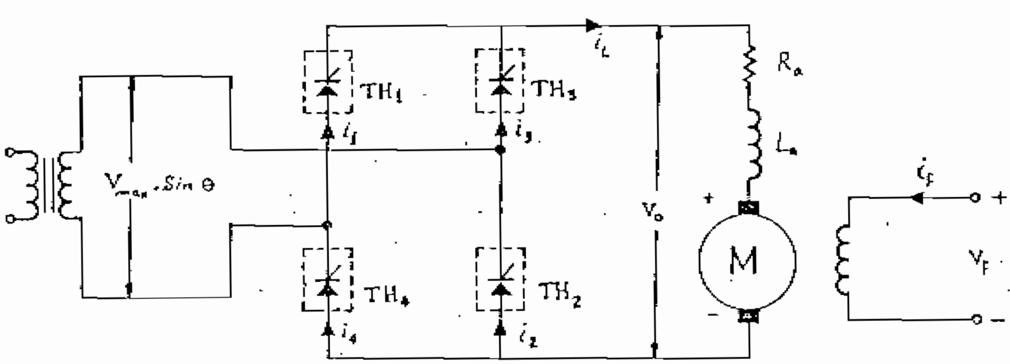

Fig. (1.1) Single-phase fully-controlled bridge feeding dc motor.

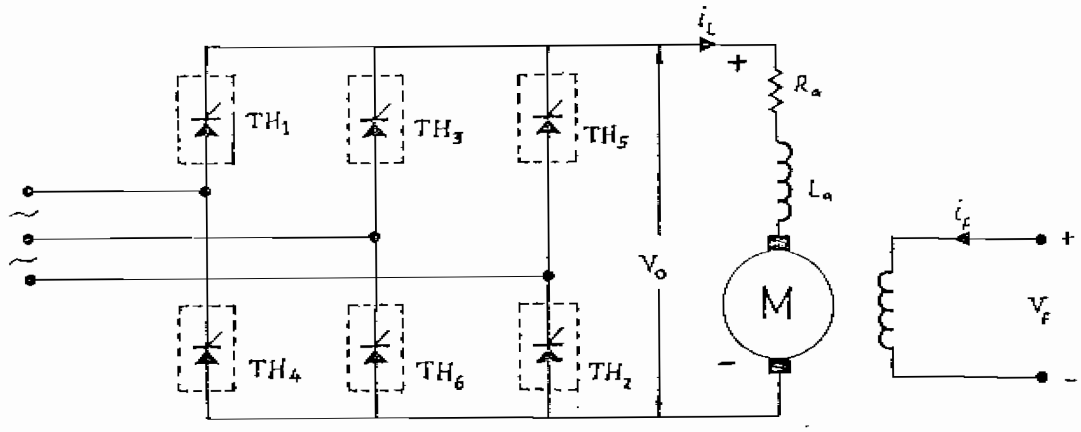

Fig. (1.2) Three-phase fully-controlled bridge feeding dc motor.

1.3.b DC Choppers:

DC choppers convert directly from one dc voltage level to another dc voltage level. They are used in dc traction systems and as an intermediate stage of voltage inverters. Their applications have a wide range, moreover, they can provide regenerative braking of dc motors by returning the stored energy back to the supply. DC choppers can be employed to supply both separately excited and dc series motors. This thesis is devoted to the speed control of the separately excited dc motor using a dc chopper.

1.4 Principle of Operation

In Fig. (1.3a), if thyristor TH1 is turned on and off in succession, the load voltage e_o will have rectangular pulses as shown. The average output voltage E_o can be obtained as follows:

$$E_o = E \cdot \frac{T_{ON}}{T} = \propto E \qquad (1.4)$$

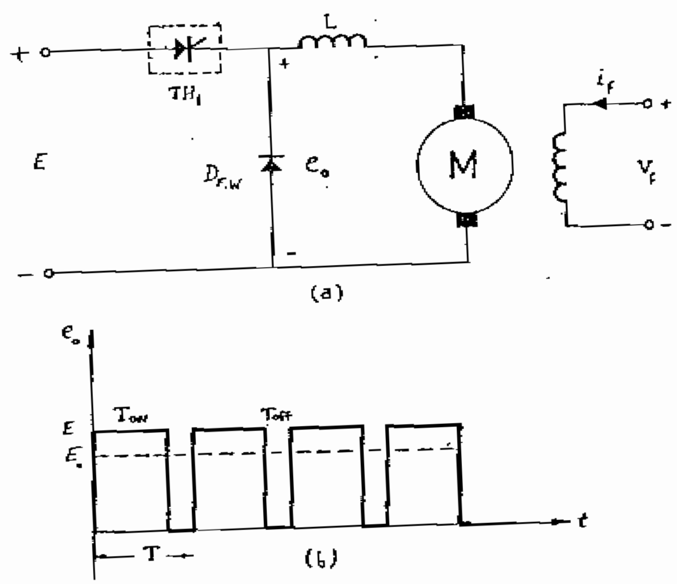

Fig. (1.3) Principle of operation.
a) Circuit. b) Output and average voltage.

where:

T_{ON} = ON-time of the thyristor, seconds.

T_{off} = Off-time of the thyristor, seconds.

T = $T_{ON} + T_{off}$ = periodic time of the chopper.

$\alpha = \frac{T_{ON}}{T}$ = duty cycle, dimensionless and,

E = the supply voltage, volts.

It should be noticed that a thyristor drawn inside a rectangle indicates that the thyristor is complete with its commutating circuit.

The output and average voltages are shown in Fig. (1.3b). The function of the free-wheeling diode $D_{F.W.}$, is to permit the flow of motor current when the thyristor is turned off with an inductive load.

Complete chopper circuit consists of the following four parts:

1. DC power source, which may be either a battery or an ac-to-dc converter.

2. Commutating circuit which turns the main thyristor off at the desired instant.

3. Power circuit which transmits power from the dc source to the load and,

4. Controller and trigger circuit which controls the power delivered to the load.

1.5 Mark/Space Ratio

The duty cycle α , and hence the mark/space ratio can be varied in one of the following ways:

a) Constant frequency system: $f = 1/T$

In this system, the chopping period T (and hence the chopping frequency f) is kept constant while the on-time T_{ON} is varied. The system may also be called "pulse width modulation".

b) Variable frequency system:

In which, the chopping period T is varied while either the on-time T_{ON} is kept constant or the off-time T_{off} is kept constant. The system may be called "frequency modulation" and it does suffer from the following disadvantages:

i . The possibility of interference with signalling and telephone-lines, is greater than that expected in constant frequency system.