DC MOTOR SPEED CONTROL USING MAGNETIC AMPLIFIER

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Abstract—Although the advance in power electronics resulted in the advance of the machine drives in general, still the high-power rating drives suffer from some industrial problems which affects the reliability of the application of power electronics on electric machine drives. Magnetic amplifiers can have an operation mode where they can work as variable voltage supply. Therefore, this paper introduces a novel drive for the separately excited dc motor method using magnetic amplifier. An introduction is given about the speed control of the dc motor drives. Then, the basic principle of operation of the magnetic amplifier is illustrated. The speed control configuration of the proposed drive is illustrated. Some design considerations, which must be taken into account, are mentioned. The simulation study is performed using MATLAB/SIMULINK software. An experimental rig is built which shows the validity of the proposed drive.

Keywords—dc drives, magnetic amplifier, separately excited DC Motor

I. INTRODUCTION

DC motors are widely used in industrial applications because they offer wide range of speed control both above and below the rated speeds, high starting torque which is useful in traction applications such as in electric trains and cranes and a wide range of torque control. Industries demand a wide and precise control of motor speed. There are many methods of speed control of DC drives such as field control, armature voltage control and armature resistance control [1, 2]. By the armature voltage control method, it is possible to control the speed of the motor for speeds below base speed but not for speeds above base speed. Flux control is used for speed beyond rated speed.

The resistance control method is the simplest method, but it is rarely used because of its great losses. It will be found in inexpensive applications to justify a better form of speed control. Ward-Leonard system is a basic armature control method. It is a motor-generator set to power the dc drive motor. It has been well discussed in [3].

Dc motors controlled by thyristor converters are the most widely used motor drive systems in industry. These systems provide speed control over a wide range. Three basic methods for solid-state control which are phase control, integral cycle control, and chopper control. In all these methods thyristors connect the supply to and disconnect it from the motor terminals. The frequency of switching is rapid. Therefore the motor responds to the average output voltage level and not to the individual voltage pulses. These methods are well discussed in [3, 4].

II. BASIC PRINCIPLE AND MAIN PROBLEMS OF THE MAGNETIC AMPLIFIER

The basic saturable reactor consists of circular or rectangular ferromagnetic core with two windings (the control winding and the load winding or the main winding). The magnetic amplifier is a combination of saturable reactors, rectifiers, resistors etc. used in control and amplification.
The control winding is connected to a dc controlled source and the main winding is connected in series with the ac load. When the control current is varied, the impedance of the main winding changes, thereby affecting and determining the output voltage appearing across the load. The direct current produces the dc flux which controls the saturation of the core so the self-inductance of the ac winding will be changed. If the direct current is large the core reaches saturation and the self-inductance of the ac winding reaches its minimum and the self-inductance of the ac winding reaches its maximum when the core is not saturated [5, 6]. But this basic circuit faces two main problems.

First one is that the ac applied across the load winding will cause ac voltage to be induced in the control winding [7]. Since the control winding is of low impedance, large currents will flow in this winding dissipating an appreciable amount of power. Also the high voltage induced in the control winding will exceed the dielectric strength which will result in immediate breakdown of the control winding.

To solve this problem the magnetic amplifier is divided into two equal cores and the control windings are connected so that they are in series opposition so that any voltage induced in one by an alternating voltage in the load winding will be cancelled by an equal and opposite voltage induced into the other so unwanted circulating currents will not appear. [7, 8]

Second problem is the slow response of the magnetic amplifier because of the highly inductive saturable reactor. When the number of control winding increases, the cross section area of the core increases and the initial permeability increases the inductance of the core will increase.

To solve this problem an external resistor called forcing resistor, is often placed in series with the control winding. A drawback of this method is that a portion of the control signal power is dissipated. [7, 8]

III. DESIGN CONSIDERATIONS

Some design considerations must be taken into account in our configuration.

3.1. Core materials
The magnetizing curve is steep; a slight change in control current will produce a large change in the output power. The material should be homogeneous, and that air-gaps should be avoided. Hysteresis losses may be minimized by proper selection of the core material. If it is chosen with high permeability and low retentivity, the losses are low. The more rectangular the core B-H loop the better will be the switching operation obtained. The less coercive force of the material, the less control power required. The core should also be characterized by stability under conditions of varying temperature and mechanical strain. [7, 9, 10, 11]

3.2. Core construction
Core can be built in any shape, but the toroidal configuration has advantages over the stacked E-I or double-backed U-type. In toroidal configuration the air gap is reduced reducing the leakage and the magneto motive force required to saturate the core. [7, 9, 10, 11]

3.3. Rectifier
The rectifier should have infinite back impedance and zero forward impedance. The diodes are self-commutated, where the current is determined by the applied voltage. Therefore the diode rectifier will not require any kind of control on the amount of energy that is converted. They are simpler, cheaper, reliable, more robust since a reduced number of electronic components are required to make the circuit work and can carry higher current, are characterized by their long life.
and ruggedness, can be operated at higher voltage than thyristors and the thyristor based rectifiers generate higher total harmonic distortion than the ones generated through the diode based ones. [12]

IV. THE PROPOSED CONFIGURATION FOR DC MOTOR SPEED CONTROL

This section explains the speed control of separately excited dc motor using the magnetic amplifier. The circuit used in this paper is shown in Fig 1,

- In our configuration three phase 3 element full wave magnetic amplifier circuit has been used instead of single phase magnetic amplifier. So the loading balance of the supply is secured due to the use of three phase supply. The form factor is improved, so the rectifier size and copper losses will be reduced by as much as 40%. The three phase magnetic amplifier has been well discussed in the known thesis by Lamm. The mode of action and performance of three phase magnetic amplifier is explained well in [13].
- Each phase of the ac supply is split into two windings to avoid demagnetization of the magnetic amplifier in the negative half cycle of the supply voltage.[14]
- Six rectifying diodes are used in series with the ac supply and the load windings of each saturable reactor. These diodes help the core to reach saturation faster as they support the internal feedback concept. Feedback in any amplifier is the process of returning a portion of the output signal to add to or subtract from the input signal. When the feedback portion of the output signal aids the input signal, the feedback is said to be regenerative or positive. Two methods of feedback are used external feedback and internal feedback. In our configuration internal feedback is used. Magnetic amplifier that uses internal feedback is sometimes referred to as self-saturating magnetic amplifier. It is accomplished by connecting rectifying components in series with the load windings of the saturable reactor. The internal feedback is simpler than the external feedback as it eliminates the resistance of the feedback windings. Also the lack of the feedback winding allows the load winding to be wound over a greater area of the reactor frame, and this, for a frame of given size, permits a greater power output than in the case of the external feedback amplifier. The external feedback is sometimes desired because its gain can be adjusted easily. [7, 9, 15, 16]
- Control windings are connected in series with the forcing resistor and the dc supply. This resistor increases the speed of response of the magnetic amplifier.
- The speed of the dc motor can be varied and controlled by changing the saturation of the magnetic core by changing the control current by changing the dc supply.
- Changing the control current demagnetizes the core and changes the effective impedance seen by the main coil.
- When maximum current flows in the control winding of the reactor which forces the magnetic core towards the saturation region so the impedance of the reactor will decrease leading to an increase in the output ac currents.
- Three phase bridge rectifier is used to rectify the output of the main coil windings. The diodes are numbered in the order of conduction sequences and the conduction angle of each diode is 120° . The conduction sequence for diodes is 12, 23, 34, 45, 56, and 61.
- The rectified voltage will feed the armature of the motor. The rectified voltage across the armature of the motor will increase leading to an increase in the motor speed.
- The field of the motor is fed from a separate dc supply.
- When a small control current flows in the control winding of the reactor. The magnetic core now is not saturated so the impedance of the reactor will decrease leading to an increase in the output ac currents.
As seen from Fig 2 the main winding of the saturable reactor is connected in series with the three phase ac supply and the diode. The parameters of the saturable reactor are mentioned in Table 1. The three phase supply is 380 volts line-line with frequency 50 HZ. The magnetic amplifier is driven into saturation by the control winding current which is a voltage controlled source driven by a unit step block parameter with an initial value = 5 and final value = 100 at a step time = 5 seconds. Then a diode based bridge rectifier is used. The output of the rectifier is connected to the armature winding of the separately excited dc motor. The parameters of the dc motor are mentioned in Table 2. The simulation result can be seen in Fig 3 the speed of the motor has been increased at (t=5sec)

Table 1: Parameters of the saturable reactor

| Parameter                  | Value |
|----------------------------|-------|
| Nominal power              | 5000 VA |
| Frequency                  | 50 Hz  |
| Winding 1 parameters       |       |
| V1 (rms)                   | 220 V  |
| R1                         | 0.005 Ohm |
| L1                         | 0.159 mH |
| Winding 2 parameters       |       |
| V2 (rms)                   | 400 V  |
| R2                         | 0.025 Ohm |
| L2                         | 0.79 mH  |
| Core loss resistance       | 400 Ohm |
### Table 2: Parameters of dc motor

| Parameter                                | Value                |
|------------------------------------------|----------------------|
| Armature resistance                      | 2.581 Ohm            |
| Armature inductance                      | 0.028 H              |
| Field resistance                         | 281.3 Ohm            |
| Field inductance                         | 156 H                |
| Field-armature mutual inductance         | 0.9483 H             |
| Total inertia                            | 0.02215 kg.m^2       |
| Viscous friction coefficient             | 0.002953 N.m.s       |
| Coulomb friction torque                  | 0.5161 N.m           |
| Initial speed (rad/s)                    | 1 rad/s              |
| DC voltage source for the field winding  | 300 V                |

**Fig 2: Matlab model**
VI. EXPERIMENTAL RESULTS

Six typical reactors are used. The control winding is used to inject dc current to the reactor, while the main winding is connected to the three phase supply. Two power backs are used. One of them to supply a constant dc voltage to the field winding of the motor and a constant three phase ac to the main winding, while the other power back is supplying a variable dc to the control winding. Six diodes are connected in series with the main winding and the ac supply. A bridge rectifier is used and its output is connected to the armature of the dc motor. By increasing the dc control current the speed of the dc motor increases and by decreasing the dc control current the speed of the dc motor decreases. Connection is as shown in Fig 1 and Fig 4 The dc control current and the speed of the motor is illustrated in the oscilloscope shown in Fig 5. The speed of the motor is in the yellow curve while the control current is in the blue curve.
The magnetic amplifier is a rugged device, it has no moving parts which increases its reliability. It has a high efficiency. The input and output circuits of the magnetic amplifier are completely isolated from each other. Gain of the magnetic amplifier can be varied simply by changing the amplitude of the control voltage. High power gain can be reached in one device. Larger gains can be obtained by cascading. The magnetic amplifier can be designed to operate at a wide range of control circuit impedances. Core can be built in any shape but it is better to be built in toroidal shape. The low speed of response has been solved by the forcing resistor and the mutual inductance between the control winding and the main winding has been solved by the series opposition connection.

VIII. CONCLUSION

This paper presents the speed control of separately excited dc motor using magnetic amplifier. The configuration was simulated using MATLAB/Simulink. It was performed in the laboratory and shows the same simulation results.

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