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Teaching Platform for DC Electric Drives

This paper describes an educational platform for teaching DC electric drives. The drive has as objective an efficient system for controlling the speed of a DC motor driven by a chopper. The chopper is manufactured using metal oxide semiconductor field effect transistors for low power consumption and high switching frequency. The control part is performed using the LabVIEW environment, thus allowing for monitoring of the main signals such as voltages, currents and speed. The applied principles and the obtained results are also shown.

Keywords: Control engineering education, DC motor drives, DC-DC power conversion, Education

1. Introduction

We are living in a world mainly based on the use of various machines, especially electric machines. The DC type is still found in many industries starting with industrial applications and ending with home use applications. Due to the presence of the embedded permanent magnets that provide an increased torque density these electric motors are found mainly in electric drives systems where space is a key factor. Such key applications found in our day by day life are transportation applications such as electric vehicles on rails, electric wheelchairs, electric scooters, electric cars, elevators.

The electric traction applications feature the speed control and the torque control and thus for the control systems these are important issues.

Along with the development of electronics and power electronics the performances of the semiconductor devices have increased while their cost has decreased. These two trends have made the semiconductor devices (i.e. bipolar, field effect metal oxide semiconductor transistors MOSFET) suited for the development of high performance power converters. At the beginning the controlled rectifiers were the mainly used power converters for driving DC motors [1]. In case of threephase power systems six or three semiconductor devices are needed and in the case of single-phase power systems four, two or one semiconductor is required.

Once the electronics evolved the switching frequency capability of the transistors has increased and another techniques has become available, namely the DC chopper with pulse width modulation (PWM) control. In Table 1 [2] it is shown a brief comparison between the various powering methods of a DC motor when semiconductor devices are used. The form factor is defined as the ration between the root mean square (RMS) value of the current flowing through the powered DC motor and the DC component of this current. By definition, a form factor value 1.0 means a pure DC source, such as a battery. When the factor is greater than 1.0 then it means it deviates from the ideal form. Manufacturers of permanent magnet DC (PMDC) motors specify a value not greater than 1.4 when continuous operation is considered.

Table 1.

Form factor	DC voltage source
1.0	Battery
1.05	Pulse width modulation (PWM)
1.4	Full-wave rectifier
1.9	Half wave rectifier

Thus, half wave rectifiers are not recommended. When a motor is driven with a high form factor then there is the possibility that a premature brush failure and excessive internal heating can occur. For higher form factors there is a need of special brushes and commutators, high temperature insulation system and therefore the motor may cost more.

The PWM control technique seems to fulfill most of the requirements. Moreover the DC motor should not be specially manufactured. When compared to full wave rectifier the number of semiconductor devices is smaller in the case of PWM. For example if one considers a one quadrant electric drive system then when full wave rectifier is used the simplest bridge (half bridge) requires three semiconductors while the PWM chopper requires two. Though, the rectifiers have the advantage to convert de AC voltage to DC voltage while the PWM chopper needs an existing DC voltage power source.

The development of the specialized engineering software has led to the enhancement of the design stage for electric drive systems.

For the given application the speed control of the permanent magnet DC motor is performed using the LabVIEW environment, which is a visual programming language [3]. The main advantage of this environment is that it allows for simulating the electric drive system based on the involved operating principles.

In order to make a step forward towards the real world, after the validation of the considered principles another software tool is used, that is, a SPICE type environment called LTSpice [4]. This software allows for simulation of the circuits using components with real world characteristics including non-linear dependencies.

2. System description

We are living The system's block diagram is shown in Figure 1. It comprises three main components: the command part, the chopper and the permanent magnet DC motor.

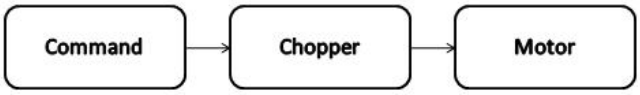
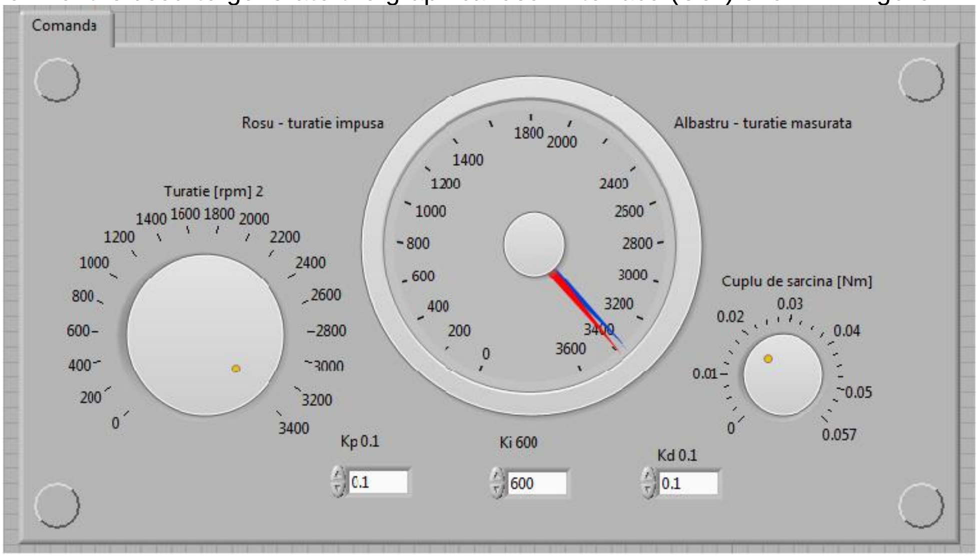


Figure 1. Main components of the electric drive system.

The command has a software part and a hardware one. The software part reflects into dataflow visual programming language, namely, LabVIEW. This environment is used to generate the graphical user interface (GUI) shown in Figure 2.



Kp 0.1: 0.1
Ki 600: 600
Kd 0.1: 0.1

Figure 2. Graphical user interface implemented using LabVIEW.

The user has the possibility to set the desired speed for the PMDC motor by turning the left side knob.

The interface also features the possibility to change the proportional, integrative and derivative coefficients, using the bottom numeric fields, in order to adjust the control loop behavior. For the moment the system allows only for speed control. The influence of the torque loop over the speed is that the system will not have the same dynamics (i.e. lower dynamics) but in the case of civil transportation applications the acceleration and the deceleration must be controlled and limited [5].

The feedback can be seen on the middle round indicator, the blue hand. The red hand is the set speed. The measured speed indicated by the blue limb is taken from the simulation model implemented in LabVIEW, i.e. the design stage. In the end, during the operating stage, the information regarding the real number of rotations (measured) of the working motor comes from the tachometer. The tachometer is connected at the rotor and it is represented by a DC machine. This machine is working as a generator and it is calibrated to give the data with a higher degree of accuracy.

The interface between the LabVIEW software and the real world is achieved using a data acquisition board National Instruments 6251-PCI, Figure 3. Its main features are shown in Table 2.

Figure 3. NI 6251 PCI data acquisition board.

Using the analogic inputs of this board the voltage obtained at the terminals of the tachometer is adapted and then converted by the DAQ board into numbers useful for the software part.

The PWM control signals are generated by software means within LabVIEW. In order to generate the required control signal, firstly, it is computed an error between the set speed and the measured one. Then the error is applied to a proportional-integral-derivative controller (P.I.D. controller) that is also implemented by software means within LabVIEW. The output of the controller is compared with a saw-tooth signal and in this the PWM signal is obtained. The control signal itself is output using the same DAQ board that has one digital output connected to the DC chopper. The diagram of the presented controlling principle is depicted in Figure 4.

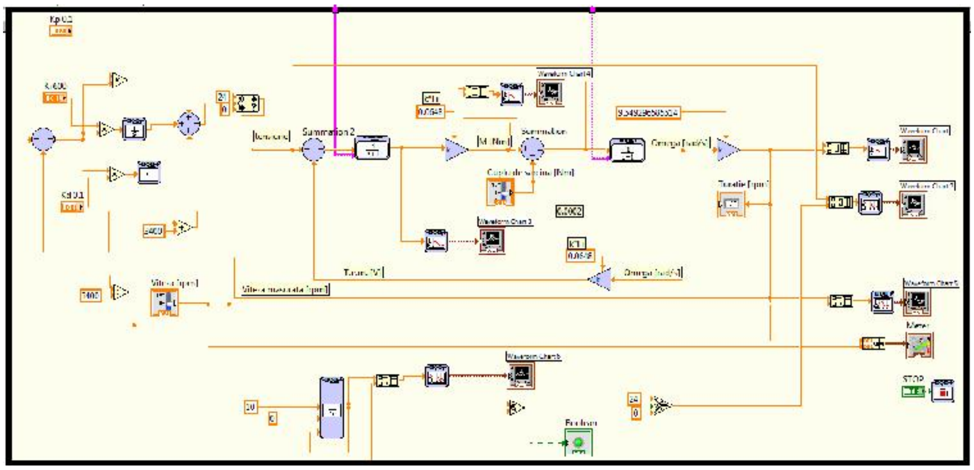


Figure 4. LabVIEW implementation of the controlling principle.

After the validation of the control principle using LabVIEW next step is to design the physical chopper for the motor.

Table 2.

Analog		
Resolution	16 bits	Input
Maximum Voltage Range	-10 V - 10 V	
On-Board Memory	4095 samples	
Sample Rate	1.25 MS/s	
Resolution	16 bits	Output
Maximum Voltage Range	-10 V - 10 V	
Update Rate	2.86 MS/s	
Digital		
Bidirectional Channels	24	Input/Output
Input-Only Channels	0	
Output-Only Channels	0	
Timing	Software , Hardware	
Clocked Lines	8	

Maximum Clock Rate	10 MHz	
Logic Levels	TTL	
Input Current Flow	Sinking , Sourcing	
Output Current Flow	Sinking , Sourcing	
Programmable Input Filters	Yes	
Supports Programmable Power-Up States	Yes	
Current Drive Single	24 mA	
Current Drive All	448 mA	
Watchdog Timer	No	
Supports Handshaking I/O	No	
Supports Pattern I/O	Yes	
Maximum Input Range	0 V - 5 V	
Maximum Output Range	0 V - 5 V	

The control signal generated at the digital output of the data acquisition board is applied at the input of the chopper's driver. The driver-chopper wiring diagram assembly is depicted in Figure 5.

In order to design it two main factors are to be given: the maximum current allowed to flow through the PMDC motor and the switching frequency.

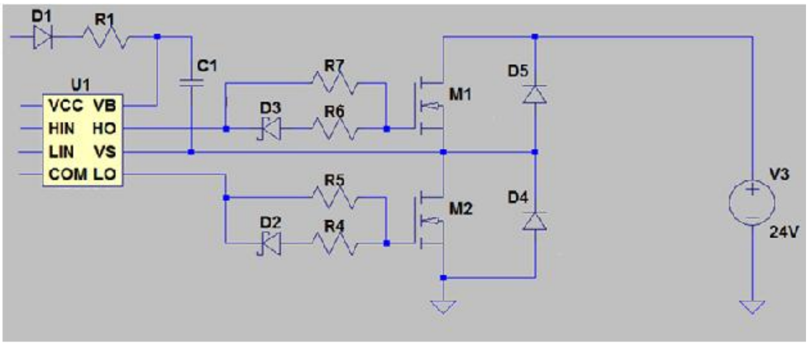


Figure 5. Wiring diagram of the chopper.

Due to the fact that the PMDC motor is a low power one then there is no need for power transistors. In this case the decision was to use bipolar transistors or the metal oxide semiconductor field effect transistors.

The chopper is implemented using MOSFET transistors. The reason for choosing this type of elements is represented by the fact that MOSFET transistors can operate at high frequencies, with low loss, compared to the bipolar transistors, which are transistors with high commutation losses [6]. The disadvantage of MOSFET versus bipolar is that the drain-source resistance when on state is greater.

The considered schematic for the chopper allows the electric drive system to operate in two quadrants (I and II). Within the first quadrant, the PMDC machine operates as a motor while in the second quadrant the PMDC machine operates as an electric generator. In fact the system begins to brake when the speed is over the no-load speed. If the systems allows then the energy generated can be recovered. Thus, a regenerative braking system can be obtained.

To improve the MOSFET transistor switching (decrease the switching losses), a driver has been used. This element not only improves the transistor commutation but it also adapts the signals received from the data acquisition board.

The simulation of the chopper was performed in LTSpice, considering the nonlinear characteristics and the switching periods of time of the elements.

The results obtained after the LTSpice simulation has been performed are shown in Figure 6. The PMDC motor is connected at the central point of the MOSFET half bridge. It has been modeled as a series circuit with a resistance, inductance and a voltage source. The value of the voltage source was in fact the back electromotive force that is proportional with the rotor speed.

With green is represented the current from the DC motor and with blue is represented the PWM voltage applied to the motor.

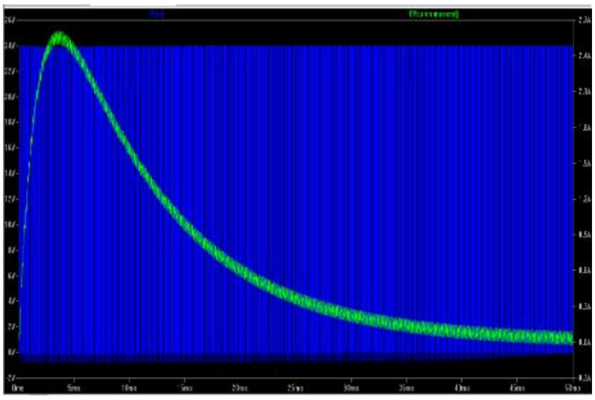


Figure 6. LTSpice simulation results.

The current ripple can be controlled by setting up a higher switching frequency for the ramp signal generator. The only issue is to check if the MOSFETs can withstand the increased thermal load and to analyze if there is a need for cooling heat sinks.

The electric drive system is based on a permanent magnet DC motor. To obtain a better analysis of the phenomena and to anticipate the possible impediments that could appear in physical realization of the system, it was used a

LabVIEW simulation of the DC motor. The parameters of the model are the rated values of the real DC motor

The datasheet specifications of the permanent magnet motor used are given in detail in Table 3.

Table 3.

Parameter		Values
Rated voltage	VDC	24
Continuous rated speed	rpm	3100
Continuous rated torque	Ncm	5.7
Continuous current	A	1.2
Starting current	A	5.68
Demagnetization current	A	10.5
Rotor inertia	gcm^2	110

The advantage of using this type of motor is the fact that it is smaller than an ordinary DC motor and it has an increased electromagnetic torque at the same size with a normal DC motor due to the increased magnetic density of the permanent magnets. For this type of motor the only way to control its speed is by varying its armature supply voltage. The field armature no longer exists and the torque constant is given by the existing permanent magnets. The draw back of such motors is that if during their operation the permanent magnets temperature increases over the so called Curie temperature then the permanent magnets are completely demagnetized and so the motor can be considered destroyed. Moreover, if the limit temperature is not reached but the armature reaction is quite important then a similar process can happen and again the motor becomes unusable. Thus, the current control for such motor types becomes a must in order to prevent a faulty operation and of course a possible failure of the motor. For the given motor the limit value of the current is 10.5A.

For the presented electric drive system the speed is controlled with a PWM voltage type. For this motor due to the starting current of 5.68A the MOSFET continuous drain current must be at least 6A. The 5.68A value corresponds to a no-load starting and so when the motor is started with load this value will increase. Looking at the voltage the drain-source voltage of the MOSFET must be no less than 24V and when the machine is in generator mode this voltage is higher for sure.

In Figure 7 there are depicted the characteristic curves of the motor taken from the catalog [7]. There are given the current efficiency, speed and torque.

From these curves it can be observed that the temperature is an important factor over many parameters such as no-load speed, starting torque and current values.

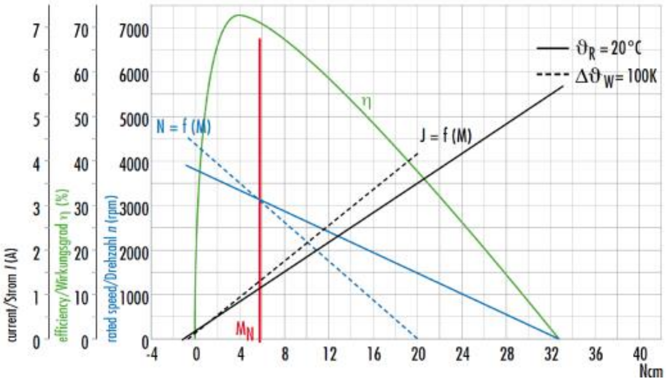


Figure 7. PMDC characteristic curves.

4. Future goals

The most important target of this electric drive system is the physical realization of the whole set. This involves the implementation of the simulated chopper using real circuit elements and the connection between the other two parts, the control part and the PMDC motor.

Another feature that is intended to be implemented is represented by the achievement of the speed reaction loop, along with the possibility to monitor the speed variation within the graphic interface, and the current loop.

For educational purposes another target is to be able to graphically monitor both the applied armature voltage and the drawn current

5. Conclusion

The platform is for educational purposes and it facilitates understanding of the phenomena that are involved in a DC electric drive system. Along with the steps involved by the designing of a PID controller it can be also observed how this controller operates, how does it influence the entire system behavior. The PWM generation algorithm is also exposed within the program and how this control signal drives the DC motor model.

The system that is presented provides real-time information which facilitates its use in a wide range of applications.

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