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Practical Platform for Open and Closed Loop Speed Control of an Inverter Driven Asynchronous Machine Used for Teaching Purposes

The paper presents a laboratory setup based on a SIMOVERT MASTER-DRIVES MC Inverter from SIEMENS used for open and closed loop speed control of an induction machine. The platform allows four quadrant operation of the machine using both the classical V/Hz scalar principle and field oriented vector control principle. The rectifier unit consists of a classical three phase diode bridge and two high voltage capacitors in order to obtain a voltage source behavior of the converter. In order to obtain the four quadrant operation of the drive, several methods are investigated out of which one is proposed and implemented. The theoretical aspects of V/Hz scalar principle and field oriented vector control principle are better explained using the proposed experimental platform.

Keywords: electrical braking, voltage source inverter, educational platform

1. Introduction

The technological advances in the vector control domain didn't eliminate the use of scalar speed control of the induction machine. Nowadays, almost all electrical drives manufacturers provide systems which can operate in several speed modes, including open loop V/Hz scalar principle. Applications for this strategy include domains with low speed range variation ($\Omega_{min}/\Omega_{max} = 1:10$) and modest dynamics, such as water pumps, ventilation installations, etc [1]. With the continuous development of semiconductor devices (more powerful and efficient power transistors) and control devices (digital signal processors, microcontrollers and newly developed digital signal controllers) the variable speed electrical drives domain is more and more versatile and divers [2], [3].

Scalar control is based on the frequency and voltage magnitude proportional relationship control. The system becomes instable when fast frequency (acceleration or deceleration) is applied; hence the reference frequency is ramped for an increased stability of the drive system [4]. Dynamic performances of the scalar control of ac drives can be improved by applying several compensation algorithms, especially in low speed control range [5], [6]. Energy saving requirements can be achieved by a proper adjustment of the flux amplitude and minimization of the machine losses [7]. In this circumstance, scalar control can be an efficient solution in a great number of applications, including automotive control systems.

From the point of view on an undergraduate electrical engineering student which studies a drive course is very important to be able to understand the theoretical aspects of the various speed control methods applied in electrical drives based first of all on the features and differences of each approach and second, based on the application domain of each strategy. The best way to achieve that aspect is this approach: after theoretical explanation one should realize practical experiments in which to observe and compare the behavior of the methods in the same environment conditions. A cheap solution in obtaining such results is to use an industrial drive system adapted to the laboratory conditions.

In this paper, a practical platform based on a SIMOVERT MASTERDRIVES MC Inverter from Siemens is developed [8]. A custom made rectifying unit is used in order to obtain the DC voltage necessary to supply the inverter. The rectifying unit is composed of a classical three phase diode bridge in conjunction with two high voltage capacitors. The obtained converter has in this way a voltage source behavior. For protection purposes and also in order to observe the transient behavior of both scalar and vector speed control strategies a four quadrant operation of the system is required.

2. Electrical Braking in AC Drives

The modern AC drive consists of an input rectifier converting AC voltage to DC voltage stored in DC capacitors. The inverter converts the DC voltage back to AC voltage feeding the AC motor at the desired frequency. The process power needed flows through the rectifier, DC bus and inverter to the motor. The amount of energy stored in DC capacitors is very small compared with the power needed, i.e., the rectifier has to constantly deliver power needed by the motor plus the losses in drive system [9].

Flux braking is a method based on motor losses because during the braking, motor flux and thus also the magnetizing current are increased. The control of flux can be easily achieved through the Direct Torque Control (DTC) because, through it, the inverter is directly controlled to achieve the desired torque and flux to the motor, so during the flux breaking it guarantees that braking is mad according to the specified speed ramp. The flux braking method based on DTC enables the motor to shift quickly from braking to motoring power when requested. In flux braking the increased current means increased losses inside the motor. The increased current generates increased losses in motor resistances. In other words, flux braking is most effective in a low power motor.

In a frequency converter the diode rectifier bridges can be replaced by the two thyristor controlled rectifiers in antiphase and that allows changing the rectifier bridge according to the power flow needed in the process.

The FORWARD Bridge converts 3-phase AC supply into DC. It feeds power to the drives via the intermediate circuit. The REVERSE Bridge converts DC back to AC whenever there is a need to pass the surplus motor braking power back to the supply network. The thyristor-firing angle is constantly regulated to keep the intermediate circuit voltage at the desired level. The forward/reverse bridge selection and intermediate circuit voltage control are based on the measurement of the supply current, supply voltage and the intermediate circuit voltage.

The IGBT based regeneration approach is based on the same principles as power transmission within a power network. In a power network several generators and load points are connected together. One can assume that at the point of connection the power network is a large synchronous generator having a fixed frequency. The input IGBT Bridge of the drive (later line converter) can be considered as another AC voltage system connected through a choke to the generator. In order to transfer power between two systems there has to be a phase difference in the angle between the voltages of the two AC systems. In order to control the power flow between the two systems the angle has to be controlled.

When a process consists of several drives where one motor may need braking capability when others are operating in motoring mode, the common DC bus solution is a very effective way to reuse the mechanical energy. A common DC bus solution drive system consists of a separate supply rectifier converting AC to DC, and inverters feeding AC motors connected to the common DC bus.

Another possibility to limit DC bus voltage is to lead the braking energy to a resistor through a braking chopper. The braking chopper is an electrical switch that connects DC bus voltage to a resistor where the braking energy is converted to heat. The braking choppers are automatically activated when the actual DC bus voltage exceeds a specified level depending on the nominal voltage of the inverter.

3. Proposed braking system

The setup that we consider is situated in the laboratory of the university and its use is purely educational. That means that we've not pushed dynamics and neither restrictive specification to be met. We're not talking about an industrial motor subjected to stressful cycles of braking and restarting so we don't need to care too much to the braking losses. And more, since is a laboratory project, it's preferable not to have high costs. All these characteristics have led us to the braking method choice of using a resistor to dissipate the built up energy which develops during the generator operation mode of the machine, taking advantage also by the simple electrical construction and well-known technology. This method has been first simulated to check its functionality, and finally it was physically built.

It is a very simple approach: using a resistive divider, the DC-link voltage is measured and compared with an imposed value of the maximum voltage allowed at the capacitor pins. Using a power transistor, a resistor is connected in parallel with the capacitor when the measured DC voltage is higher than the maximum imposed value. The circuit is simulated using PSpice and depicted in Fig. 1.

In order to simulate the behavior of the entire system some simplifications had been made.

The resistors R_1 and R_2, the capacitors C_1 and C_2 and the power supply V_1 will simulate the power circuit present downstream of the inverter, the power supply V_2 will simulate the 24V alimentation for the operational amplifier (this also present near the inverter) and the 250Ω resistor R_8 is the braking resistor.

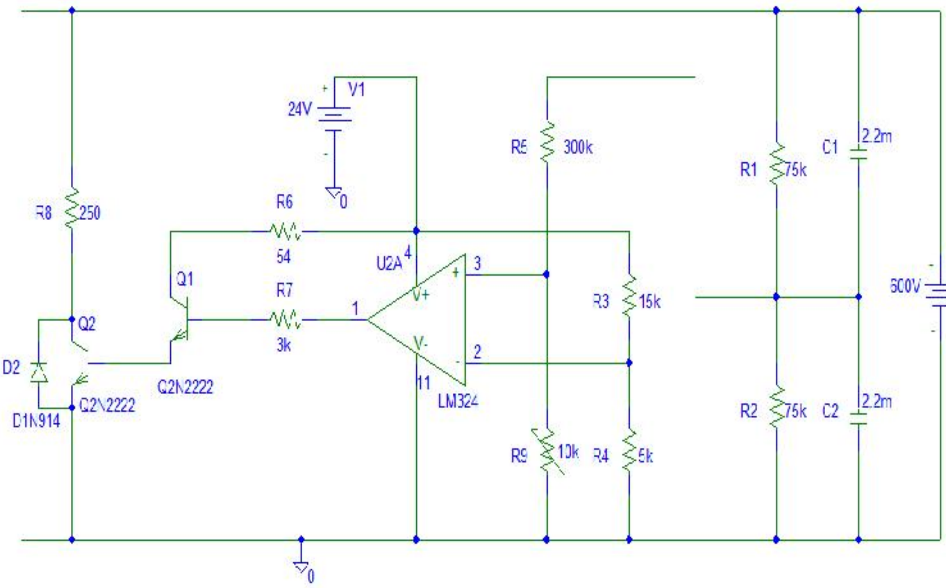

Figure 1. PSpice Schematics circuit diagram.

In Fig. 2 is shown the final result of the simulation with all the voltages and currents of the circuit. Using the potentiometer R_9 the threshold value of voltage is settled. The simulation shows a flow of current in the resistor R_8 that means that the motor is braking. The value of resistance of the potentiometer needed to brake is 7kΩ.

The next step after obtaining concluding simulation results was to design the PCB layout of the circuit using PCB express development kit, which is free software available online [10].

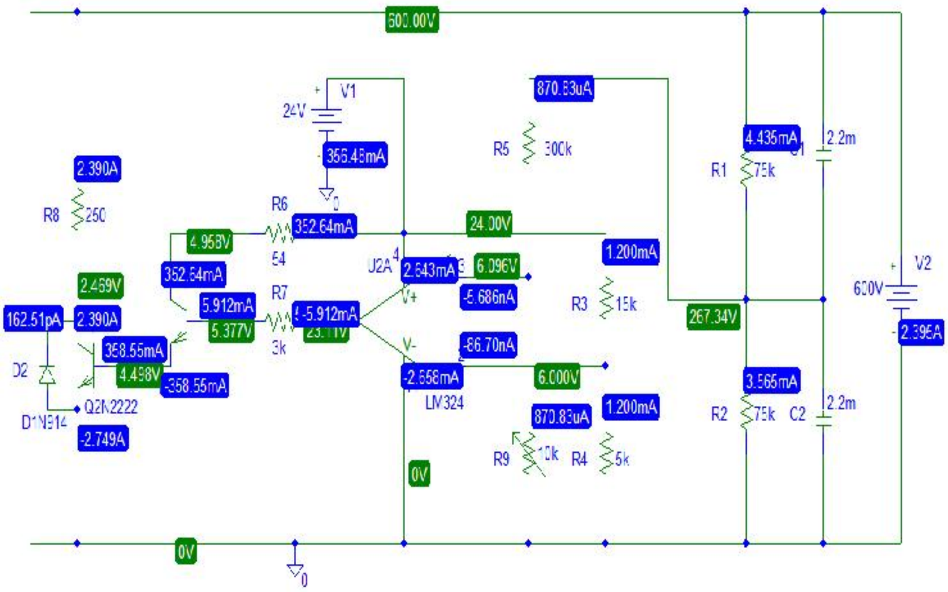

Figure 2. Simulation of the breaking operation.

The designed layout is depicted in Fig. 3. Placing all the components and connecting them in the correct way avoiding to cross the connections, is possible to arrive at the result shown in Fig. 3.

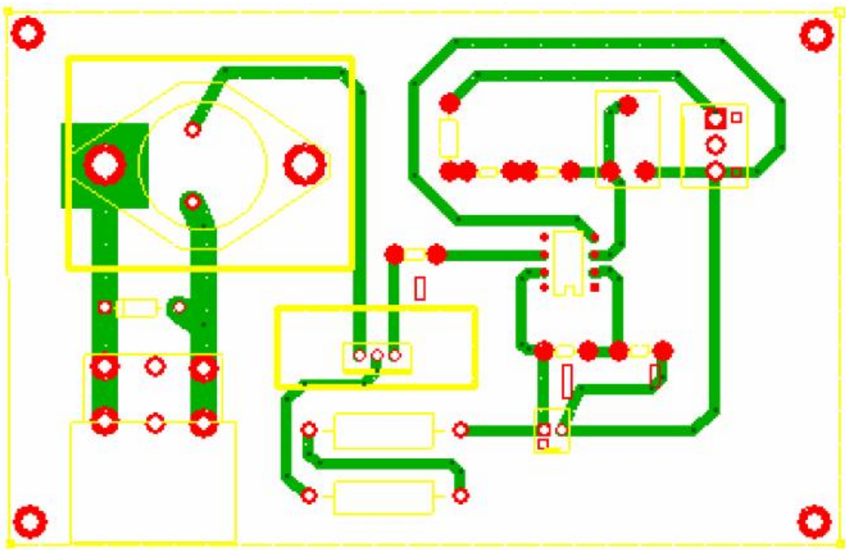

Figure 3. PCB layout of the breaking circuit.

Using the press and peel technique the designed layout was transferred on a copper plate. After all components were soldered the board looks as in figure 4. After testing the circuit behavior at low voltage the board was ready to use.

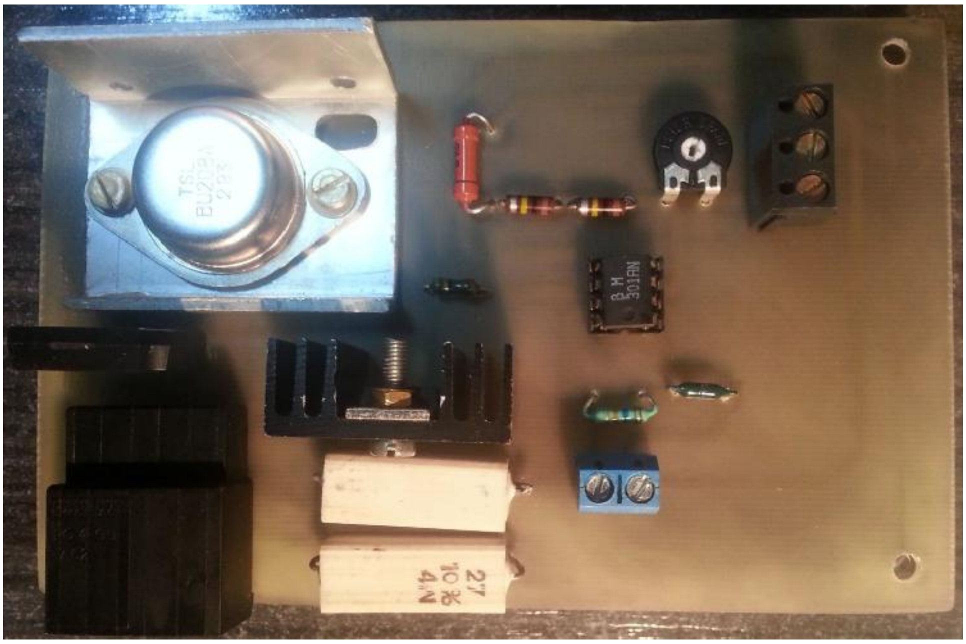

Figure 4. PCB of the braking circuit.

4. Experimental platform

The setup is presented in the diagram from Fig. 5. From the PC, through serial communication is possible to impose speed references the motor and also to acquire measured signals. When it’s running, at the pins of two capacitors is a voltage of about 550V. When instead, by the software, is imposed a braking cycle, that voltage will increase and when it will exceed the threshold of 600V on the not-inverting pin of the amplifier will be a voltage greater than the one on the inverting pin.

The comparator will so change the state of its output and by a little flow of current will feed the base of the little BJT which, enabling the flow of current between its collector and its emitter, will feed the base of the big transistor switching it on conduction. In this way there will be a flow of current through the resistor, around 2.3A, that makes possible a faster and stronger braking. When the braking period is over the output of the amplifier will change sign again and the transistors are again blocked.

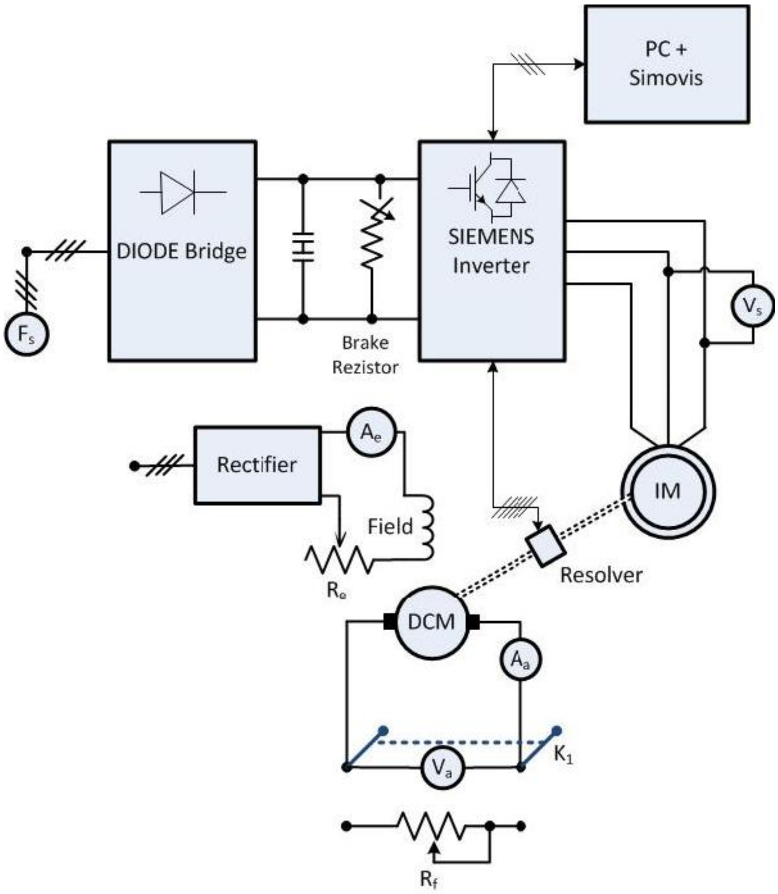

Figure 5. Experimental setup.

5. Conclusion

In this paper, a practical platform based on a SIMOVERT MASTERDRIVES MC Inverter from Siemens is developed. A custom made rectifying unit is used in order to obtain the DC voltage necessary to supply the inverter. The rectifying unit is composed of a classical three phase diode bridge in conjunction with two high voltage capacitors. The obtained converter has in this way a voltage source behavior. For protection purposes and also in order to observe the transient behavior of both scalar and vector speed control strategies a four quadrant operation of the system is proposed and implemented. Several scalar control strategies can be studied by our students by using the developed hardware setup presented in this paper.

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