SPEED CONTROLLER DEVELOPMENT FOR BRUSHED DC MOTORS USING PWM

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Abstract: The use of electric motors for the traction of urban vehicles has been increasingly common. Within the scope of the speed variation of these electric machines, there is still an added cost for the acquisition of efficient and reliable controllers. This article aims to present a speed controller development for brushed direct current motors using commercially accessible components.

Keywords: MOSFETs; PWM; Electric Motor; Continuous Current; Arduino.

DESENVOLVIMENTO DE UM CONTROLADOR DE VELOCIDADE PARA MOTORES DC ESVOVADOS UTILIZANDO PWM

Resumo: A utilização de motores elétricos para a tração de veículos urbanos tem sido cada vez mais comum. No âmbito da variação de velocidade dessas máquinas elétricas, ainda há um grande custo agregado para a aquisição de controladores eficientes e confiáveis. Portanto, o objetivo desse artigo é apresentar o desenvolvimento de um controlador para motores de corrente contínua e escovados, utilizando componentes comerciais de fácil acesso.

Palavras-chave: MOSFETs; PWM; Motor Elétrico; Corrente Contínua; Arduino.

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1. INTRODUCTION

The automotive industry has been reinventing itself over the past few decades to achieve a cleaner powertrain. About 16% of CO_2 emissions come from the transport sector and 12% come from fuels used in vehicles [1]. Thus, one of the alternatives found by industries around the world is the replacement of vehicles powered by internal combustion by electric propulsion vehicles.

Powering electric vehicles varies depending on vehicle brands, vehicle type, application, capacity and many other factors. Vehicles with brushed motor, brushless AC and DC motors can be found on the market. Although the functioning of these engines is similar, the type of speed control can vary from one model to another.

With the advancement of technology for the control of AC motors, DC motors presented a reduction in their application in original traction systems [2]. Although, because it is an easily accessible and low-cost motor, it is still widely used in projects for conversions of urban vehicles and transport equipment. Figure 1 shows the DC motor model used in an electrical conversion project in a Renault Sandero 2012, at Centro Universitário SENAI CIMATEC, made available for the study.

Figure 1. Electric motor 2kW DC.

Source. Author.

Another important point is that the speed control of a DC motor is carried out in a simpler way compared to AC motors. Thus, it is possible to control the motor speed through devices composed of MOSFET transistors and potentiometers using Pulse Width Modulation (PWM) for speed variation.

For the development of the conversion project it was necessary to budget a controller for use in the 2 kW electric motor. However, the suppliers found offered a universal controller, which had a higher price than that practiced in other similar applications. Therefore, it was necessary to develop a prototype controller, with low cost, applied to the direct current electric motor available for studies. In the development of the prototype, easily accessible electronic components were used, allowing the control of the engine rotation efficiently. Table 1 shows some specifications of the engine model taken as a reference.

Table 1. Specifications of the DC motor available.

DC Motor	
Type	Brushed with independent excitation
Power	2000W
Tension	24v
Current Máx.	120A
Rotation Máx.	3000 RPM

Source. Author.

2. METHODOLOGY

The most common type of DC motor control is by varying the supplied voltage. By connecting the motor in series with a variable resistor, for example, it is possible to have a control of the voltage and current available for motor consumption, limiting its torque and power. This type of control is applied to brushed motors, not working on brushless motors.

For a refined and efficient control, it was taken as a parameter what has been used in the automotive industry, using MOSFETs transistors and PWM control. To facilitate the development, an Arduino UNO module was used to generate the MOSFETs and motor drive signals.

Pulse Width Modulation, or PWM, is a technique for getting analog results with digital means. Digital control is used to create a square wave, a signal switched between on and off [3]. Thus, in a simplified way, the PWM works as an oscillating digital output, capable of varying the effective voltage level (RMS) of its output by modulating the on and off times of its cycle. This control is performed from the pulse width, where this represents the time the signal (or source) is turned on. The period represents the time of a wave cycle, as shown in Figure 2.

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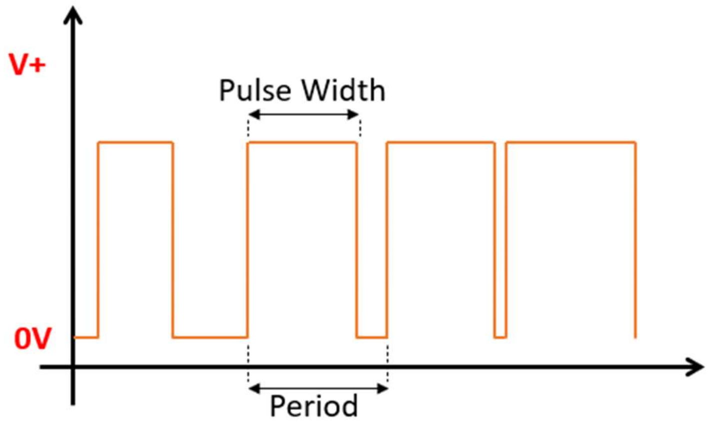
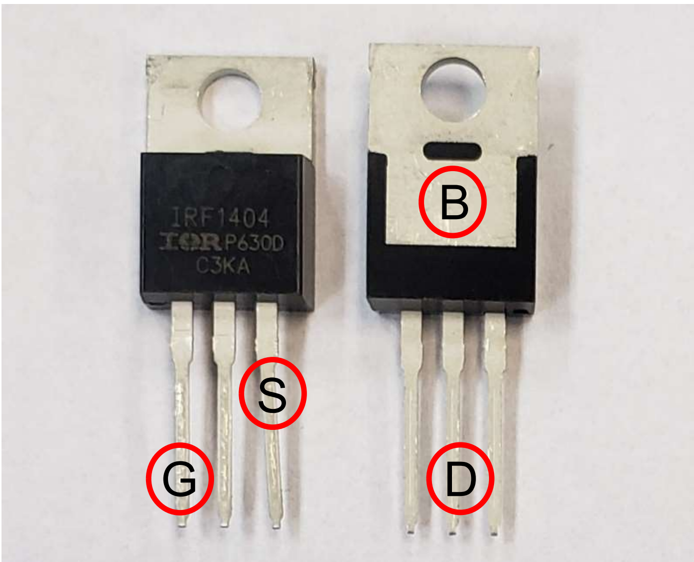
Figure 2. PWM Square Wave



Source. Author.

MOSFETs are field effect transistors, which have the characteristic of controlling the output voltage, based on the voltage variation in the gate. In conjunction with a PWM signal, it is possible to adjust the voltage provided at its output, being widely used in dimmers, switched sources, sound amplifiers, among others. There are the MOSFETs that perform the control from the positive charges (PNP) and the models that perform the control from the electrons (NPN). For reasons related to electron portability, the P-channel transistors are little applied in power electronics [4]. Figure 3 shows the MOSFET model used in the construction of the controller.

Figure 3. MOSFET IRF1404



Source. Author.

The MOSFET is a four terminal device, and the four terminals are called drain (D), gate (G), source (S) and body (B) [5]. In the NPN type, the MOSFET body has the same polarity as the drain, being negative.

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The source is the terminal responsible for supplying the electrons to the device, and it is connected directly to the power source. The drain is the terminal responsible for draining the electrons, and it is connected to the negative terminal of the motor. Finally, the gate is the terminal responsible for controlling the channel width and, consequently, the flow of electrons between the energy source and the motor. The channel width variation is made from the voltage variation, through PWM control, using a potentiometer.

The greater the voltage applied to the base, the smaller the channel will be, decreasing its internal resistance and releasing the passage of electrons. Proportionally, the opposite also occurs, so that by decreasing the voltage at the base, the larger the channel will be, increasing the internal resistance and restricting the passage of electrons.

Thus, from the modulation of the pulse width provided by the potentiometer and the variation of the current supplied to the motor by the MOSFETS, it is possible to obtain control of the motor speed in a simplified and efficient way.

2.1 Controller Circuit and Composition

The circuit is divided into two parts, one for control and other for power. In the control circuit an Arduino Uno was used to generate PWM signals for motor control from the reading of a potentiometer connected to its analog input, later replaced by an electronic accelerator pedal of the converted vehicle itself.

The use of Arduino brought with it some limitations related to the voltage and current capacity of its components, since the electric motor used has much higher rated voltage and current (24V / 120A) than the controller supported (12V / 0.5A). To circumvent the controller supply voltage limitations, a voltage regulator in parallel with the vehicle battery has been installed to maintain the voltage within specification.

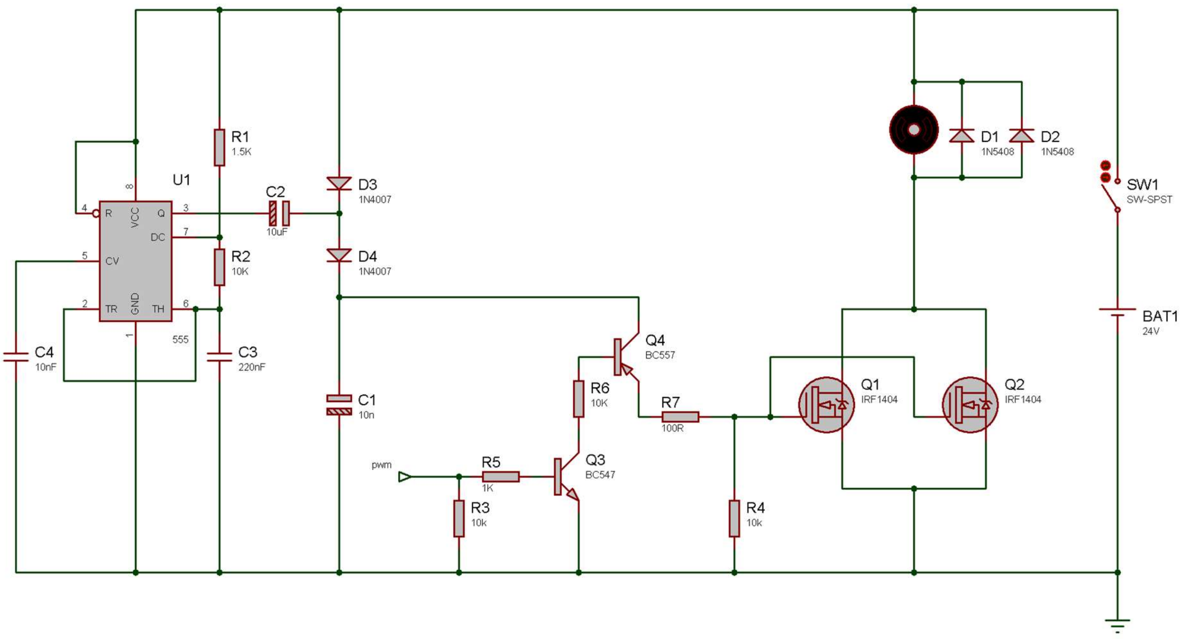
The current limitations were supplied with the use of a power circuit composed of voltage doublers and MOSFETs. The dimensioning of the power circuit was carried out from the analysis of the electrical characteristics of the motor used in the conversion. With 2 kW of power, powered by 24V, a rated current of approximately 80A was expected during its operation. Tests on benches and on the prototype were carried out and peaks of 300A were verified during the start.

With capacities for 40V output voltage, 115A rated current and 650A peak, the MOSFET IRF1404 was chosen for the vehicle's power circuit. In order to reduce heat dissipation and increase system durability, 2 IRF1404 were installed in parallel for load sharing.

To ensure the operation of the MOSFETs within the maximum current capacity region, a voltage greater than the drain voltage must be applied to the gate, which led to the need to use a voltage doubler circuit between the driver output and the power circuit input. The voltage doubler circuit was built using a CI555 oscillator IC, capacitors, and resistors.

The circuit diagram of the controller was developed in the Proteus software, to perform off board tests and correct possible errors. The Figure 4 represents the layout of the control and power circuit.

Figure 4. Layout of the control and power circuit



Source. Author.

Through Figure 4 it is possible to identify the control and power circuits of the controller. A general safety switch SW1 has been added to completely de-energize the circuit in case of an emergency. Diodes D1 and D2 have also been added to prevent the voltage from the counter-electromotive force from returning to the circuit and damaging the components.

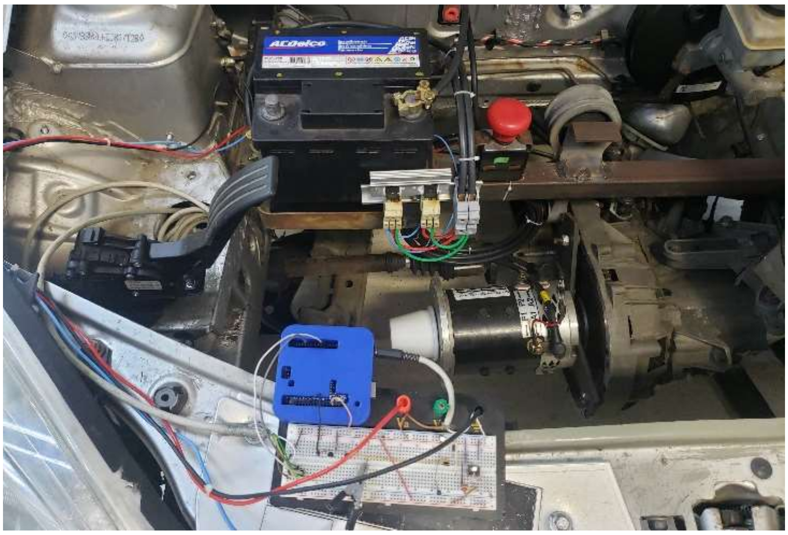
To simplify the modeling and facility the circuit understand, the Arduino was replaced by the PWM signal, positioned between resistor R3 and R5. Thus, in the elaboration of the functional prototype, this PWM signal will be generated through the potentiometer used together with the Arduino Uno described above.

3. RESULTS AND DISCUSSION

After validating the concept in software, a functional prototype of the developed controller was built. To make it feasible, a protoboard for Arduino was used, facilitating assembly and adjustment before a possible printed circuit board manufacturing.

The control potentiometer was replaced by the vehicle's own electronic accelerator, matching the original usability characteristics of a common car. Figure 5 shows the prototype board developed, positioned together with the motor used to convert the vehicle.

Figure 5. Prototype board and electric motor

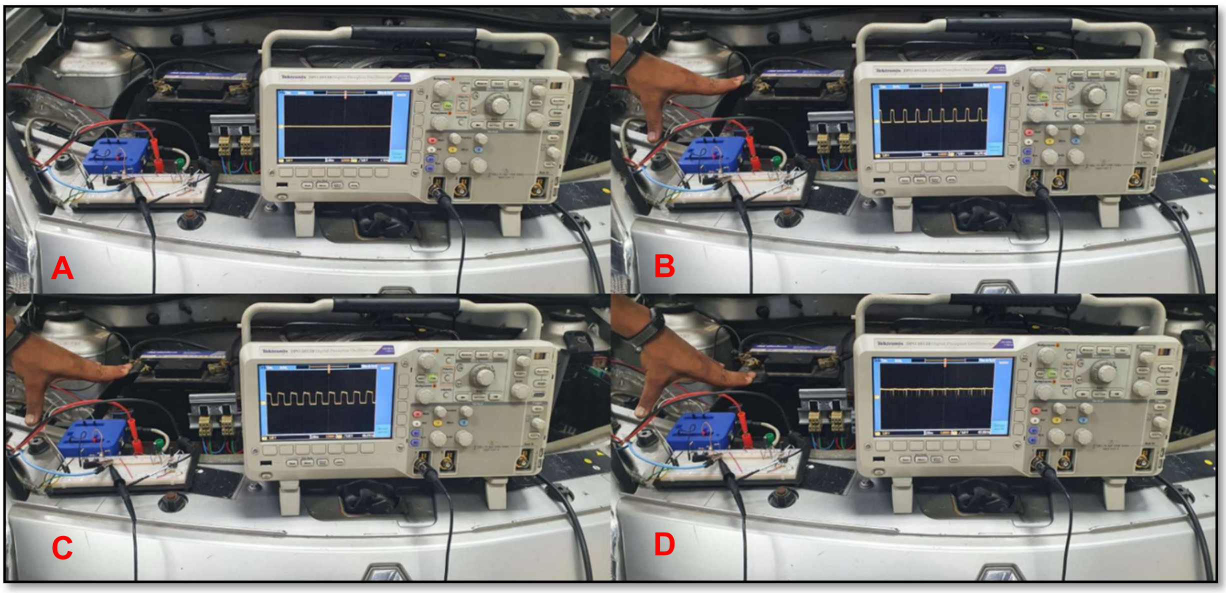


Source. Author.

As it is a heat source, the transistors were placed outside the breadboard, coupled to a heat dissipation board, in order to avoid possible damage to the circuit and compromise the prototype's operation. The temperature measured in the MOSFETs was 85 °C.

With an oscilloscope, it was possible to verify the formation of the PWM by activating the accelerator. Thus, tests were carried out simulating the vehicle's acceleration and deceleration. PWM waveforms with accelerator at rest (a), 25% (b), 50% (c) and 100% (d) acceleration were recorded. Figure 6 below shows the curves generated in the controller tests.

Figure 6. PWM verification with an oscilloscope



Source. Author

4. CONCLUSION

Although the technology of MOSFET transistors and pulse-width modulation is not so recent, its use has become increasingly versatile and functional. The study of speed controllers for motors ranges from control circuits to power circuits, becoming something complex and challenging.

The developed prototype presented satisfactory results, enabling the control of DC motors up to 2000W of power and with an operating voltage of up to 24v, using easily accessible components and low purchasing value. Thus, the final value for the construction - about R$ 1000,00 - of the controller was considerably lower than what is practiced in the market for devices with similar specifications, costing about R$ 7500,00. For the complete validation of the prototype, durability and efficiency tests must be carried out over longer periods.

However, for the control of motors with higher power and voltage, it is necessary to resize the components and protection systems, as well as the use of a specific integrated circuit, in order to replace the Arduino and allow the addition of transistors for greater capacity of current supply. In addition, a specific cooling system for the power circuit is important as, in operation, MOSFETs can reach high temperatures.

5. REFERENCES

[1] FERREIRA, Tânia Raquel Machado. A fiscalidade automóvel como instrumento de proteção ambiental. Dissertação de Mestrado, Instituto Superior de Contabilidade e Administração do Porto, 2020.

[2] HASHMNIA, Nasser; ASAEI, Behzad. Comparative Study of Using Different Electric Motors in the Electric Vehicles. Proceedings of the 2008 International Conference on Electrical Machines.

[3] HIRZEL, Timothy. Foundations: PWM. Available at: <https://www.arduino.cc/en/Tutorial/Foundations/PWM>. Accessed on: 20 Jul. 2021.

[4] Martins, D. C. Transistores de Potência. 1ª Ed. Florianópolis, 2018.

[5] CHENG, Yuhua; HU, Chenming. MOSFET MODELING & BSIM3 USER'S GUIDE. Springer Science & Business Media, 1999.