

Traction System for Electric Vehicles Using a Variable Frequency Three-Phase Induction Motor Driver with Regenerative Braking

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Abstract. This paper describes the development and implementation of a traction system, based in the utilization of a three-phase induction motor controlled by a Power Electronics Inverter, to be used in electric vehicles. This system allows the speed control of the vehicle, forwards and backwards, and also permits regenerative braking. The induction motor is fed, through the inverter, by a set of batteries. During the operation in the regenerative braking mode, the induction motor returns, through the inverter, the vehicle kinetic energy to the batteries.

Keywords. Electric vehicles, Three-Phase Induction Motor, Power Electronics Inverter, Speed Controller, Regenerative Braking.

1. Introduction

Fossil fuels become each time less abundant and expensive, and with the problems of worldwide pollution, they also become inadequate to be used in such a large scale. The automotive industry is one of the biggest spenders of this limited resource. This fact may be changed with the use of electronic propelling systems, such as the appliance of a three-phase induction motor driven by a controlled inverter, replacing the internal combustion engine.

Formerly, DC series motors were preferred for traction applications, as their drive systems are relatively simple. Nowadays, more precise digital algorithms, using microcontrollers, have been developed to control power inverters with the purpose of driving induction motors, which makes them a far better choice than DC motors.

Induction motors are considered a better choice because of their robustness, reliability and low price. The electronics involving the drive also makes them an efficient choice. The regenerative braking system, which allows delivering power back to the batteries while

braking, or even when vehicles go downhill, is also possible when using induction motors.

The use of a three-phase induction motor instead of a single-phase one is a choice that concerns to its superior torque characteristic and better power/weight relation.

The project in hand also includes monitoring capability in its features, which allows the continuous measurement of the motor speed value and direction, and the charging conditions of the batteries.

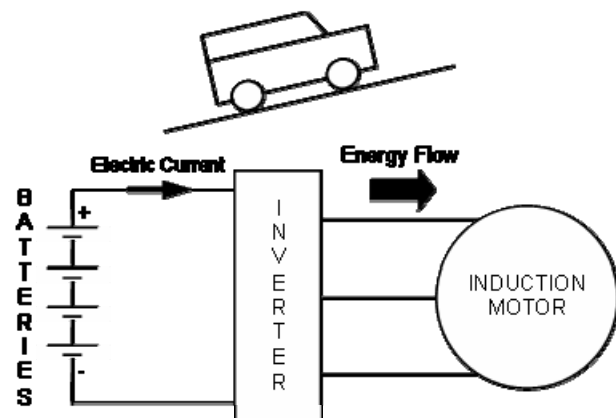


Figure 1. Vehicle in acceleration or keeping constant speed

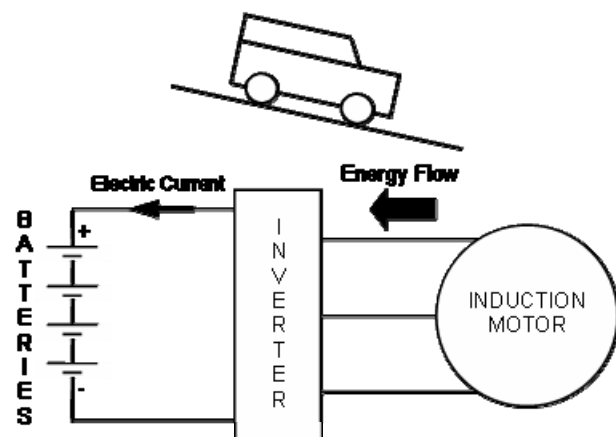


Figure 2. Vehicle braking or in downhill

When the vehicle is accelerating or maintaining speed, it requires power, which means that the batteries are feeding the motor (Figure 1). While braking, energy is being returned from the motor to the batteries (Figure 2). Because this energy flow can be very fast, the batteries may not be able to absorb all the energy, and so it is necessary to use an energy storage element capable of fast charging, such as capacitors or even ultracapacitors.

2. The Regenerative Braking System

The use of the vehicle inertia is the key to return energy back to the batteries, which would normally be wasted by producing heat in the brakes of the vehicle. This implies converting mechanical energy into electric energy.

The inverter that drives the induction motor allows it to operate in four quadrants of the torque (τ) versus rotational speed (n) graph, showed in Figure 3. In the first quadrant, with positive torque and speed, the motor is being fed by the batteries, and the vehicle moves forward. In the second quadrant, with negative torque and positive speed, the motor is decelerating (braking) and returning energy to the batteries. In the third quadrant, with negative torque and negative speed, the motor is again being fed by the batteries, but the vehicle moves backward. In the fourth quadrant, with positive torque and negative speed, the motor is decelerating (braking) and returning energy to the batteries when moving backward.

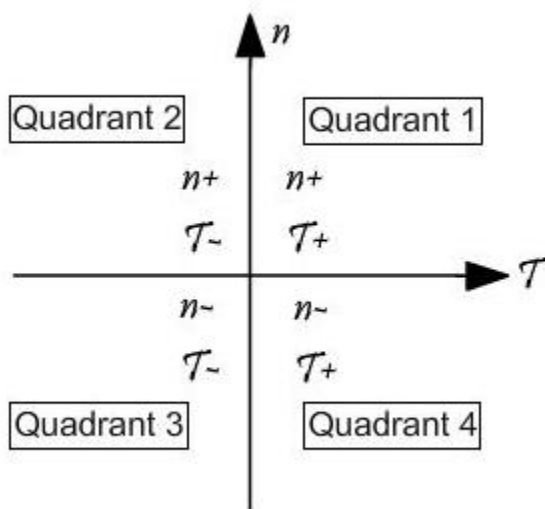


Figure 3. Four quadrants motor operation

3. Dynamic Braking

Besides the regenerative braking, the inverter has a dynamic braking system, which has the function of protecting the inverter, batteries and fast storage elements from transient over voltages that can happen when the vehicle is suddenly brake (when its speed is strongly decreased). This system consists of inserting a resistor in parallel with the DC side of the inverter, avoiding that the voltage rises to undesired values. The insertion of this resistance is controlled by a switching semiconductor, as shown in Figure 4. The idea behind the dynamic braking system is to dissipate the kinetic energy that comes from a sudden brake, and that can not be absorbed by the fast storage elements and the batteries (because it is concentrated in a very short period of time) in form of heat in the resistor. This system wastes the kinetic energy in the case of abrupt brakes, but is necessary for safety reasons.

The switching of the semiconductor that inserts the resistor in parallel with the DC side of the inverter is controlled by a chopper circuit (Figure 5). The chopper sets a reference voltage, so that, if exceeded, the switching semiconductor is activated in order to connect the resistor in parallel with DC side of the inverter.

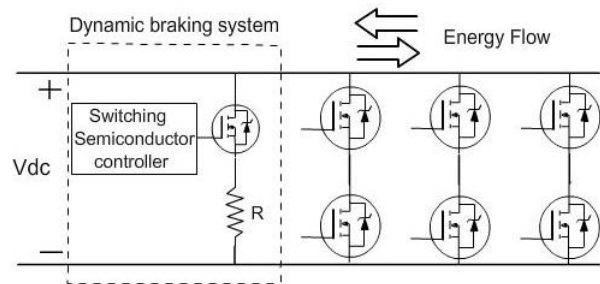


Figure 4. Inverter with dynamic braking system

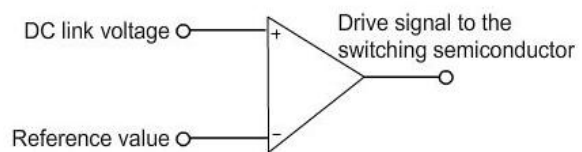


Figure 5. Chopper controller

4. The Controller

A three-phase induction motor has to be fed by three sine wave voltages phase shifted of 120 degrees in time. In order to drive and control the motor, a velocity/frequency function has to be considered. As higher the frequency of the sine waves, the faster the motor will run, and as higher the amplitude of the sine waves, the higher will the torque be. This kind of control is created through a microcontroller generating PWM signals which are applied to a three-phase inverter (Figure 6). The inverter produces three voltages that are applied to the three-phase induction motor, with waveforms whose fundamental components have sine wave shapes, shifted 120° from each other (Figure 7).

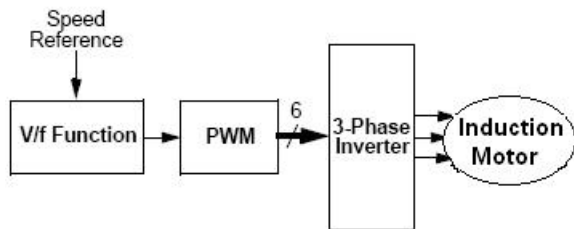


Figure 6. Developed system block diagram

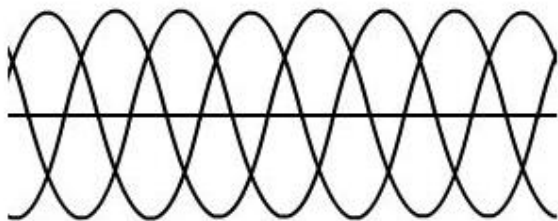


Figure 4. Three sine waves 120° shifted

The ability to change the frequency, amplitude and order of these sine waves, makes the controller able to change the speed and rotation direction of the motor, fitting this application to be used in a vehicle.

The motor magnetic field rotating speed (n_s - in *RPM*) can be calculated from the number of poles (p) of the motor, and the frequency of the voltages applied to the motor windings (f - in *Hz*). Its value is given by equation (1). The rotating speed of the rotor is slightly smaller than this value.

$$n_s = 120 \times \frac{f}{p} \quad (1)$$

5. Conclusions

This work intends to present a traction system prototype, which consists in a developed Power Electronics inverter with digital controller, designed to drive a three-phase induction motor, to be used in an electric vehicle. The inverter allows regenerative braking, in order to optimize the efficiency of the electric vehicle regarding its energy consumption.

6. Acknowledgements

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