

Study of the Electronic System and Inverter components in a Hybrid Vehicle

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Summary - The following paper presents the study and analysis of the different electronic components that are inside an Inverter System in a hybrid vehicle, and the explanation of its function using electronic simulators (softwares).

I. NOMENCLATURE

DC: Direct Current
 PZEV: Zero Partial Emission
 HV: Hybrid Vehicles
 MG: Motor-Generators
 ICE: Internal Combustion Engine
 IGBT: Insulated Gate Bipolar Transistor
 IPM: Intelligent Power Module
 LIVE WIRE: Live Wire Software
 PWM: Pulse Width Modulation

II. INTRODUCTION

Due to the need for reduction of vehicles' pollutant emissions and the high costs that conventional fuels have reached in recent times, alternative technologies have been implemented in many countries in these last years. These technologies can improve the conditions of vehicles' propulsion by reducing their pollutants [2].

Within the most innovative technologies are the hybrid vehicles (VH). This technology has succeeded in establishing very important emission reduction figures.

Hybrid technology is located in the PZEV level - Zero Partial Emissions Level; which means that the vehicle generates zero emissions in certain moments. When this technology is massively widespread, it will allow the operation of vehicles which will not generate emissions at certain times. This will reduce significantly the levels of contamination [1].

The important basis of a HV -Hybrid Vehicle- is given by an internal combustion engine working together or alternative with one (or two) electric motor. This motor can also be generator in some conditions and the entire system uses a high voltage battery to store electric charge [1].

This advanced technology allows the use, as well, of kinetic energy from braking to convert the electric motor into a generator and set the load of the high voltage battery.

Of course, this is made possible by the built-in electronics in the control unit of the system [1].

In the design of a hybrid car, the ICE - Internal combustion engine is the power source that is used as a last option; and has an electronic system to determine which motor to use and when to do it [1].

In some, it is possible to recover kinetic energy when braking, which tends to dissipate as heat in the brakes, turning it into electric energy. This type of brakes are called 'regenerative'.

This work proposes a study of the electronic components that are part of the inverter system, analyzing each of the functions fulfilled for the operation of electric motors and their control logic to achieve the efficiency of the hybrid system.

III. DEVELOPMENT OF THE PROYECT

The first step consists in analyzing each stage of operation of the inverter. For this purpose, a Toyota Prius vehicle is used. The objective: To proceed to disassemble the entire module and interpret each of the elements and the role they play in the system. Then, in an electronic simulator we will develop parts of the complete circuit of the inverter, in order to facilitate its study.

The development of the project is described in the following block diagram, in Figure 1.

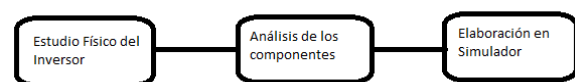


Figure 1. Complete System in Simulink.

Once expressed our point of scope within this project, we will proceed with each of the points previously mentioned.

IV. INVERTER FUNCTIONS

For the development of this point, a 2005 Prius vehicle is used - Figure 2. The investor is placed on the left hand side, in the compartment of the engine block of the vehicle.



Figure 2. Prius vehicle

The inverter complies with the following main functions:

- Raise the 220V voltage (approximately) at a voltage of 500 VDC (approximately); this is accomplished with a booster or amplifier circuit.
- With the 500 VDC voltage and using power electronics, generate a three phase alternating current to obtain the movement of MG1 and MG2 independently. The power amplifier is located inside the inverter, but the HV system control unit is in charge of its control.
- Allow to reverse the operation of MG1 and MG2, making them - at moments - turn into generators, and carrying this charge to the high voltage HV battery.
- Using the voltage of the high voltage HV battery, generate a three phase alternating current, which is able to move an electric motor that operates the compressor system for the air conditioning.
- Allow the 12V battery charge using the charge of the high voltage HV battery as a source. For this, a converter circuit DC – DC is used, incorporated in the same assembly (converter/inverter assembly unit). All the management is carried out by the electronic control unit of the HV System.

In addition to these main functions, the investor - Figure 3 – has other additional functions, as for example, temperature and flow measurements of the internal components in the system. These functions are always based on the monitoring of the HV ECU, to prevent any malfunction that may put the system at risk.



Figure 3. Inverter System

Once the use of the inverter is understood, we disassemble it to locate each component and proceed to perform different interpretations and verify the different electronic circuits.

V. ELEMENTS IN THE INVERTER SYSTEM

The inverter disassembly procedure is very simple. We raise all the screws that hold it by the base and at the moment of lifting it is recommended to use a clamp, to clog cooling pipes and avoid spilling. It is recommended to place it on a table to make the job easier. Figure 4.



Figure 4. Inverter System Disassembled

At the bottom section, it presents some ducts through which the coolant circulates.

This contributes to the cooling of the investor, as it is subject to voltages and high currents that tend to warm it up.

Figure 5



Figure 5. Coolant Conduction Ducts

When analyzing the internal part of the investor, we realize that the system is divided in two parts: One responsible for managing the motor-generators and the other that handles the AC electric motor of the air conditioning and the DC-DC converter. The first one contains a BOOSTER, which raises the 220 V from the battery up to a voltage of 500 V. And the second one that operates with a 220V voltage approximately. The Figure 6 shows a diagram from each of these parts:

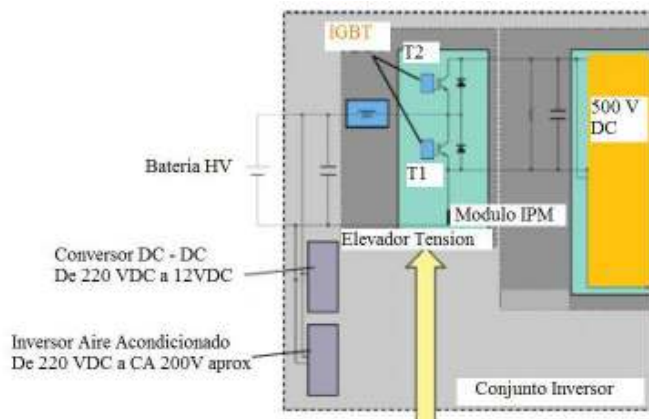


Figure 6. Stages of work of the Inverter

The voltage Booster is of utmost importance in the Inverter System. It is composed of a reactor and module called IPM – Intelligent Power Module. This module contains internally a couple of high power IGBT transistors, which are triggered very precisely to perform two specific functions. The first one: Create together with the reactor a SWITCHING source that raises the voltage. The second function: Allow the passage of voltage to the battery at the moment when the motor-generators are working as generators.

The IPM module and the reactor are important elements of power. At the 500 V outlet, this module has a RC circuit, Resistance-Condenser, which generates stability to the system and discharge the condenser when it is disconnected from the batteries. These are seen in Figure 7.



Figure 7. IPM Module and RC- Resistance and Condenser

This package has 3 condensers whose function is to store the high peaks of voltage and then, deliver this voltage, thereby maintaining a high value. Also, improve the ripple and make it more consistent. This voltage reaches values of 500 V approximately. In parallel to this package of coils, we found a discharge resistance equivalent to 63 K Ohm, which consists of several resistors of high values connected in parallel in order to achieve a better power dissipation in the condensers' discharge, when the system is disabled. Notice, that if it has a single resistor, the power that should dispel would be too high. Figure 8



Figure 8. Discharge Resistors

The reactor is a coil that is in series with the circuit, as it can be seen in Figure 9. All connections are linked with strong screws and at this point, there should be no resistance or voltage drops.

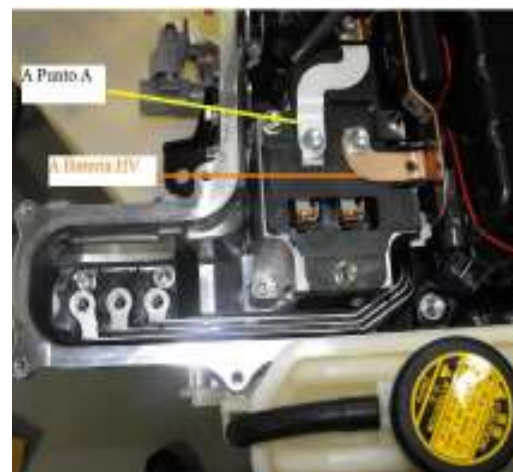


Figure 9. Coil or Reactor

VI. GENERATION OF ALTERNATING CURRENT

Each motor-generator MG1 and MG2 is a three phase AC electric motor. The connection of each one of them is star type, as in Figure 10. Detail of the operation of the three phase electric motor will be explained later. For this example, we are going to proceed on the basis that each one of these motors require three phases of alternating current that are 120 degrees out of phase in between, in relation to the rotation of the motor.

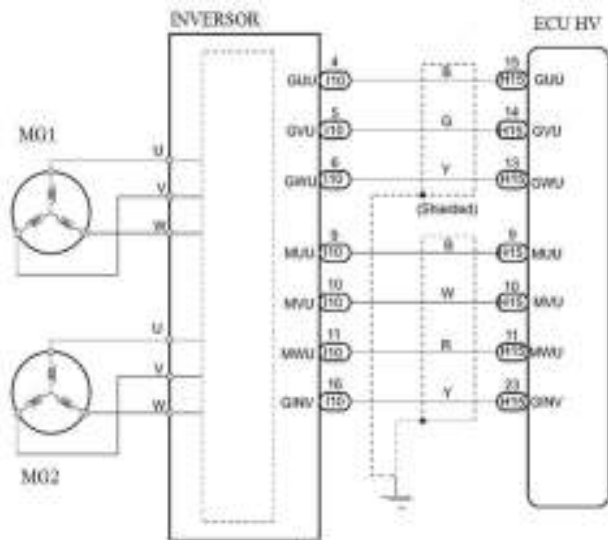


Figure 10. Motor-Generators Control System

According to the graphic in Figure 10, each of these phases – U, V and W – should be analyzed. In each one, there must be a current flow that changes direction with relationship with time. The entire strategy of generating this alternating current and dephasing it at the right time is managed by the HV ECU. Though, the power of this mechanism is given by the inverter that using some powerful IGBT transistors (Insulated Gate Bipolar Transistor) manages this complicated procedure. The circuit connection of each of these phases, with the inverter - specifically in the transistors area - can be seen in Figure 11.

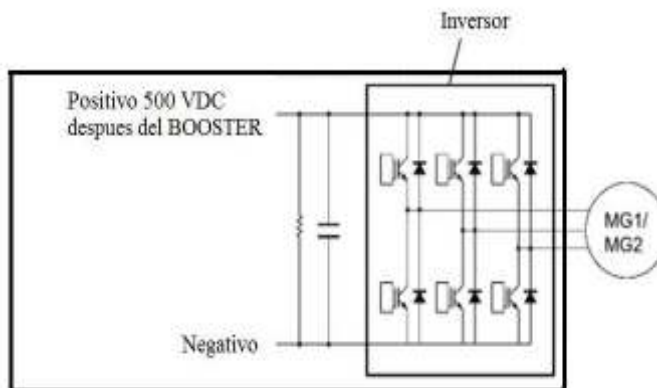


Figure 11. MG1 and MG2 Control

There are several parameters that the HV Module checks, such as, for example, the temperature of the MGs or inverter and the current they use. This data can be seen in the scanner. For this, the system incorporates innovative components which will allow us to evaluate these parameters. In Figure 12, the sensors that measure the internal current in the inverter circuit can be observed.



Figure 12. Current Sensors inside the Inverter

As a complement to the current measurement, the HV system can evaluate the internal temperature of the circuit or inverter or motors. In this case, in Figure 13 you can see one of these sensors, which can also be monitored in the scanner:



Figure 13. Temperature Sensor in the Inverter

VII. DEVELOPMENT OF CIRCUITS – FIRST STAGE

The first part to study consists on the work of the IPM and the way in which raises the voltage. In the first step, the HV ECU control unit activates the T1 IGBT transistor, charging the coil (Reactor) directly with the HV battery voltage. When the HV hybrid system control unit turns off the T1 transistor, it generates an auto induction in the reactor coil. This will produce an extra tension at point A. At this time, the 2 T2 transistor is disabled, and the 2 D2 diode is the only available path, which will be polarized with a positive voltage. In other words, only positive voltage will pass to the condenser; and

D1 will not allow the passage of this positive voltage to ground, due to it cannot be polarized. See Figure 14.

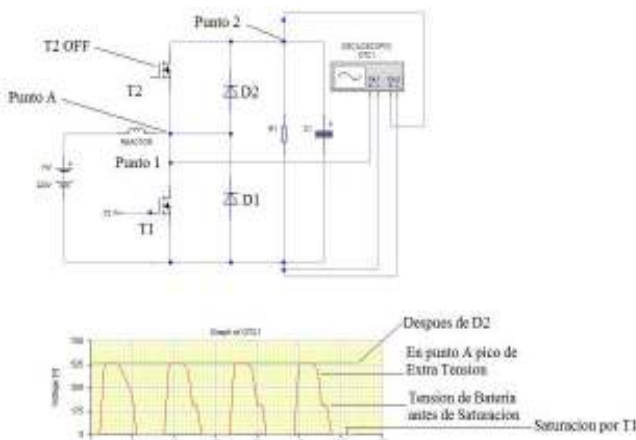


Figure 14. Voltage Booster Circuit Simulator

When additional extra voltage peaks pass through the diode, they reach the condensers' pack, and they help stabilize this voltage.

For the operation of the IPM – Intelligent Power Module, in the strategy of charging the battery, each of the phases of the motor-generators works in alternating current. This is generated by the inverter in Stage 2 - Figure 15 - and goes toward one of the motor-generators, when working as an electric motor. But at times, this is going to generate electrical power using the movement of the vehicle (Regenerative braking). At that moment, it will operate as a generator and in this case, MG1 or MG2 will be those to generate alternating current. This current must enter the battery as direct current. For that, it must go through Stage 2 and the IPM System.

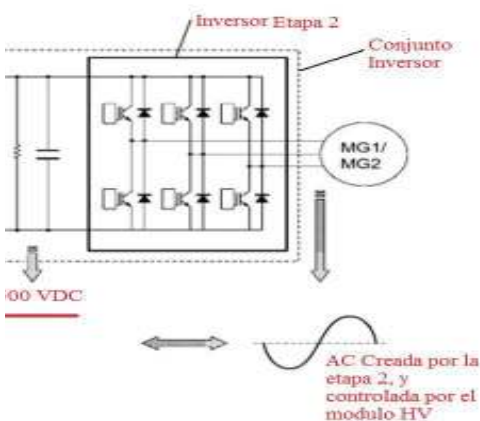


Figure 15. Regeneration of Energy Stage

In Figure 16, it can be appreciated how this mechanism works electrically, which is similar to that of a vehicular alternator.

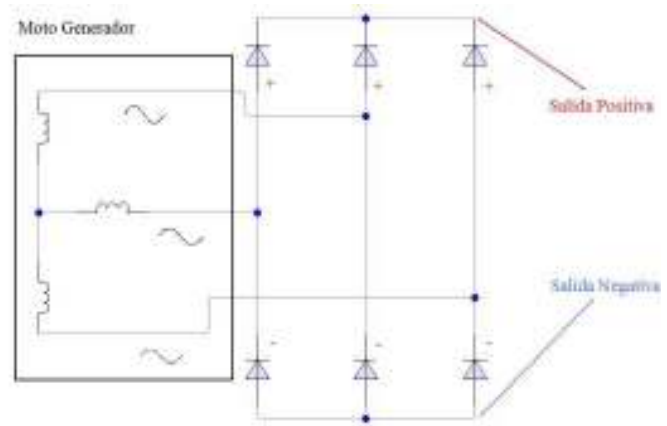


Figure 16. Operating Circuit to Recharge the Battery

Once it passes through this circuit, there is a positive and negative output of direct current, which is also stabilized, thanks to the condensers pack. It is interesting to observe the way in which this voltage will go through the HV battery.

As a first step, the incoming voltage must be greater than the one of the HV battery. Then, when this voltage arrives at the IPM, it will not pass directly, since the 2 Diode is not properly polarized. This is when the HV Control Unit System ceases to operate T1 - that controls the switched source - and allows the activation of T2; creating a step for the voltage that is located in Point 3 (Shown in the figure below). It must be remembered that the voltage at Point 3 is the product of the current generated by the MG – Motor-generators.

At that moment, the battery will start to receive charge, passing through the reactor which - due to its low resistance - will not generate a high voltage drop. Figure 17 shows the passage of the voltage through T2, shaded in orange.

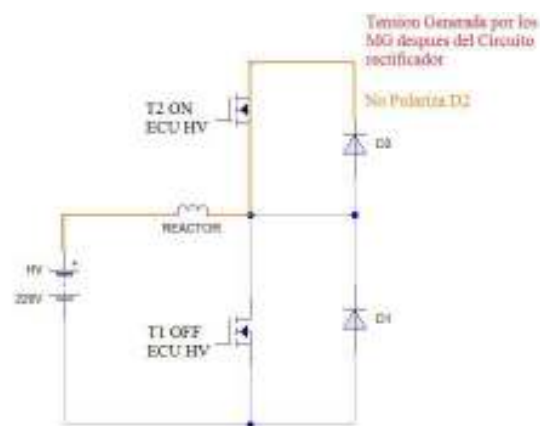


Figure 17. Battery Charging Circuit

VIII. MOTOR-GENERATORS ACTIVATION CIRCUIT

The three-phase electric motor (Motor- Generator MG) essentially consists of a rotor and a stator. Both parts are formed by a large number of ferromagnetic foils, which have slots, in which are housed the stator and rotor windings, respectively. By feeding the three-phase stator winding with a three-phase voltage system, it creates a rotating magnetic field, which induces an electromagnetic force in the coils of the rotor. All these coils form a closed circuit, and a current flow through them, forcing the rotor to rotate in the same direction as the rotating field of the stator [4]

For the activation of these motors and to represent the star configuration in three phases, DC motors will be used. In the Figure below, the transistors pack are shown and the connection of each motor phase. A demonstration on how to generate the reversal of the flow is shown in Figure 18.

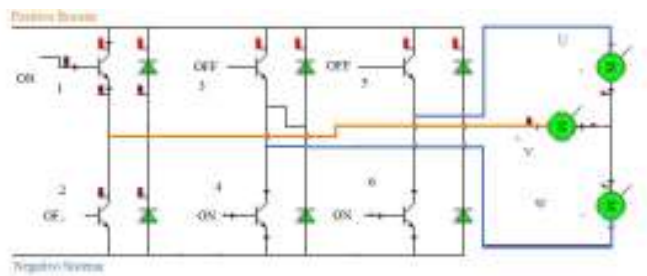


Figure 18. Three-Phase MG Control Circuit

In first place, Transistors # 1, 4 and 6 are going to be active. So, when Transistor # 1 becomes active it will commute positive; taking then through the manifold and going directly to the Phase V.

At the same time, it can be seen that when enabling Transistor # 4, Phase W is commuted negative. Also, Transistor # 6 is enabled and placed negative in Phase U. If you want to invert the current on the coils of the motors, it is necessary to activate transistors # 2, 3 and 5. And, in this way, when transistor # 2 is activated, it will commute Phase V to negative. The negative is taken by the issuer and commuted through the manifold.

When transistor # 3 is activated, this will turn Phase V into positive. The positive is taken by the manifold and is transferred to the Phase through the issuer. And at the moment when Transistor # 5 is activated, this one will commute Phase U into positive. This one will take it by the manifold and it will pass it to the phase through the issuer. The red lines on the chart represent "Positive" and the blue lines represent "Negative".

It can be observed that the polarities on the coils are reversed in both groups of activations. When polarities are reversed, a real inversion takes place in the current flowing through them, which gives an alternating current. The frequency of operation will be the rate at which the transistors will be triggered, and the features in the sequence of activation are the ones that will allow the gap of 120 degrees in the electric motor.

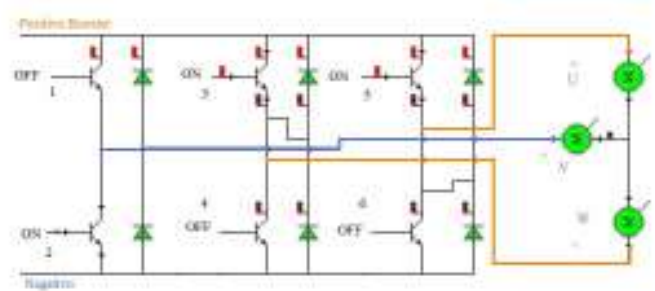


Figure 19. Commutation of the Three Phase Current

The entire strategy of operation is performed by the HV module but the power of the system is handled by the inverter, with the powerful IGBT transistors.

IX. ANALYSIS OF RESULTS

The first results presented are related with how the signals U, V and W were obtained. These signals command the activation of the motor-generators, using an oscilloscope. Figure 20.

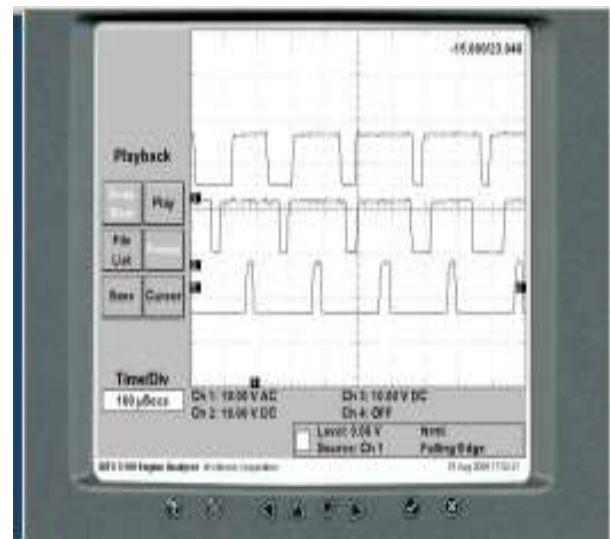


Figure 20. U, V and W Signals

Trigger signals from the 6 IGBT's are presented below. The ones shown above are formed from these signals.

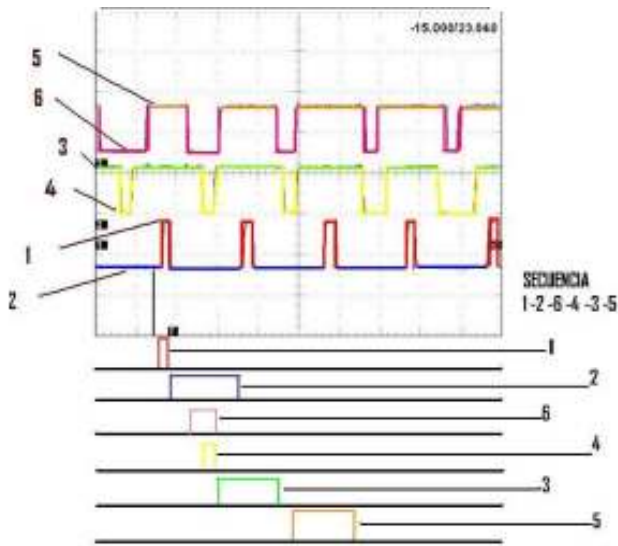


Figure 21. Trigger signals of IGBT's – Motor-Generators Control.

X. CONCLUSIONS

All the work developed was implemented under a simulation platform, whose results are expected to be verified with the construction and development of a prototype in the near future.

The results are as expected. The result of the research clearly illustrates the actual operation of the inverter, as well as the performance of each of its components.

For the control of electric motors, the technique that uses the HV control module system - for the command of the IGBTs - is by PWM - Pulse Width Modulation.

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