Three-phase inverter IGBT based for ACIM motor drives

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Work Reference: WED-2013-02

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Abstract

In this article we try to describe the control of an ACIM engine feed from the grid. To achieve it we have a rectifier, which lets us to storage in a bus the direct current gets from the conversion of alternating current. Then we add a three phase inverter, whose design is the main goal of the project. That device converts DC in the AC which will feed the motor. To reach this purpose it is necessary to choose one way of doing the control of the inverter, we pick out SPWM modulation, and we programmed it using the simulation program PSIM. Finally we have the engine, whose parameters where obtained from a real motor. Looking for more realism we have designed a voltage/ frequency starting control.

Besides there were another aspects to consider, such as the search of real components, it was the reason of doing the simulation, because thanks to that we realized that the three phase inverter module we have chosen was unable to bears the maximum current peak that requires the engine. We also had to consider the possibility of put a heat sink, and at the end we add one in the rectifier and another in the inverter, to avoid the destruction of both devices.

Keywords

Three-phase inverter, SPWM modulation, AC Induction Motor Drives

Student work for Power Electronics (academic year 2012 – 2013)

Introduction

The goal of the work is the control of a three-phase induction motor (ACIM) feed from the grid. To get our aim, we have thought about a first step composed by a non-controlled rectifier with a filter, followed by an inverter with IGBTs, and at the end, the motor.

We used a SPWM modulation to control the engine. It was made comparing two different waves, a sinusoid and a triangle one.

Triangle wave´s frequency is the IGBT´s frequency switching, in this case it is 5 kHz (The IGBT module used allows a maximum of 20 kHz, that information has been obtained from the datasheet).

The signal which is compared with the triangle one is a 50 Hz shine, that is the wave we want to obtain. Changing the amplitude modulation (m_a) we can get a different Duty Cycle and therefore a different Pulse-width modulation.

We have used a non-controlled rectifier with a LC filter that gives us a signal without current peaks and reduce the voltage ripple.

In the simulation we worked with an engine whose characteristics have been acquire from a real machine. In order to get more realism during the test.
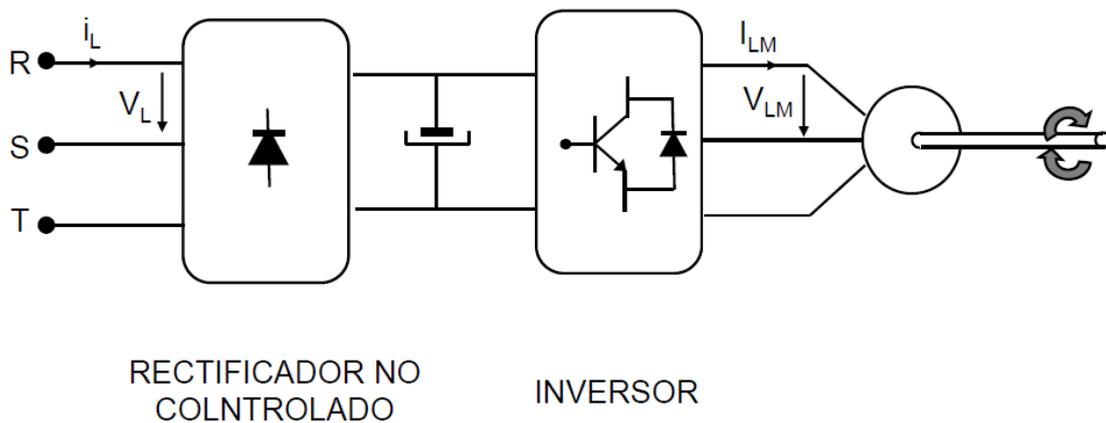

Fig.1. - Typical AC motor drive

The following picture represents the design we have developed for this article.
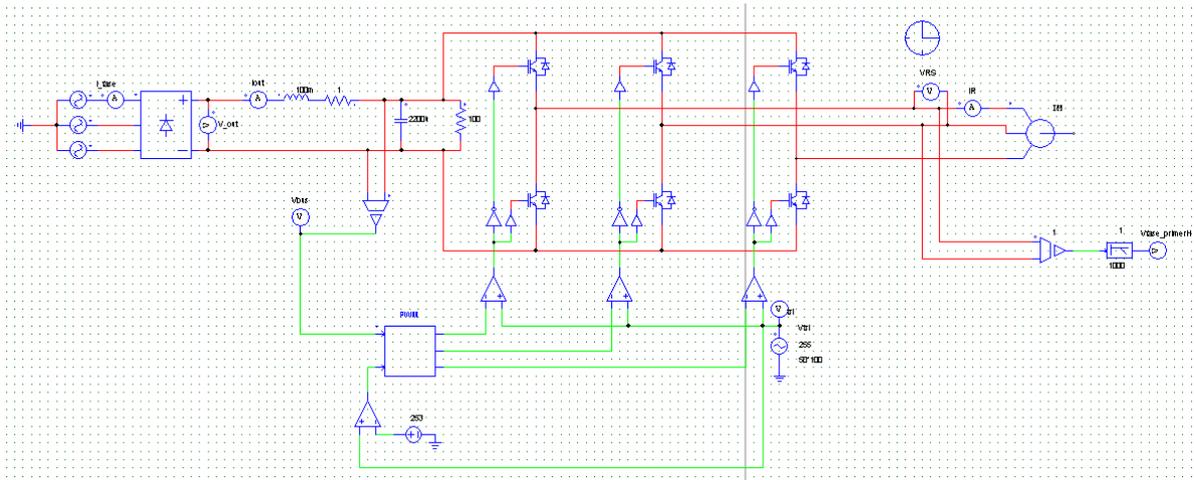
Fig. 2.- Simulation scheme for the proposed circuit.

SPWM Modulation

There are many different ways to control an engine (square wave modulation, space vector modulation...). We have chosen the SPWM one. That kind of control is based in the comparison between a variable shine and a fixed triangle signal. It lets us to get the SPWM, a wave whose width is changing in a way that the maximum width represents the maximum amplitude of the fundamental component, which is a shine as well. (Analogous for the least one).

 The case has a particularity, as we have three legs it is necessary to delay 120º the shines that are going to be compare.

It was developed in the program we have made in Cblock (an element of the simulation program PSIM that allows to program in C language).
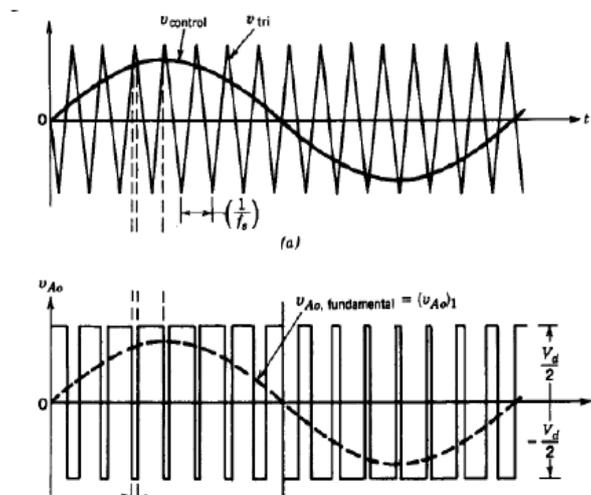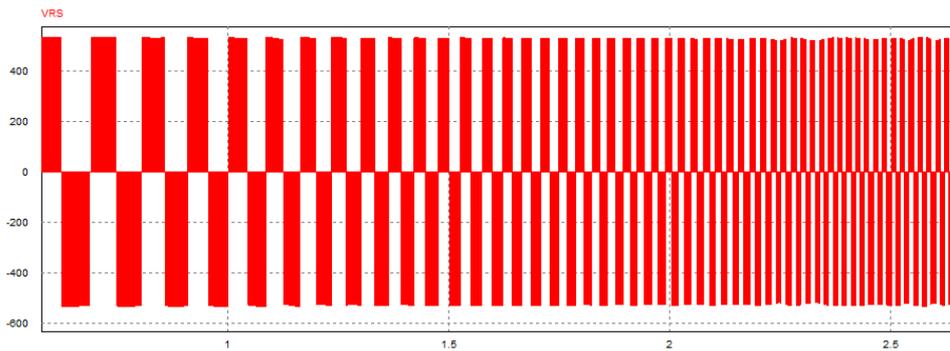

Fig.3- SPWM modulation
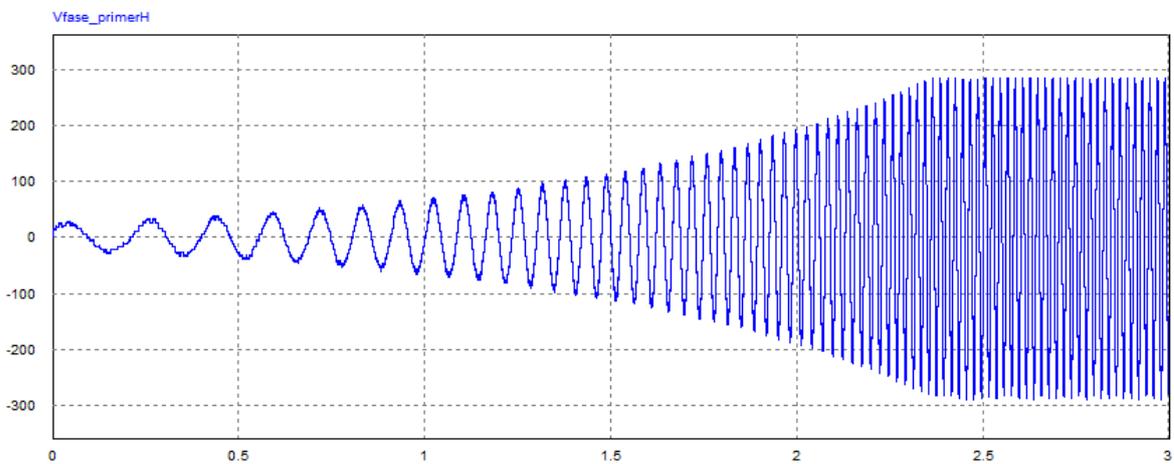
Fig.4- Simulation scheme of SPWM

Fig.5- Fundamental component

IGBTs from the same leg will be alternately switching, it means that when one of them is close the other is open. Regarding this fact, we must be careful because we might do a short circuit in the leg. To avoid it, we have to program in the PIC the dead times.
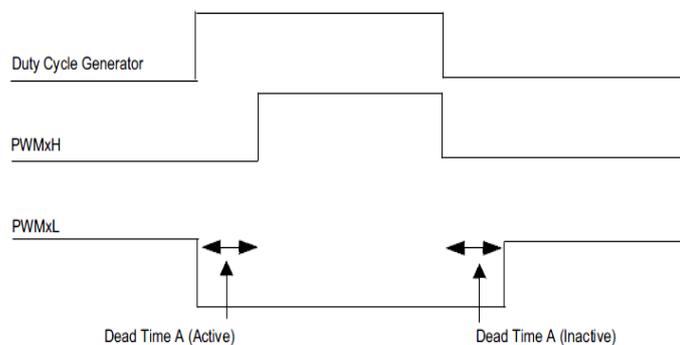

Fig.6- Dead-Time Timing diagram

Code Description

Thanks to the code we are able to program the SPWM modulation as well as the amplitude and frequency regulation. Moreover we have done a voltage/ frequency starting of the motor for the purpose of keeps approximately constant the flux density. What is the methodology used in industry.

Firstly, we read the input voltage of the bus (input 0)

> Vbus=in[0];

To avoid considering the voltage peak produced in the capacitor (which is not loaded initially) during the first moments, me have to set the next condition

> if (Vbus<400) Vbus=400;

After that we have :

> if (Vi>230) {Vi =230;}

We need it because this requirement provides us the security that the output voltage of the inverter will never be higher than 230 V_{rms}. (maximum established in the start control).

Variable Vi has been initialized to 20V (initial point of the start ramp) and it is increased 5 to 5 until reach 230 V. The voltage/frequency ratio is directly proportional and like the maximum frequency is 50 Hz we could say that:

> Fred=50*Vi/230;

If we have Fred is immediate to estimate Tred.

To represent shines we define a square wave (which is formed comparing a triangular signal with a level of continuous) in whose rising edges we draw.

As we have a triphasic system, these sinusoids are delay between them 120 grades. They have a 127 level of continuous and depending on the amplitude can reach the maximum level (255). That amplitude values have been chosen to bring this project to a possible implementation on an 8 bits microcontroller.

```
out[0]=nivel+A*sin(2*pi*t1/Tred );
out[1]=nivel+A*sin(2*pi*t1/Tred -(2*pi/3) );
out[2]=nivel+A*sin(2*pi*t1/Tred -( 4*pi/3));
```

Then we have:

```
t1=t-tini;
```

where "t1" is the time variable which has been used to draw the sinusoids. "t" is an internal variable of the program that increases in every execution cycle through a step chosen before when we launch the simulation. "tini" is the variable where we storage "t" value when the next condition is true:

```
if (t1>Tred)
      {t1=0;   tini=t,    Vi=Vi+delta_Vi; } ;
```

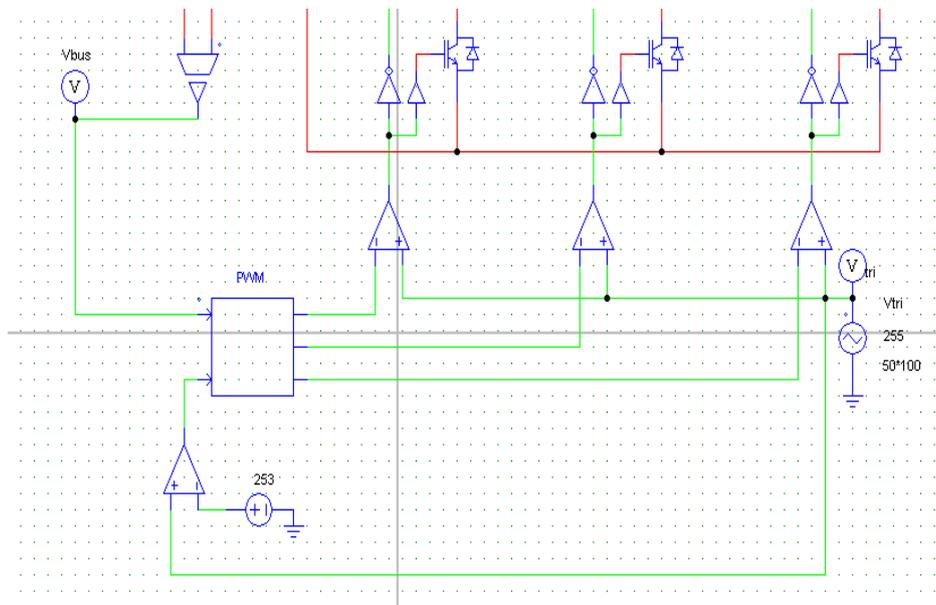By this way we can show shine waves whose frequency changes from one cycle to another.

Fig.7- CBlock module

Inverter

We used a three-phase inverter with IGBTs. It transforms the continuous current stored in the bus in alternate current (AC) for the induction motor. Thanks to the SPWM modulation we are able to obtain the desired output voltage:

$$V_{linea,rms} = \frac{\sqrt{3}}{2 \cdot \sqrt{2}} \cdot m_a \cdot V_{bus}$$
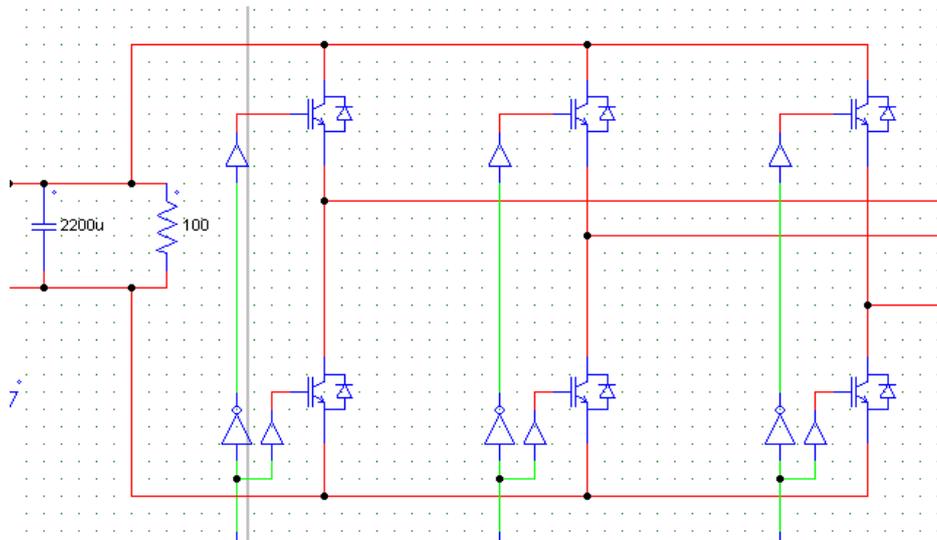
Fig.8- Simulation scheme for the Three-phase inverter
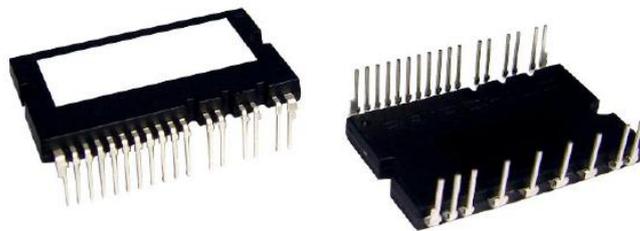
We chose FNB41560 Fairchild module
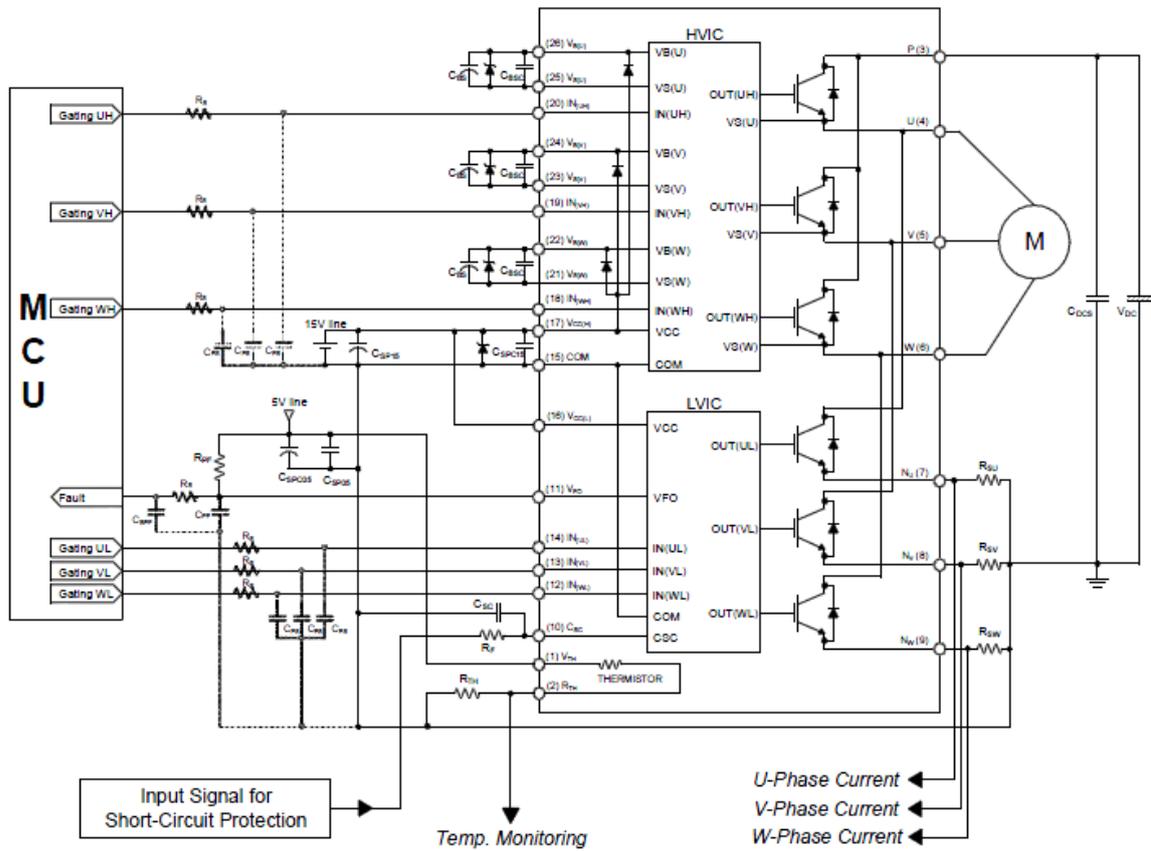

Fig.9- FNB41560

Fig.10- Internal Equivalent Circuit and Input/Output Pins

The module (FNB41560) is perfect for use the Bootstrap technique. It allows us to control the above IGBT in the branch which bears a floating voltage.

The circuit operation: while the IGBT2 is open, the other one is close so it causes that the capacitor loads quickly. With the switching, the voltage stored in the capacitor polarizes the superior circuit control drive that excites the IGBT1.
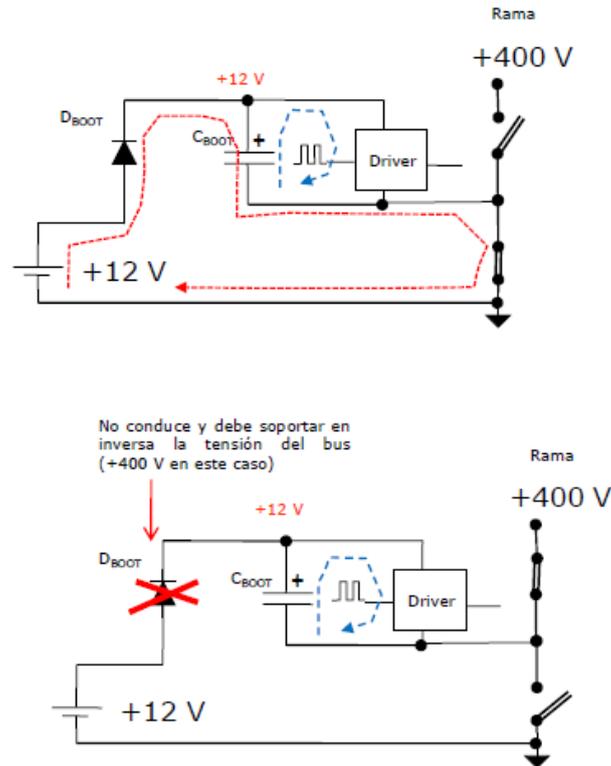
Fig.11- Bootstrap technique

We have chosen this device because the maximum voltage that we could have in the continuous bus is 538V.

$$V_{bus} = V_0 = \frac{3 \cdot \sqrt{3}}{\pi} \cdot V_m$$

$$V_{bus} = \frac{3 \cdot \sqrt{3}}{\pi} \cdot 230 \cdot \sqrt{2} = 538\ V$$

And this module bears as maximum 600V and 15A.

Rectifier

This model transforms in continous voltage the alternate voltage. Thanks to the employ of a LC filter we reduced the voltage ripple. Coordination between condenser and inductance permits obtains a square current without peaks.
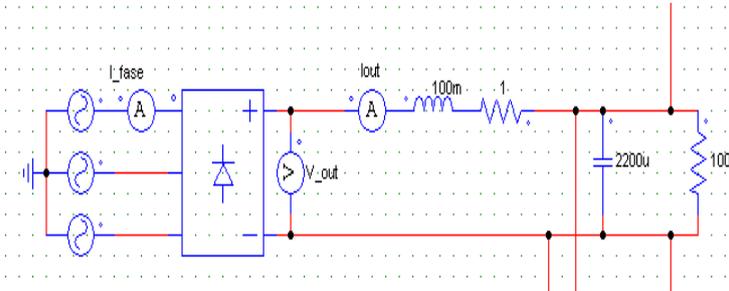

Fig. 12.- Rectifier simulation scheme

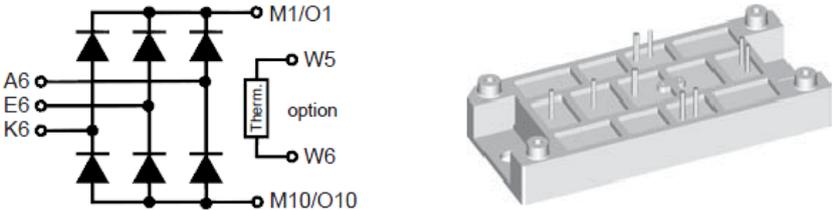The rectifier is a device produced by IXYS, model VUO 155.

Fig. 13.- VUO 155 rectifier

We consider the maximum isolation peak voltage and the maximum isolation peak current, they appear in datasheet related with the element capacity to bear overvoltage, which could be produced by a beam. However, with the VUO 155 the design has not problems with these parameters.
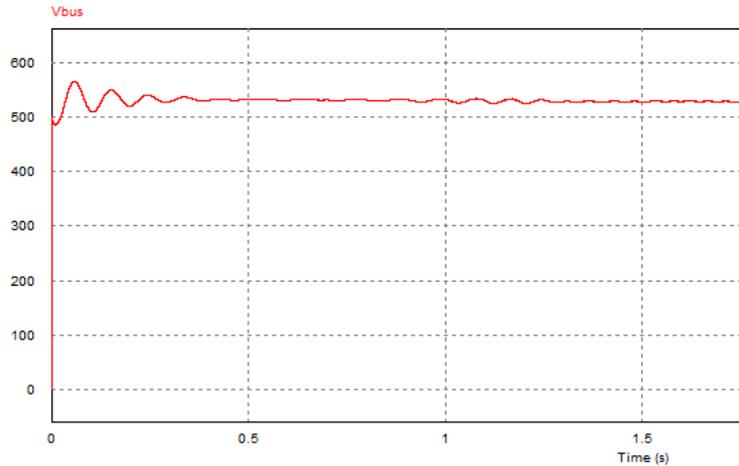
Fig. 14.- Bus voltage

Thermal design

An important point to considerer in any power electronic design is to evaluate the necessity of introduces a heat sink. Not pay attention to this vital part could mean the component destruction.

FNB 41560´s datasheet give us information about the maximum power that can dissipate (34W). Without heat sink the power could overtakes 103W. Comparing the technical characteristics we choose PE-16 (100mm long). The thermal resistance case to sink is 0,2ºC/W and thermal resistance sink to ambient is 0,8ºC/W. The maximum power dissipated by the components is 10W (IGBT) and 7W (bootstrap diode).

The maximum power that the rectifier module can dissipate is 190W, but without a heat sink it ascends to 938W. However, with the use of the same component (PE-16, 100mm) it is reduced to 21W.
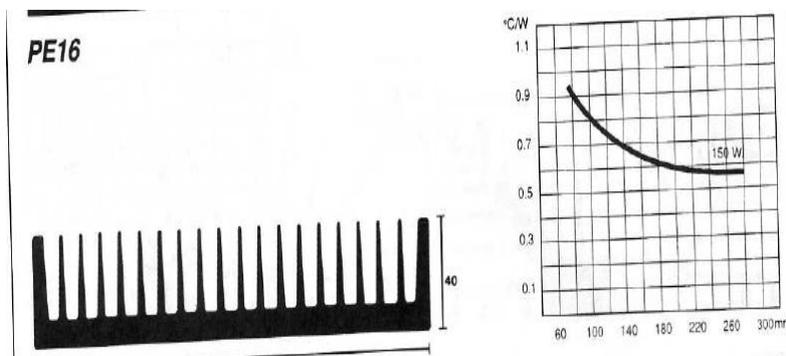

Fig. 15.- Heatsing used

AC Induction Motor (ACIM)

To simulate the motor we have chosen some parameters extracted of a real 7.5 kW motor. The voltage is 230/400V, frequency 50 Hz, 2 pair of poles and its circuit equivalent parameters:

P (kW)	7,5
Rs (Ω)	0,7384
Ls (H)	0,003045
Rr´(Ω)	0,7402
Lr´(H)	0,003045
Lm (H)	0,1241
J (kg.m^2)	0,0343
p	2
n (rpm)	1440

Fig. 16.- Heatsing used

We have done the following test with the motor to evaluate the correct operation.
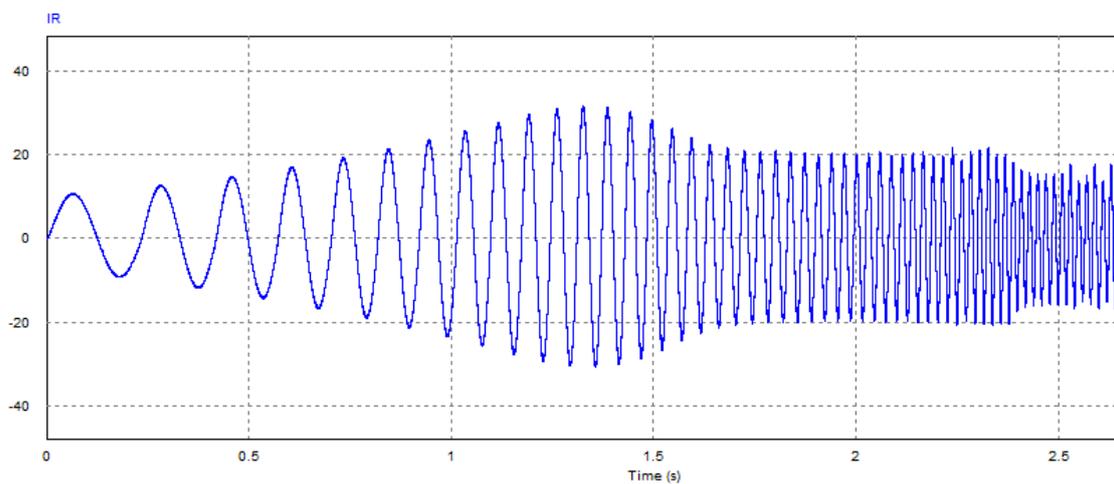
➢ Load: 20 Nm

Fig. 17.- Phase R current

As we can see in this picture, the IGBT three-phase inverter we have chosen (FNB41560) wouldn´t bear a peak current of 30 A (the maximun is 15A) So we have to change it.
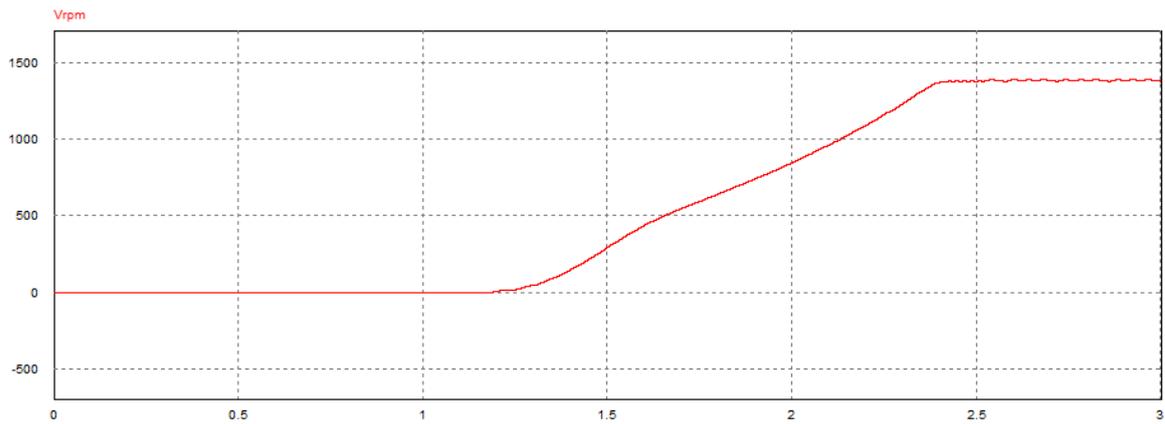
Fig. 18.- Engine speed (rpm)

Acknowledgements

References

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- Problemas de Electrónica de Potencia. Andrés Barrado Bautista, Antonio Lázaro Blanco
- Electrotécnia de Potencia. Ernst Hörnemann, Heinrich Hübscher, Dieter Jagla and others
- Wikipedia
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