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Current Control of the Single-Phase Full-Bridge Power Inverter

This paper shows the Matlab/Simulink implementation of the current control in a single phase full-bridge power inverter. In order to increase the performances of the power inverter an LC filter is connected at the input. Mathematical modelling of the power inverter is based on the switching functions. Unipolar asymmetric PWM modulation method, and hysteresis current control will be analyzed for a connected RL load to power inverter output. Simulation results based on the Matlab/Simulink® control implementation are shown.

Keywords: power inverter, Matlab Simulink, single-phase, asymmetric PWM, unipolar

1. Introduction

The single phase power inverter are widely spreading at low power [1]-[4] and they are used in backup power supply, household appliances, ac single phase motor control to convert the dc power obtained from the solar photovoltaic cells or fuel cells into the single phase ac voltage.

The objective of this paper is to obtain a complete Simulink implementation model of the single phase full bridge power inverter by using the mathematical model based on the switching functions, unipolar asymmetric PWM modulation, and hysteresis current control.

The switching functions are increasingly used for the mathematical modeling of the static power converters. In this paper the full bridge single-phase power inverter topology modeled using switching functions is shown. For each leg of the power inverter, the switching function is defined as follows:

$$f_c = \begin{cases} +1 \\ 0 \end{cases}.$$ (1)

The output voltage of the single phase power inverter (Fig.1) can be obtained by multiplying the input voltage with the appropriate switching functions for each leg:

$$\overline{u}_s = \overline{f}_c U_d \tag{2}$$

where $\overline{u}_s = \begin{bmatrix} u_{An} & u_{Bn} \end{bmatrix}^T$ represents the output voltage vector, $\overline{f}_c = \begin{bmatrix} f_{cA} & f_{cB} \end{bmatrix}$ vector of the switching functions of the power inverter.

The inverter input current can be expressed as:

$$i_i = \overline{f}_c \overline{i}_s, \tag{3}$$

where $\overline{i}_s = \begin{bmatrix} i_A & i_B \end{bmatrix}^T$ is the vector output current.

Input current is a reflection of the output current multiplied by the appropriate switching function.

In conclusion, it is possible to obtain the outputs signals (voltage, current) of the power inverter voltage by means of the switching function.

The following hypothesis have been used to mathematical modeling and simulation with switching functions of different kinds of the power converters: the ideal power semiconductor devices are considered, switching frequency and the conduction voltage drop are neglected; no power losses of the power inverter; the dead time is neglected; the DC link voltage has a constant value.

In order to outline the application of this theory in the simulation of the power converters a simple example is shown below. Based on the deducted mathematical model the corresponding block diagrams are defined by using Matlab/Simulink software environment.

2. Mathematical model of the single phase power inverter

This section presents the mathematical model and simulation block diagram of the single phase bridge power inverter (Fig.1). By using the two-level switching function (1) the output voltage of the power inverter can be obtained:

$$u_{An} = U_d \cdot f_{cA}$$
$$u_{Bn} = U_d \cdot f_{cB} \tag{4}$$

By using the same switching function, f_{cA}, f_{cB}, the input current i_i is determined accordingly:

$$i_i = i_A \cdot f_{cA} + i_B \cdot f_{cB} \tag{5}$$
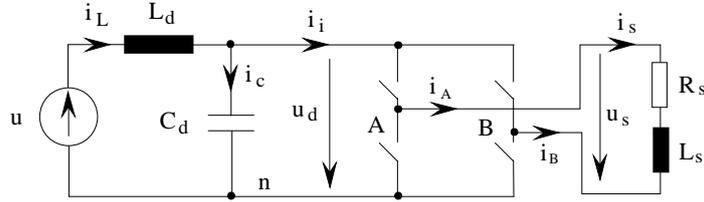
Figure 1. Single-phase full bridge power inverter [1].

The expressions of the RL load voltage and current are easily found by using the Kirchhoff laws applied to the existing power inverter topology (Fig.1):

$$u_s = u_{An} - u_{Bn} \text{,} \tag{6}$$

$$i_s = i_A \text{ and } i_s = -i_B \text{.} \tag{7}$$

By using the switching functions f_{cA} and f_{cB}, the load voltage is as following:

$$u_s = U_d \left(f_{cA} - f_{cB} \right). \tag{8}$$

By using eqs. (5) and (7) the input current of the power inverter is found:

$$i_i = i_s \left(f_{cA} - f_{cB} \right) \tag{9}$$

The mathematical model of the RL input filter

By knowing the input DC voltage u and the parameters of the RL filter the adequate output signals are determined:

$$i_L = \frac{1}{L_d} \int_0^T \left[u - U_d(t) \right] dt \text{,} \tag{10}$$

the filter current,

$$i_C = i_L - i_i \text{,} \tag{11}$$

the DC capacitor current, and:

$$U_d(t) = \frac{1}{C_d} \int_0^T i_c(t) dt \text{,} \tag{12}$$

the voltage across the DC capacitor.

The mathematical model of the single-phase power inverter with RL input filter

Taking into account the RL load, the load voltage is obtained as follows:

$$u_s = R_s i_s + L_s \frac{di_s}{dt} \tag{13}$$

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In order to obtain the mathematical model of the series input filter and the single-phase power inverter, the eqs. (6) and (9) have been added to the above equations (10-12).

In Fig.2 by using the Laplace transform of the equations (10-12), the structural block diagram of the RC input filter is shown.
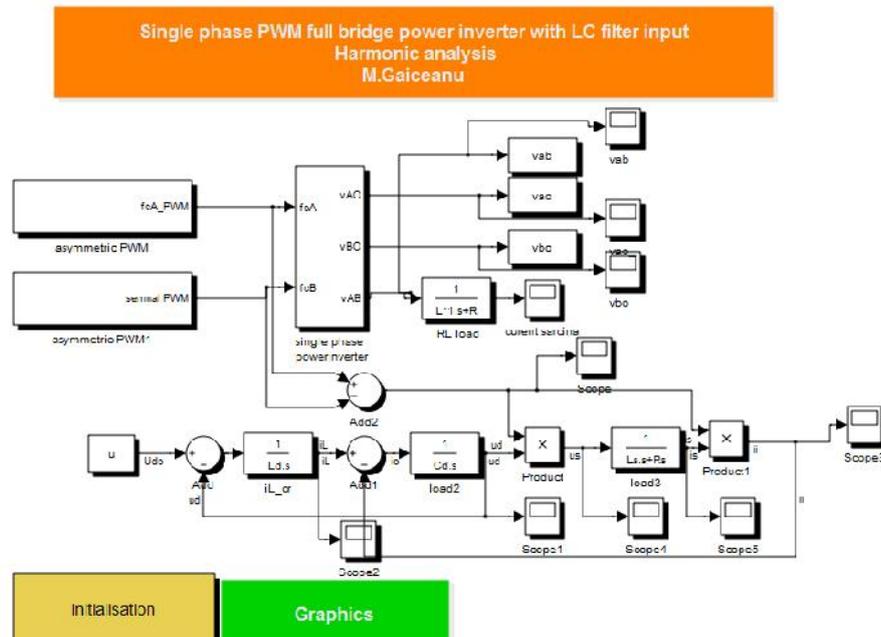
Figure 2. Matlab/Simulink implementation of the single phase PWM full bridge power inverter with LC input filter.

In the Fig.2 the implemented Simulink model of the unipolar asymmetric modulation PWM single phase full bridge power inverter is shown.

In the following Section the asymmetric PWM block (from Fig.2) is explained. The outputs of the asymmetric PWM and PWM1 blocks are the switching functions f_{cA} and f_{cB}.

3. Unipolar asymmetric Pulse Width Modulation

The switching frequency of the unipolar PWM modulation is double of the bipolar PWM well-known method and the voltage across the active power semiconductors is reduced to half compared with the voltage in the PWM bipolar modulation case.
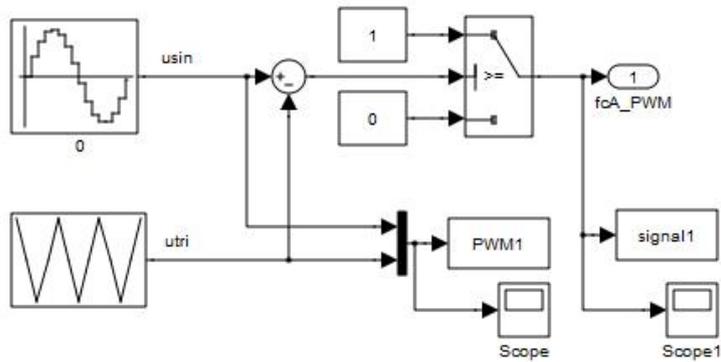
Figure 3. Asymmetric PWM Simulink block in order to generate the switching function f_{cA}.

By including a 90 degree phase delay to the sinusoidal PWM control signal, and a sampling time of 0.001s the second switching function is delivered f_{cB}.

In order to obtain the sinusoidal reference for asymmetric PWM modulation method and the triunghiular carrier voltage the following Simulink functions have been set (parameter Rf=10):
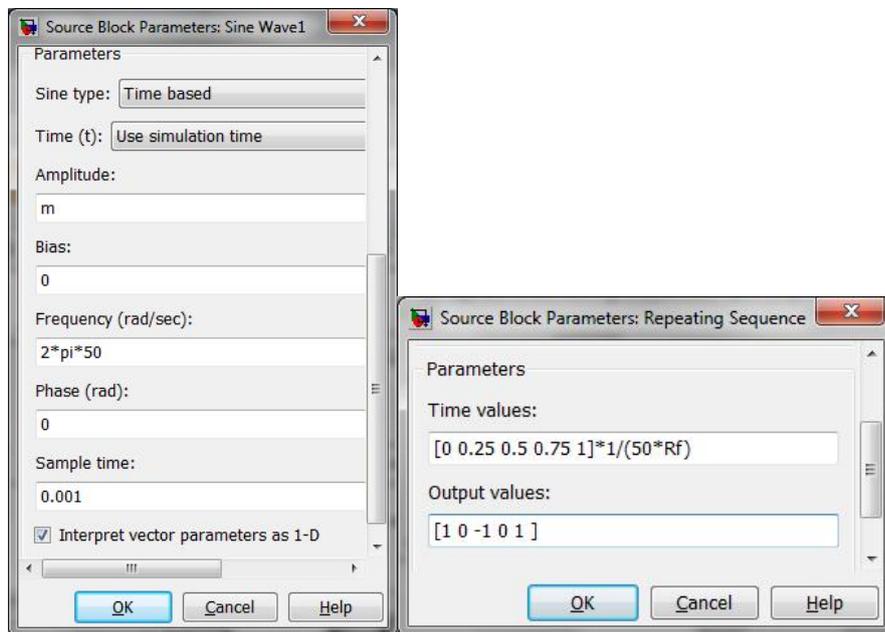
Figure 4. Sinusoidal reference(usin) and Repeating table(utri).
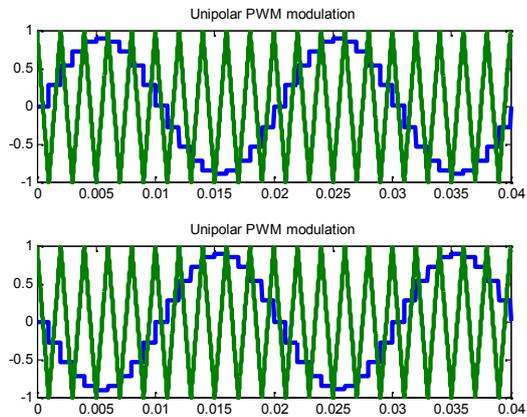
Figure 5. a. b. (from top to bottom): Matlab/Simulink simulation results of the unipolar asymmetric sinusoidal PWM modulation.

The two level unipolar SPWM is formed by two sinusoidal reference waveform with the same magnitude and reference frequency, one of them being the reference phase (Fig.5a) and the other is out of phase by 180 degree (Fig.5b), having the same triangular carrier signal. The asymmetric sampled PWM consists of sampling the reference signal at both peaks of the triangular carrier, resulting in a double switching frequency compared with the symmetrical sampled PWM modulation method (Fig.5).

4. Hysteresis Current control

On the one leg of the bridge power inverter is setting a current reference i_A^* (Fig.6). The real current is varying around the reference current according to the imposed hysteresis width band (Fig.9). Control circuit of the load current i_A is as following (Fig.6):
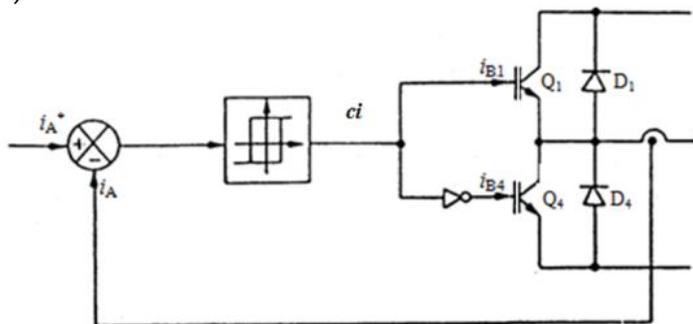
Figure 6. The principle of the hysteresis current control.

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The Matlab/Simulink implementation of the hysteresis current control is shown in the Fig.7 and it consists of the closed current loop control having as input the current reference and the output the actual load current. By comparing the reference with the feedback current the resulted current error is minimised through the hysteresis regulator. At the bottom of the Fig.7 the detailed LC filter connected to the RL load is shown.
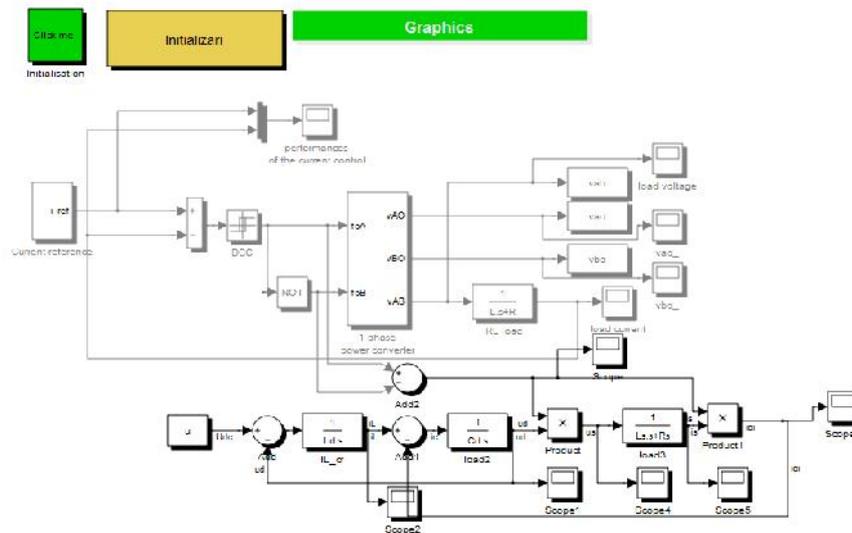
Figure 7. Matlab/Simulink implementation of the hysteresis current control of the single-phase full bridge asymmetric sampled unipolar PWM modulation with LC filter input.

In the fig.8 the Matlab/Simulink implementation of the 1phase power converter block from Fig. 7 is shown.
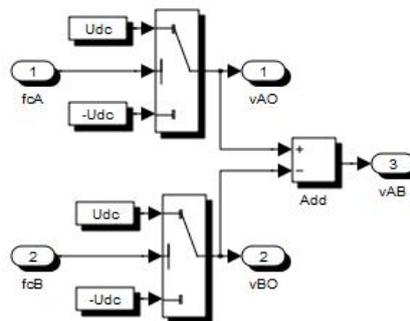
Figure 8. Matlab/Simulink implementation of the single-phase power inverter.

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The results are the modulated 2 levels PWM phase voltage vAO, vBO. Taken into consideration that vAO=u_{An} and vBO=u_{Bn} (according to the Figures 2 and 8) by using eq. 6 the load voltage u_{AB} is obtained.

The hysteresis regulator compare actual current i_A with the imposed reference i_A^*. Depending on the sign of the error and hysteresis band the commutation of the bi-positional regulator is determined by the conditions:

$$c = \begin{cases} 1 \rightarrow 0, & i = i^* + BH \\ 0 \rightarrow 1, & i = i^* - BH \end{cases}$$

(14)

The controller output $c \cdot i$ (Fig.6) will provide the adequate switching states for the switching power devices Q1 and Q4 (running in an opposite phase).
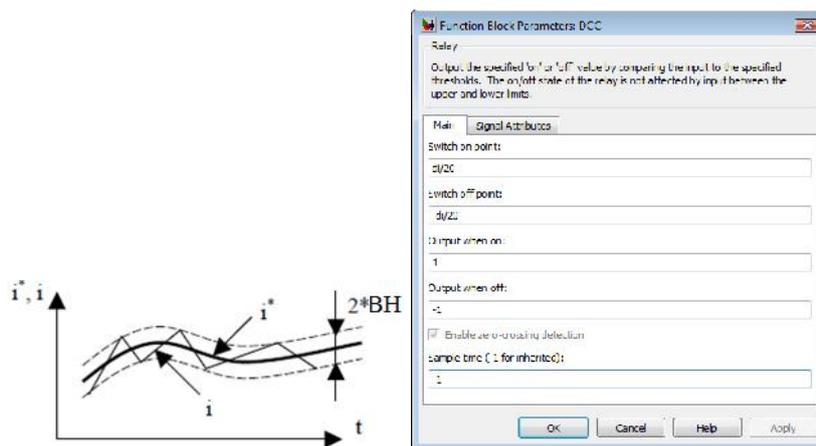
Figure 9. From left to the right: Hysteresis current regulator principle, Simulink mask of the DCC (di=3) block from Fig. 7.

5. Simulation results

The asymmetric sampled, unipolar PWM modulation has been implemented for a single phase full bridge power inverter with fixed DC link voltage input of Udc=350V connected through an input filter: Ld=0.007H, Cd=1000e-6 F to an inductive RL load: Ls=0.03 H; Rs=50 Ω; sample time tA=0.001s,the amplitude modulation factor m=0.9 and frequency modulation factor mf=20, hysteresis bandwidth (di parameter from Fig.9) 2BH=0.15, inductive load.

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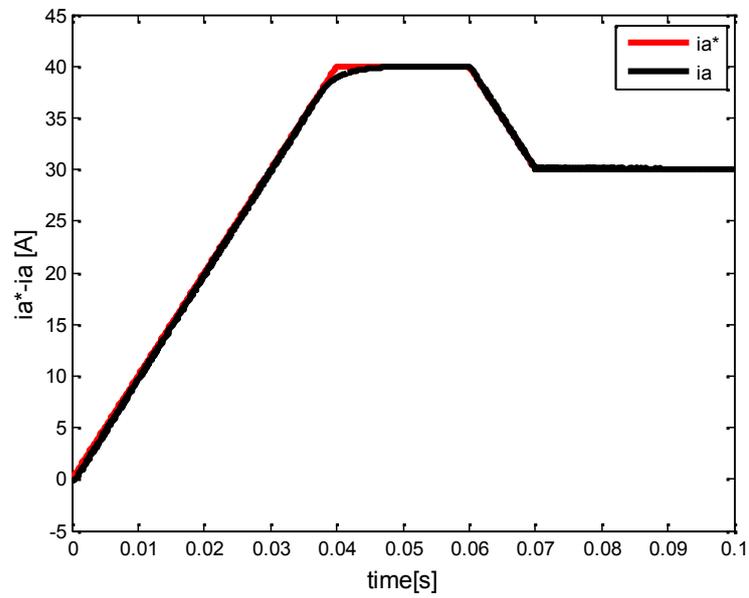
Figure 10. Load Current control: The reference and the actual load currents.

In the Fig. 10 the load current control is shown, the reference current is tracked by the actual load current.
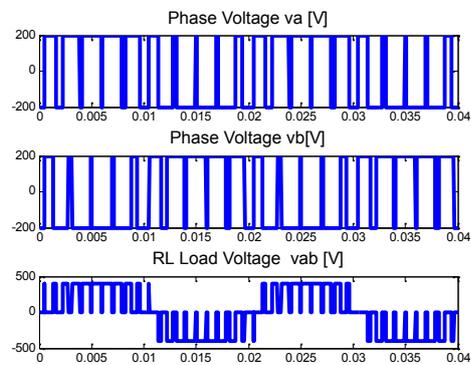
Figure 11. From top to bottom:The v_a potential, the v_b potential, the v_{ab} load voltage.

In the Fig. 12 harmonic analysis results of the single phase power inverter are shown.
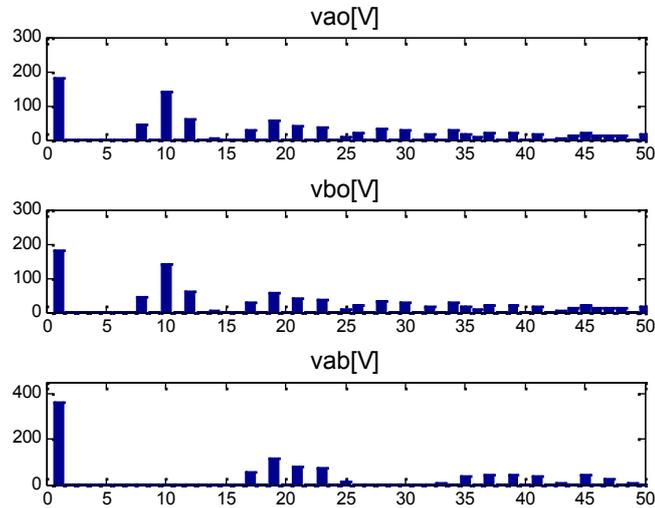
Figure 12. The harmonic spectrum of the v_{ao}, v_{bo} and v_{ab} voltages.

Conclusions

The Matlab/Simulink implementation method of the full bridge single phase power inverter with the intermediate LC filter is shown in the paper. Complete methodology of the Simulink implementation for power inverter, based on the switching functions, is provided. By using the unipolar asymmetric PWM modulation the advantages of doubling the switching frequency is taken. Moreover, the lower harmonic distortion is obtained and the half of the DC voltage is applied on the power semiconductors dispositives, comparative to bipolar symmetric PWM modulation [5]. As a control strategy, the hysteresis current control is chosen. The actual load current follows appropriately the reference current (Fig.10). Detailed Simulink files and the harmonic analysis based on the Matlab software files are provided.

Appendices:

A) Harmonic Analysis
    The armonica.m Matlab Function has been built:

```
function armonica(x)
N=length(x);
arm=2/N*abs(fft(x));
figure (1)
```

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```
Y=arm(2:N/2);
h=1:1:(N/2)-1;
bar(h,Y)
```

B) The graphic file:

```
figure(1)
subplot(3,1,1); armonica(vao); axis([0 50 0 300]); title('vao[V]','FontSize',13)
subplot(3,1,2); armonica (vbo); axis([0 50 0 300]); title('vbo[V]','FontSize',13)
subplot(3,1,3); armonica (vab); axis([0 50 0 450]);title('vab[V]','FontSize',13)

figure(2)
plot(vab(:,1),vab(:,2),'LineWidth',3)
title('three level PWM load voltage','LineWidth',13)
figure(3)
subplot(2,1,2)
plot(pwm(:,1),pwm(:,2),pwm(:,1),pwm(:,3),'LineWidth',3)
title('Unipolar PWM modulation')
subplot(2,1,1)
plot(pwm1(:,1),pwm1(:,2),pwm1(:,1),pwm1(:,3),'LineWidth',3)
title('Unipolar PWM modulation')
figure(4)
plot(signal1(:,1),signal1(:,2),'LineWidth',3)
title('PWM signal')
figure(5)
subplot(3,1,1);plot(vao(:,1),vao(:,2),'LineWidth',3);title('Phase Voltage va
[V]','FontSize',13)
subplot(3,1,2);plot(vbo(:,1),vbo(:,2),'LineWidth',3);title('Phase Voltage
vb[V]','FontSize',13)
subplot(3,1,3);plot(vab(:,1),vab(:,2),'LineWidth',3);title('RL Load Voltage  vab
[V]','FontSize',13)
```

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