University Mohamed Boudiaf of M'sila

Faculty of Technology
Department of Electrical Engineering
Academic Masters: CE+RE
Lab: Advanced power electronics

Lab: N° 03

Single phase PWM rectifier

1. Lab objectives

The core idea of this lab is the study and simulation of a single-phase grid-connected PWM rectifier.

2. Advantages

PWM rectifiers are bidirectional power flow devices allowing to generate less harmonic currents, and to control the power factor on the grid side.

3. Theoretical study

- Structure of the single-phase rectifier

Figure (1) describes the structure of the single-phase PWM rectifier. The converter is powered by a AC current source and feeds a DC load.

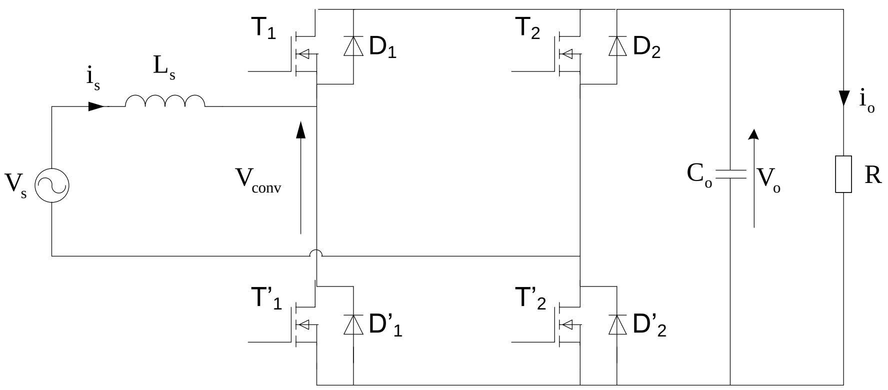

Figure (1): Structure of the single-phase PWM rectifier

- <u>Control strategy: sinusoidal PWM</u>

The control signals of T_1 and T_1' are complementary; the same for those of T_2 and T_2'. The control instants of the switches result from the comparison of a high frequency triangular carrier with a sinusoidal reference voltage v_{ref}.

<u>- Required theoretical task</u>

- Represent the phasor (Fresnel) diagram of the grid side fundamental quantities under the condition of unit power factor operation,

- Show that the PWM rectifier necessarily steps up the input voltage,

- Propose a sizing method of the line inductance as well as the output capacitor,

- Study the PWM rectifier when operating as:

- a reactive energy compensator,
- a parallel active filter.

<u>4. Simulation of the PWM rectifier</u>

<u>- Simulation scheme</u>

The PWM rectifier is connected to a single phase grid with a frequency of 50 Hz and an RMS value of 230 V. The converter is connected in its DC side to a resistive load of 8 kW. The line inductance is rated at $L_s = 2mH$. The filtering capacity is set to $C_o = 47mF$ with an initial value of 400V. Figures (2,3,4) give an idea about the simulation of the converter in the SimPowerSystems environment.

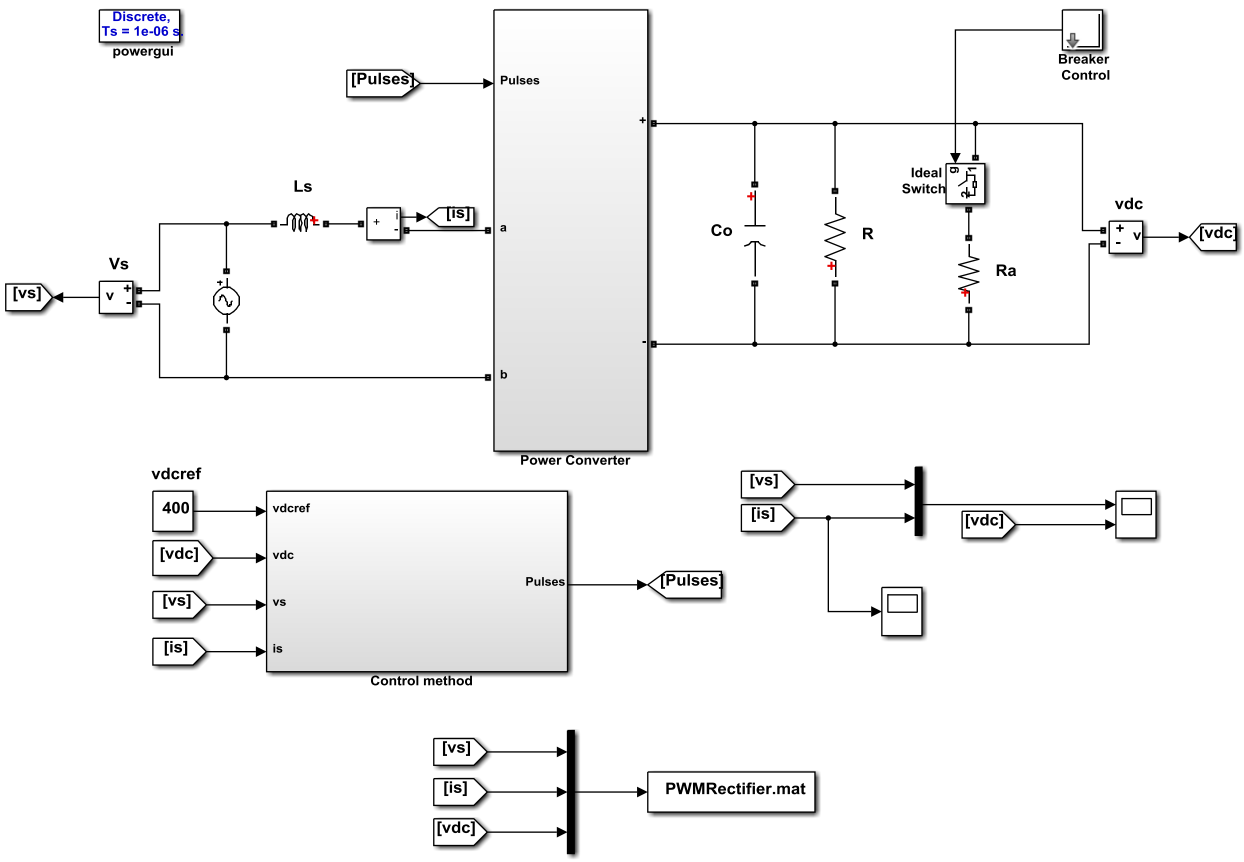

Figure (2): Simulation diagram of a single-phase PWM rectifier

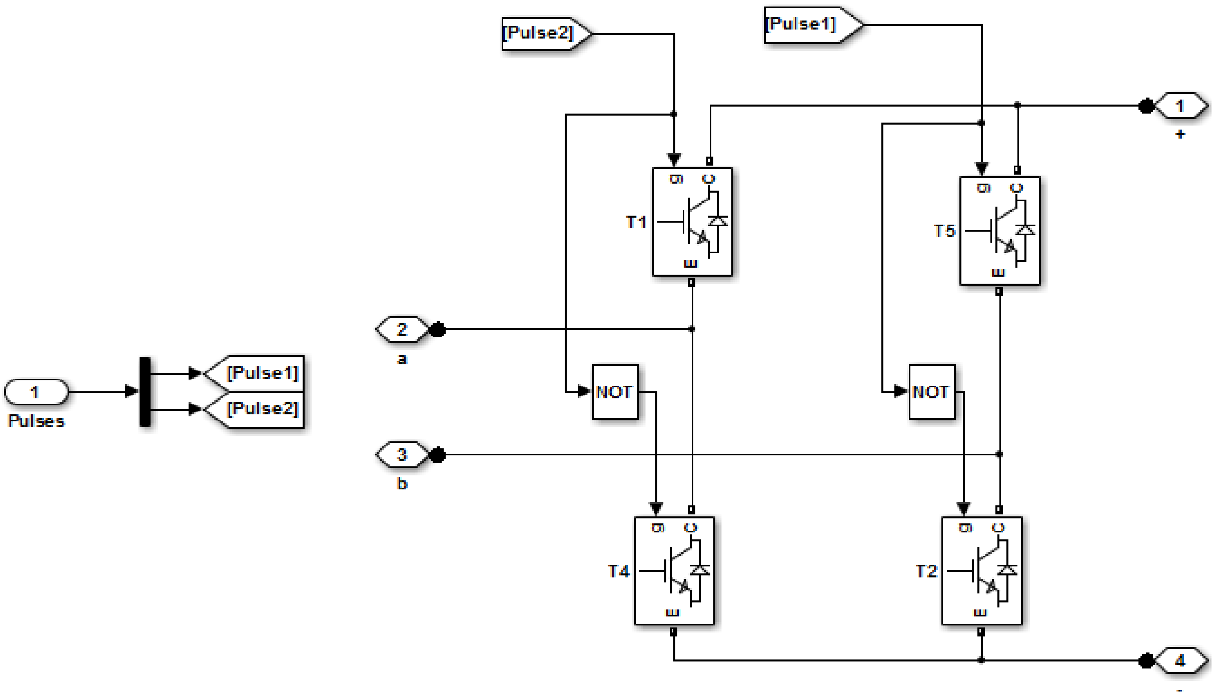

Figure (3): Power circuit of the single-phase PWM rectifier

- PWM rectifier control

The objective of the control is to keep the DC bus voltage constant, while having a sinusoidal line current and a power factor close to unity. This last condition requires that the current reference be in phase with the grid voltage. Two control loops are necessary to ensure proper operation of the rectifier. The internal loop is for current control, while the DC voltage must be controlled by an external loop. Figure (4) illustrates the regulation scheme comprising a PI regulator for the voltage loop and a proportional regulator (P) for the current loop.

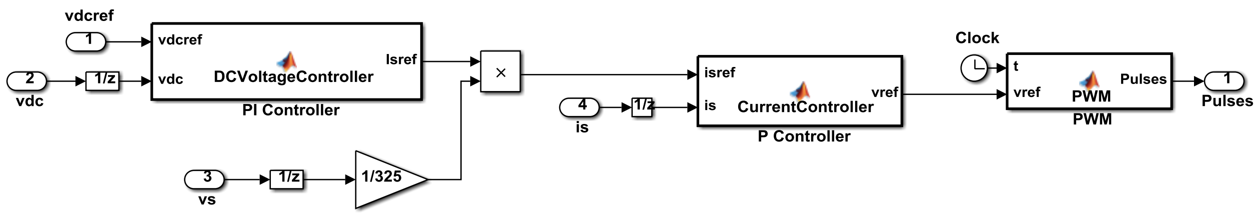

Figure (4): Control scheme of the single-phase PWM rectifier

The different Matlab Functions are defined as follows:

```
function Isref = DCVoltageController(vdcref,vdc)
%#codegen
% DC voltage PI regulator

 % Parameters
kpv=2.5;
kiv=10;
Tsv=1e-5;

% Inputs

%vdcref: DC voltage reference
%vdc: DC voltage

% Error calculation

evdc=vdcref-vdc;

% Calculation of the error integral noted int_evdc

persistent int_evdc
if isempty(int_evdc)
int_evdc=0;
end

int_evdc=int_evdc+Tsv*evdc;

% PI regulator output
```

```
Isref=kpv*evdc+kiv*int_evdc;

function vref = CurrentController(isref,is)
%#codegen
% Line current Proportional regulator

kpi=80;

% Inputs

% isref: Line current reference
% is: Line current

% Proportional regulator

ei=isref-is;

% Output

vref=kpi*ei;

function Pulses = PWM(t,vref)
%#codegen
% SPWM technique

Vpm=200;
fp=5000;

% Input

% vref: Reference voltage

% Bipolaire triangular carrier

 vp=Vpm*asin(sin(2*pi*fp*t))*2/pi;

% Pulses generation

if vref >= vp, S=1; else S=0; end;

Sp=1-S;

% Outputs

Pulses=[S,Sp];
```

Saving and plotting results

The simulation results are saved in a ".mat" file as shown in figure (5).

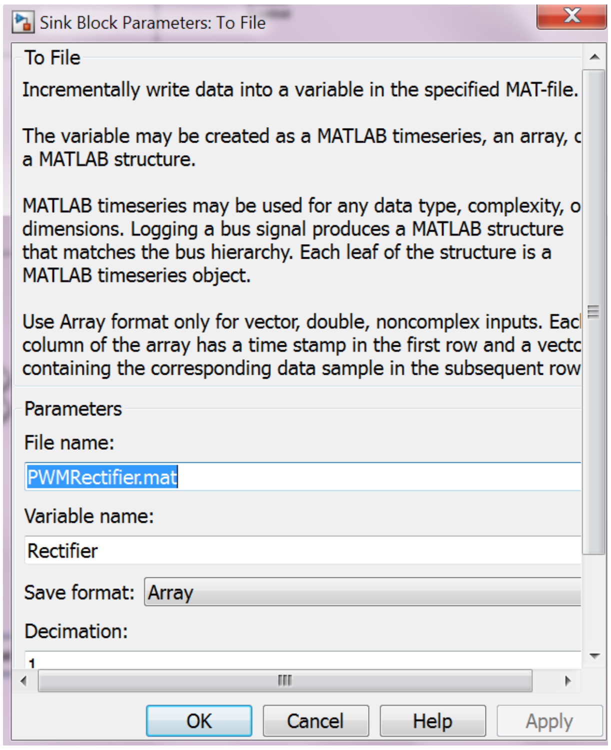

Figure (5): Saving data to a file

In order to properly present the results obtained, the following Matlab code allows you to plot the simulation results.

```
clc; clear all; close all;

load PWMRectifier.mat

t=Rectifier(1,:);
vs=Rectifier(2,:);
is=Rectifier(3,:);
vdc=Rectifier(4,:);

taille=9;
figure(1)
plot(t,vs,'k',t,is,'k');
xlabel('Time (s)','FontSize',taille,'FontName','times new roman', 'FontWeight','bold');
ylabel('v_s (V)','FontSize',taille,'FontName','times new roman', 'FontWeight','bold');
axis([0 1.5 -335 335])

figure(2)
plot(t,vdc,'k');
xlabel('Time (s)','FontSize',taille,'FontName','times new roman', 'FontWeight','bold');
ylabel('v_d_c (V)','FontSize',taille,'FontName','times new roman', 'FontWeight','bold');
```

axis([0 1.5 0 410])

- Required work:

1. Simulate the converter over a horizon of 1.5s with a sampling period of $T_s = 1\mu s$ and a switching frequency of 5kHz. A second additional load of $R_a = 20\Omega$ is connected in parallel at $t = 0.7s$ to the existing load by closing the ideal switch. The reference voltage is set at $v_{dcref} = 400V$. The parameters of the PI regulator are: $k_{pv} = 2.5$, $k_{iv} = 10$, $T_{sv} = 10\mu s$. Whereas, the gain of the proportional regulator is equal to $k_{pi} = 80$, with $T_{si} = 10\mu s$.

- Plot the waveforms of the output DC voltage, grid voltage and current. Plot the frequency spectrum of the grid current. Comment on the results found.
- Study the influence of the switching frequency as well as the line inductance on the total harmonic distortion (THD).
- Propose a method for calculating the controller gains of the DC voltage as well as the line current.
- If a PI regulator is considered for the current loop, calculate its parameters and repeat the converter simulation. Compare the results found.
- Add a phase locked loop (PLL) to estimate the phase of the grid voltage.

2. Simulate the hysteresis current-controlled PWM rectifier. Compare the simulation results obtained with those of the previous question. What conclusions can be drawn?