

# **Modeling and Simulation of a Photovoltaic System Connected to a Low-voltage Three-phase Utility Grid**

**A. SATIF**

Laboratory of Electrical Engineering and Telecommunications Systems  
National School of Applied Sciences (ENSA)  
Kenitra, Morocco

[amal.satif@uit.ac.ma](mailto:amal.satif@uit.ac.ma)

**L. HLOU**

Laboratory of Electrical Engineering & Energy Systems  
Faculty of Science- Ibn Tofail University  
Kenitra, Morocco

**N. HMINA**

Laboratory of Electrical Engineering and Telecommunications Systems  
National School of Applied Sciences (ENSA)  
Kenitra, Morocco

**R. ELGOURI**

Laboratory of Electrical Engineering and Telecommunications Systems  
National School of Applied Sciences (ENSA)  
Kenitra, Morocco

[elgouri.rachid@yahoo.fr](mailto:elgouri.rachid@yahoo.fr)

## **Abstract**

The photovoltaic industry is present everywhere in the world, but there is a clear concentration in the industrialized countries. As part of their energy strategy and given their dependence on the outside for the energy supply, industrialized countries give priority to the development of renewable energies and sustainable development, including photovoltaic (PV) energy. This work aims to facilitate the approach of this fascinating and promising technology: it concerns the coupling of PV systems to the utility grid from the control/synchronization point of view. For this purpose, this work presents the modeling and control of a three-phase inverter for grid-connected PV system, an improved digital PI current control algorithm is used to remain the current injected into the grid sinusoidal and a performance synchronous reference frame Phase-Locked Loop (dqPLL) is used as the synchronization technique.

## **Keywords**

Photovoltaic, Grid-connected inverter, Synchronization, Current control.

## 1. Introduction

In a distributed generation system, the PV system is connected to the low-voltage three-phase utility grid using a three-phase inverter which is applied as a power conditioner and must ensure the higher effectiveness of the PV generator (Ogbomo et al., 2017). To attain this level of efficiency, grid variables such as voltage, phase angle and frequency should be continuously controlled to guarantee the correct operation of PV grid-connected inverter. Therefore, a control of the three-phase grid-connected inverter is necessary as mentioned by (Parvez et al., 2016), and a synchronization algorithm is needed to achieve the perfect synchronization between the PV generator and the three-phase power utility grid (Ahmad et al., 2016; Blaabjerg et al., 2006).

Given the multitude of problems concerning grid interconnection, various methods for grid synchronization have been proposed in the last decades, (Jaalam et al., 2016) presented a paper where they gave a review of different synchronization methods for grid-connected inverters, and several control techniques used for grid-connected inverters have been presented (Kalyanraj et al., 2017; Parvez et al., 2016). This work is carried out to increase the efficiency of three-phase photovoltaic grid-connected systems by simultaneously addressing both above-mentioned issues, by providing an improved control technique to remain the current injected into the grid sinusoidal and a performance synchronous reference frame Phase Locked Loop to achieve the synchronization between the PV system and the utility grid for high efficiency.

The rest of the paper is organized as follows: the first part of the article gives a presentation of the system adopted for the simulation, the second part describes techniques used to guarantee the grid interconnection. The third part presents finding and discuss the results. Finally, a conclusion and future research perspectives will be depicted at the end of the article.

## 2. System Presentation

The fundamental objective for PV grid-connected systems is to control the power flow between the PV generator and the utility grid (Anzalchi and Sarwat, 2017). In their paper, (Rey-Boué et al., 2012) mentioned that the global PV system can be separated into two subsystems, the power and the control subsystems, whose block diagrams are depicted in Figure 1.

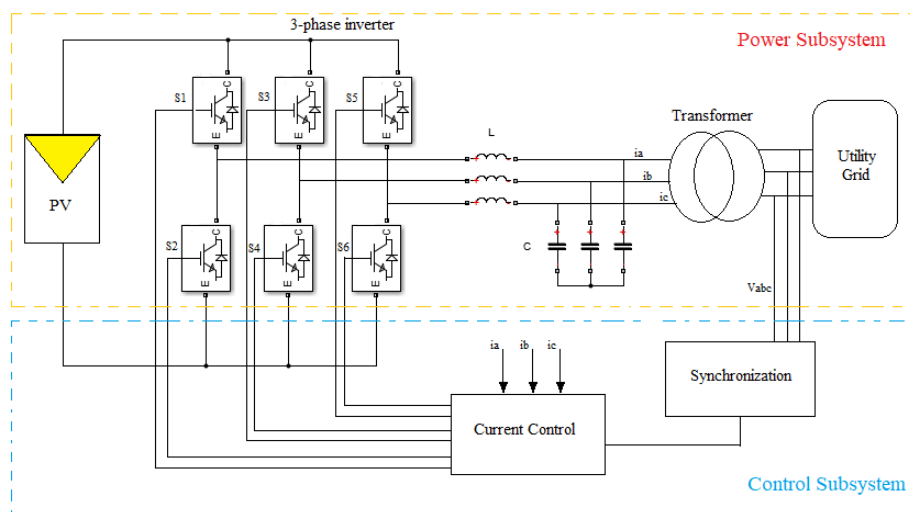


Figure 1. Power and control subsystems for the three-phase grid-connected PV system

In our work, the PV system described in Figure 1 is simulated to confirm the effectiveness of its control structure and to determine its performance parameters using the software of MATLAB/Simulink.

### 3. Control System

#### 3.1 Synchronization Technique

The main purpose of the synchronization algorithm is detecting the phase angle of the three-phase utility grid voltages with ideal dynamic response and precision in order to obtain the synchronization of the controlled three-phase inverter currents and ensure the correct behavior of the inverter control strategy. There are several studies giving different structures for synchronization algorithms (Jaalam et al., 2016), the Phase-Locked Loop (PLL) is considered as the best known and ideal one. In this work, an improved three-phase PLL method is adopted, its structure is shown in Figure 2, it is made by the Park transformation (Park, 1929), a PI regulator (Ruz et al., 2011) with the role of the loop filter, and an integrator as the voltage-controlled oscillator (VCO).

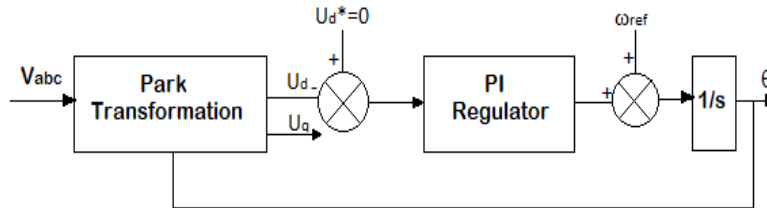


Figure 2. Block diagram of the dq-PLL synchronization technique

As presented in Figure 2, the dqPLL is executed in the synchronous (dq) reference frame. Its input variables are the grid voltages  $U_{abc}$ , which are then converted into DC components using Park transformation (abc-dq). The PLL is locked by setting  $U_d^*$  to zero, which acts as a phase detector. A PI controller acts as a loop filter and controls this variable, minimizing the phase error to zero. The  $\omega_{ref}$  represents the utility nominal frequency that is added to the output of the regulator and outputted as the grid frequency. An integrator as a voltage-controlled oscillator (VCO) is then connected, as output, the phase locked angle of the grid  $\theta$  is given. MATLAB/Simulink block diagram of the synchronization strategy is presented in Figure 3.

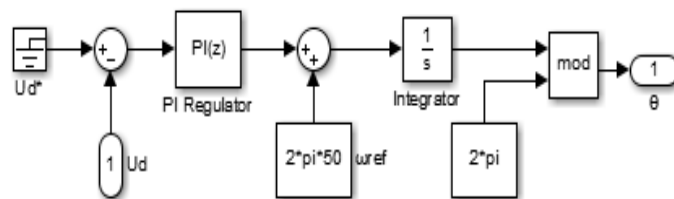


Figure 3. Simulink block diagram of the dqPLL.

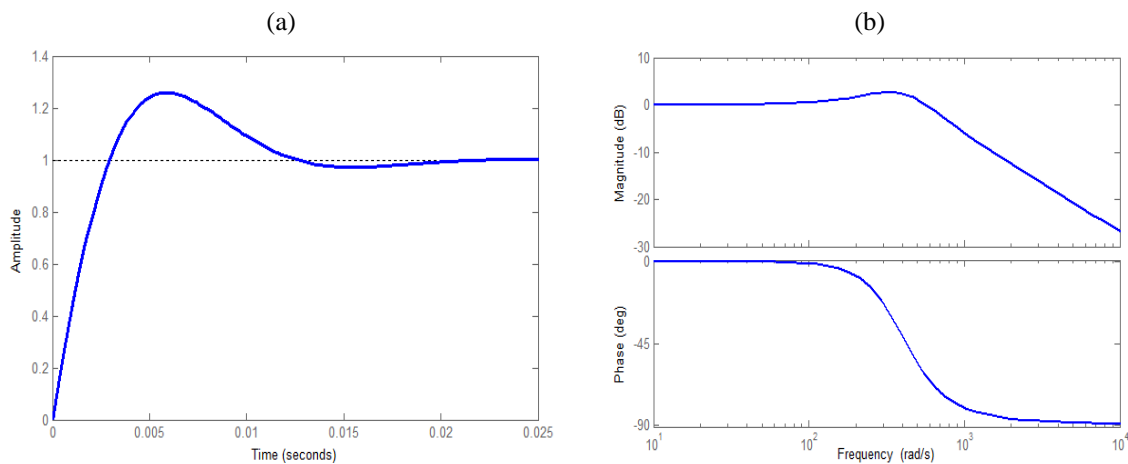


Figure 4. (a) Step response and (b) Bode plot of the design dqPLL algorithm.

As a model example of the proposed dqPLL, gains of the PI controller are calculated to reach a  $t_s=20$  ms providing fast response of the algorithm. The step response and the Bode plot of the model dqPLL algorithm are given in Figure 4a, and Figure 4b, respectively, where an overshoot of 25% is obtained.

### 3.2 Current Control

This control has been performed using PI controllers (“Electric Motor Control - 1st Edition,” n.d.; Parvez et al., 2016), the proposed control loop uses two controllers to regulate the d–q components of the line currents to ensure the best synchronization between the three-phase inverter line currents and the three-phase utility grid voltages. The block diagram of the equivalent current control model adopted in this paper is depicted in Figure 5.

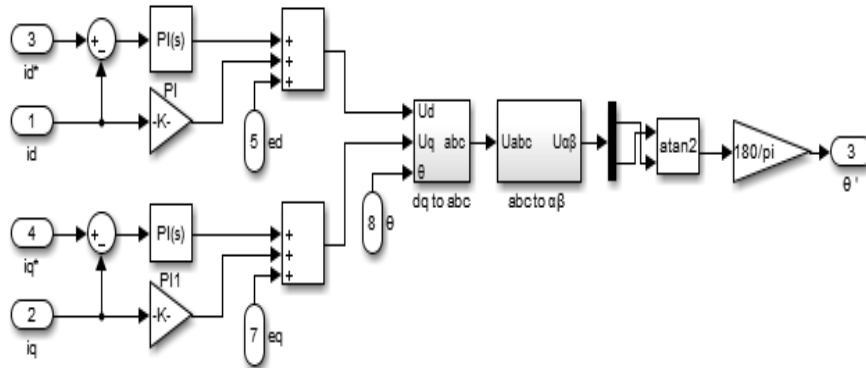


Figure 5. Simulink block diagram of the current control strategy

### 3.3 SVPWM

For the inverter, the gating pulses for individual switches are generated using the Pulse Width Modulation (PWM) strategy. Numerous PWM methods have been produced and described during the last few decades, (Valan Rajkumar et al., 2013) mentioned that the Space Vector Pulse Width Modulation (SVPWM) is suitable for digital signal processing implementation and optimization of switching patterns. Also, with microprocessor development, the SVM becomes prominent and possibly the best one for three-phase inverters. The constant switching frequency and excellent DC-link voltage utilization are the principal points of interest for the SVM (Nisha et al., 2012).

For a two-level three-phase inverter, there are eight possible different states, each of them determines a voltage space vector. As shown in Figure 6, six voltage space vectors form the axis of a hexagon and divide the space into six sectors. Accordingly, SVM is a digital modulating technique where the purpose is to define a combination of active and zero vectors to approximate a provided reference voltage.

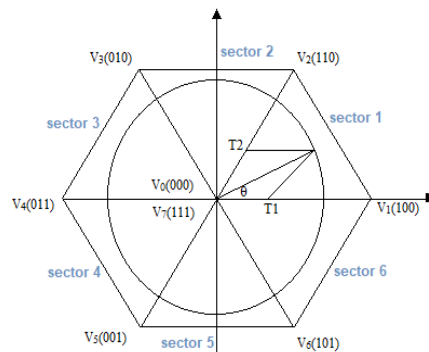


Figure 6. Space vectors in SVM.

In SVM, the three-phase reference voltages  $U_a^*$ ,  $U_b^*$ , and  $U_c^*$  are converted using Clarke's transformation to the complex two-phase orthogonal ( $\alpha\beta$ ) plane.

SVM can be effected through the following steps (Abdalahman et al., 2012):

- Calculation of reference voltage and angle ( $\theta'$ ).
- Identification of sector number that is calculated by comparing the angle calculated from the last step with angles range of each sector.
- Calculation of time duration T1, T2, and T0.

In Figure 7 and 8 are shown the simulation results for the sector allocation and the transistors switching signals at the output of the developed SVM algorithm in this work.

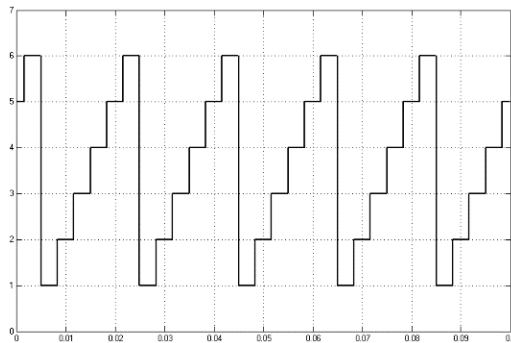


Figure 7. Sector allocation

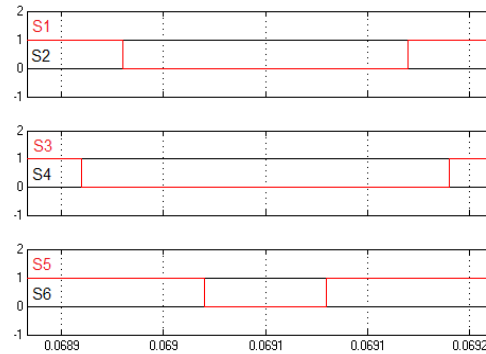


Figure 8. Transistors switching signals

#### 4. Simulation of the Grid-Connected System

In this section, the proposed system is modeled and simulated to confirm the effectiveness of its control with a nominal power of 10 kW. The inverter input is 300V DC. The association inverter/utility-grid is regularly done by the utilization of a grid filter to reduce the inverter output harmonics. In the simulation design, 1.1mH inductors with an internal resistance of 0.045-Ohm and 4uF capacitors are applied as an LC-filter in order to reach the desired voltage and attenuate ripples in current characteristics. A three-phase step-up transformer is used to accomplish isolation. Then, 3 current sensors and 3 voltage sensors are used to obtain the injected current into the grid and grid voltage respectively. Finally, a three-phase 220V, 50Hz AC source is applied to model the utility grid. Figure 9 shows the Block diagram of the overall PV grid-connected system.

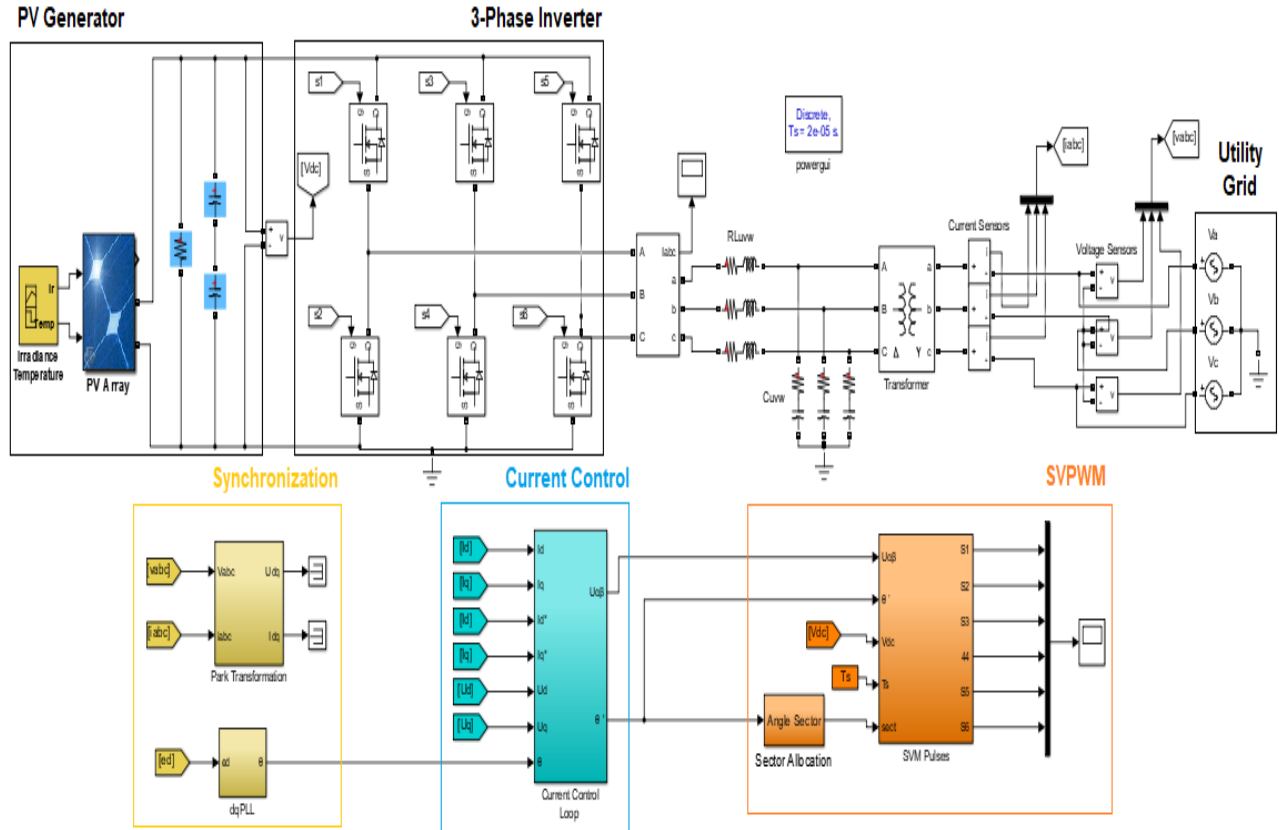


Figure 9. Simulink block diagram of the grid-connected photovoltaic system.

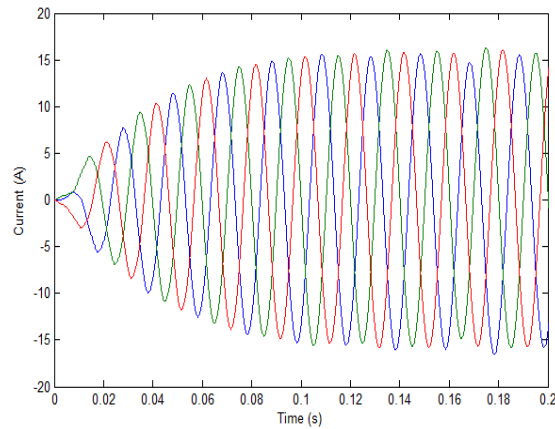


Figure 10. Time evolution of the three-phase currents injected to the utility grid.

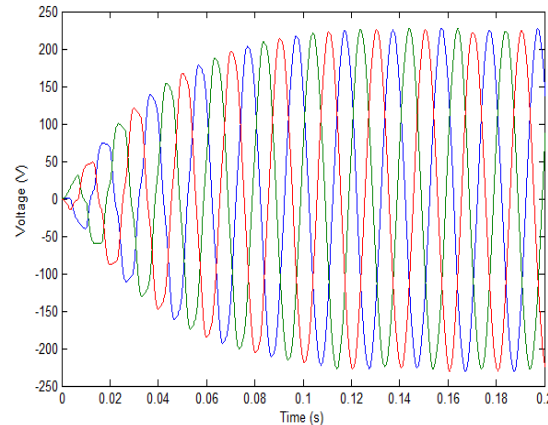


Figure 11. Time evolution of simple Voltages at the output of the inverter.

The results presented in Figure 10 and 11 show that the inverter/grid synchronization and control are done with success. At this point, the photovoltaic grid-connected system is managed successfully.

## 5. Conclusion

The problem of integrating photovoltaic modules into the built environment is different now from a few years ago when photovoltaic systems were only imagined in isolated sites. Photovoltaic comes to the city, by the technique of connection to the power utility grid. Our goal in this study was the simulation of a photovoltaic system and its connection to the utility grid, using a performance technique for grid synchronization and an improved control strategy to control the injected current into the utility. The results mentioned in this paper show that the photovoltaic grid-connected system was managed successfully.

The integration of a PV production to the utility grid is not without negative impacts, it is this point which must be treated in what follows.

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## **Biographies**

**Amal SATIF** a PhD student attached to Laboratory of Electrical Engineering and Telecommunications Systems at the National School of Applied Sciences (ENSA)- Ibn Tofail University, Kenitra, Morocco. She obtained a Master's Degree in Control, Industrial Computing, Signals and Systems at Faculty of Sciences Semlalia- Cadi Ayyad University, Marrakech, Morocco. Her research interests are solar energy and structures of static converters.

**Laamari HLOU** Professor at Faculty of Sciences- Ibn Tofail University, attached to Laboratory of Electrical Engineering and Energy Systems, and currently a Director of The Department of physics in Faculty of Sciences- Ibn Tofail University, Kenitra, Morocco. M. HLOU is the coordinator of Microelectronics and Embedded Systems Master and he is the author and co-author of several papers published in indexed journals. M. HLOU research interests are Renewable Energies, Information processing (audio and image domains), and Embedded Systems (DSP / FPGA).

**Nabil HMINA** Director of the National School of Applied Sciences Kenitra, Morocco. M. HMINA is the Jury President, member of several theses and Habilitations for research orientation, and he is the author and / or co-author of several articles and conferences in notorious newspapers and international conferences. Some of M. HMINA's duties and responsibilities are:

Partner and / or coordinator of several European projects (MISSION, CREMAR, PORFIRE, BATTUTA, GNUM, OSMOSE ...) ...

- Vice-President for Academic Affairs and Information Technology of the University Ibn Tofail, 2005-2011,
- Responsible for the implementation of several IT projects in Moroccan universities,
- Partner and / or coordinator of several European projects (MISSION, CREMAR, PORFIRE, BATTUTA, GNUM, OSMOSE...),
- ...

**Rachid ELGOURI** Professor of Electrical Engineering, Director of Laboratory of Electrical Engineering and Telecommunications Systems at the National School of Applied Sciences- Ibn Tofail University, Kenitra, Morocco. M. ELGOURI is the author and co-author of several papers published in indexed journals and has participated in national and international conferences. His research is divided into several axes in:

- The domain of renewable energies and in particular photovoltaic energies,
- The domain of information processing and embedded systems (DSP / FPGA),
- The domain of information security, Watermarking applied to the audio domain,
- The domain of sensor networks.



