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Interfacing Photovoltaic Systems to the Utility Grid: A Comparative Simulation Study to Mitigate the Impact of Unbalanced Voltage Dips

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***Abstract*—**This paper presents the modeling and the control of a grid-connected photovoltaic system (PVS). Firstly, the MPPT control of the PVS and its associated DC/DC converter has been analyzed in order to extract the maximum of available power. Secondly, the control system of the grid side converter (GSC) which is a three-phase voltage source inverter (VSI) has been presented. A special attention has been paid to the control algorithms of the GSC converter during grid voltages imbalances. Especially, three different control objectives are to achieve; the mitigation of the grid imbalance adverse effects, at the point of common coupling (PCC), on the injected currents, the elimination of double frequency oscillations in active power flow, and the elimination of double frequency oscillations in reactive power flow. Simulation results of two control strategies have been performed via MATLAB software in order to demonstrate the particularities of each control strategy according to power quality standards.

***Keywords*—**Renewable energies, photovoltaic systems, DC link, voltage source inverter, space vector SVPWM, unbalanced voltage dips, symmetrical components.

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I. INTRODUCTION

RENEWABLE energies are energy sources that use natural resources considered inexhaustible namely wind, sun, biomass ... These energies do not produce greenhouse gases and pollutants emissions, and do not generate waste. Also, these energies do not use fossil resources of the planet, such as natural gas or oil, with reserves diminish with excessive consumption and increase of electrical energy use [1], [2]. For example, the European Union should meet the goal of 20% of total consumption from renewable energy sources by 2020. Furthermore, the share of renewable sources of energy is required to achieve 55% of global energy consumption in 2050.

Despite the growth in the use of renewable energy sources, various factors still prevent the use of these energies. The main reason is that until recently, the production costs of these energies were much higher than those of fossil fuels [1], [3]. In addition, renewable energy sources are not constant; e.g. wind suddenly falls or clouds cover the sun.

Optimal exploitation of these sources would also require the construction of facilities in remote areas, including the connection to the main network would be both expensive and difficult. However, the situation is changing rapidly. Policies put in place have helped boost demand for renewable energy sources in the world, causing a rapid reduction in their production costs [4], [5]. Given the rising price of gas and oil in recent years and the initiatives taken by governments, there is no doubt that renewable energy sources have a bright future.

Among the most promising systems for the renewable energy use, there are Hybrid Renewable Energy Systems (HRES). The term HRES refers to the generation of electric power systems using different types of sources. The use of several sources of energy in a hybrid system should have a beneficial effect on the production of energy, in terms of cost and availability [3]-[5]. Among the means of production of renewable energy, wind energy systems and photovoltaic systems have large production capacities.

In this paper, we are interested in the study of a grid-connected photovoltaic system. In the literature, several studies [2], [3], [5] dealt with the consideration of static performances, the energy efficiency and the sizing of some configurations comprising a photovoltaic generator and some interfacing converters while exhibiting the various models describing the behavior of a PV Cell / PV Module / PV panel [6], [7].

For selecting an appropriate model for our simulations, several factors were considered. The most important is the accuracy that can be obtained knowing that there is always a compromise between accuracy and simplicity.

Indeed, there are two types of photovoltaic system structures: the system connected directly to the network and the intermediate DC bus system. The first configuration consists of a photovoltaic generator which is connected to the electrical grid via an inverter [8], [9]. This device has the fewest components but its major drawback is the immediate and total stopping of the production of energy at a problem occurring upstream of the inverter. In addition, the maximum power point tracking control is approximate because the cells do not deliver the same current due to differences in their internal structure and sunshine which they are subject. For the intermediate DC bus configuration, the photovoltaic generator is connected to a DC bus via a DC-DC converter [10]-[12]. An inverter delivers a modulated voltage. This is filtered to reduce harmonics (THD). Is then obtained at the output of this device a useable voltage which may be injected to the network. The study of this configuration is introduced in this work through the satisfactions it develops.

In this work, the control systems for grid side inverter are

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designed for operation during unbalanced conditions. Indeed, two control systems were studied: the IARC technique and BPSC technique [13]-[15]. A comparative study was also presented to allow the choice of the appropriate technique depending on the intended purpose.

II. MODELING AND CONTROL OF THE PHOTOVOLTAIC CONVERSION SYSTEM

A PVS is a system that combines a PV generator controlled via its associated converters. As a PVS does not deliver a constant power their association with appropriate control systems provides a controlled power generation. From a technological point of view, the reliability is not just a matter of compliance with standards for electricity supply, but also maintenance, given the particular conditions of the network they are connected [2], [11].

The performance of a PVS, its performance and lifetime, are influenced partly by design, that is to say the architecture, components, sizing, type of components etc. and other hand by the choice of the operating strategy. In this paper, the selected architecture is that of Fig. 1.

A. Modeling of the PV Generator

Considering the complexity of modeling the behavior of the PV system, we used the model of [2]. This model has allowed us to know the I-U and P-U characteristics of the panel. It also allowed us to vary the voltage, current and power while also varying the number of cells in series and the number of panels in parallel [2]-[4].

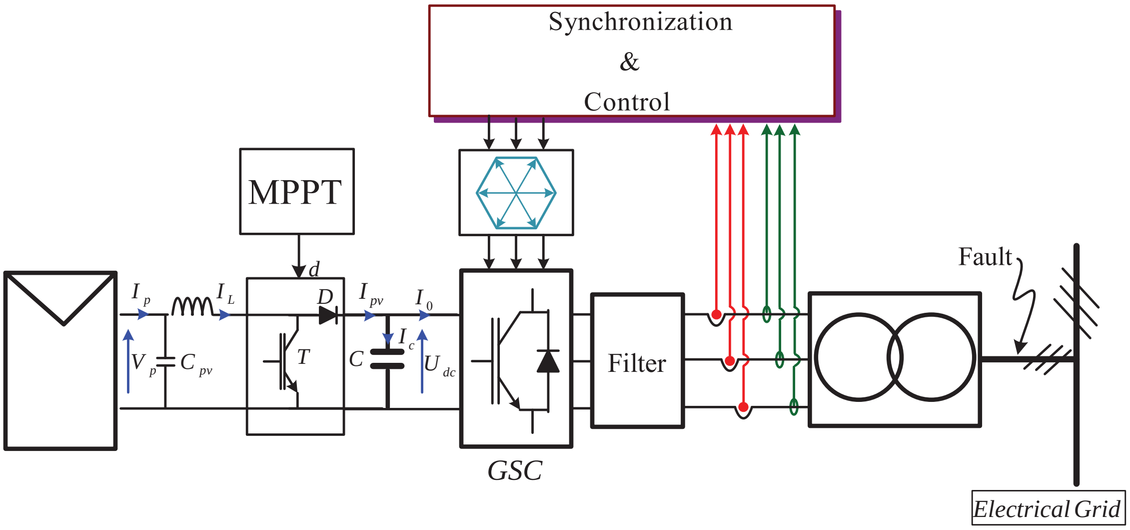

Fig. 1 Configuration of the studied system

According to the literature, the modeling of a panel composed of "N_s" modules in series and "N_p" modules in parallel is given by [2].

$$I_p = N_p \left[I_{ph} - I_0 \left(\exp\left(\frac{\frac{V_p}{N_s} + \frac{R_s I_p}{N_p}}{V_T} \right) - 1 \right) \right] - \frac{N_p V_p}{N_s R_{sh}} - \frac{R_s I_p}{R_{sh}} \tag{1}$$

Herein,

$$V_T = \frac{n K_B T}{q} \tag{2}$$

With the growth of PVS-based applications use, it usually becomes important to control these systems with DC/DC piloted by the famous Maximum Power Point Tracking (MPPT) technique allowing to produce permanently the maximum power output under any given weather conditions. the maximum of available power.

Though, MPPT can be used with a mechanical tracking system that physically moves the modules to make them point more directly at the sun, it is a fully electronic system that varies the electrical operating point of the PVS to its optimum [11], [12].

The DC/DC converter was modeled, in state space representation, as:

$$\begin{cases} V_p = L \dfrac{dI_L}{dt} + U_{dc}(1-d) \\ C \dfrac{dU_{dc}}{dt} + I_0 = (1-d) I_L \end{cases} \tag{3}$$

B. Control of the PV System

The power delivered by the PVS depends on the irradiation, the temperature and the terminal voltage. One way to optimize the power flow to the DC load is to introduce a chopper for imposing an operating point close to the Maximum Power Point (MPP).

Several algorithms have been proposed for carrying out the MPPT control. Following a classification of various existing

MPPT according to their basic principle, the most commonly encountered methods are commonly known as Hill Climbing respectively Perturb & Observe (P&O), the increment of Conductance (IncCond) and artificial intelligence (fuzzy logic, neural networks) [2], [4], [12]. In this paper a fuzzy logic controller (FLC) has been used.

III. CONTROL OF THE GRID SIDE CONVERTER UNDER GRID IMBALANCES

As we mentioned a control method was applied to the grid side converter. The control strategy consists of two control loops. The internal loop is based on the control of the network current and the external loop is based on the regulation of the DC bus voltage and the management of the reactive power [8], [9].

In order to inject the produced energy to the grid there was used a Phase Lock Loop (PLL) for synchronizing the output voltage of the inverter with the grid [13], [15].

As we focused on the study of the integration of a PVS to the electrical grid affected by a voltage imbalance, we begin by expressing the active and reactive power injected to the grid which are written as:

$$P_g = v_g . i_g = \left(v_g^P + v_g^N + v_g^Z\right).\left(i_g^P + i_g^N + i_g^Z\right) \\ = \left(\begin{bmatrix} v_{ag}^P \\ v_{bg}^P \\ v_{cg}^P \end{bmatrix} + \begin{bmatrix} v_{ag}^N \\ v_{bg}^N \\ v_{cg}^N \end{bmatrix} + \begin{bmatrix} v_{ag}^Z \\ v_{bg}^Z \\ v_{cg}^Z \end{bmatrix}\right) . \left(\begin{bmatrix} i_{ga}^P \\ i_{gb}^P \\ i_{gc}^P \end{bmatrix} + \begin{bmatrix} i_{ga}^N \\ i_{gb}^N \\ i_{gc}^N \end{bmatrix} + \begin{bmatrix} i_{ga}^Z \\ i_{gb}^Z \\ i_{gc}^Z \end{bmatrix}\right) \tag{4}$$

$$Q_g = \left(v_{g\perp}\right) . i_g = \left(v_{g\perp}^P + v_{g\perp}^N + v_{g\perp}^Z\right).\left(i_g^P + i_g^N + i_g^Z\right) \\ = \left(\left\{\frac{1}{\sqrt{3}} . \begin{bmatrix} 0 & 1 & -1 \\ -1 & 0 & 1 \\ 1 & -1 & 0 \end{bmatrix}\right\} . \left\{\begin{bmatrix} v_{ag}^P \\ v_{bg}^P \\ v_{cg}^P \end{bmatrix} + \begin{bmatrix} v_{ag}^N \\ v_{bg}^N \\ v_{cg}^N \end{bmatrix} + \begin{bmatrix} v_{ag}^Z \\ v_{bg}^Z \\ v_{cg}^Z \end{bmatrix}\right\}\right) . \left(\begin{bmatrix} i_{ga}^P \\ i_{gb}^P \\ i_{gc}^P \end{bmatrix} + \begin{bmatrix} i_{ga}^N \\ i_{gb}^N \\ i_{gc}^N \end{bmatrix} + \begin{bmatrix} i_{ga}^Z \\ i_{gb}^Z \\ i_{gc}^Z \end{bmatrix}\right) \tag{5}$$

where the exhibitors P, N and Z denote positive, negative and zero sequences voltage components respectively. The subscript "⊥" is used to represent the vector offset by 90°.

The first studied control strategy is called Balanced Positive-Sequence Control (BPSC) and the second one is called Instantaneous Active Reactive Control (IARC) [13], [14]. According to the theory of the two strategies, the control currents are given respectively by (6) and (7):

$$i_g^* = \frac{\left(v_g^P + v_g^N + v_g^Z\right) \cdot \left(i_g^P + i_g^N + i_g^Z\right)}{\left|v_g^P\right|^2} \cdot v_g^P + \frac{\left(v_{g\perp}^P + v_{g\perp}^N + v_{g\perp}^Z\right) \cdot \left(i_g^P + i_g^N + i_g^Z\right)}{\left|v_g^P\right|^2} \cdot v_{g\perp}^P \tag{6}$$

$$i_g^* = \frac{P_g \cdot v_g + Q_g \cdot v_{g\perp}}{\left|v_g^P\right|^2 + \left|v_g^N\right|^2 + 2 \cdot \left|v_g^P\right| \cdot \left|v_g^N\right| \cdot cos\left(2 \cdot \omega \cdot t + \varphi^P - \varphi^N\right)} \tag{7}$$

IV. SIMULATION RESULTS

In this section, simulation results obtained in MATLAB/Simulink are presented for a PV system connected to an electrical grid affected by a single-phase voltage imbalance that has been used to study the dynamic system behavior.

The default scenario is shown in Fig. 2. It is a Type E voltage dip (50% of the rated voltage in phases "b" and "c" at 0.2 sec).

The consequences of the aforementioned default are presented and analyzed in Figs. 3 and 4 respectively. Particular attention was focused on the quality of active and reactive power exchanged with the electrical grid and also currents system injected to the point of common coupling (PCC).

The photovoltaic system was controlled to track the maximum power point (extract maximum energy). Furthermore, the grid side converter was controlled via BPSC and IARC techniques in order to remedy the adverse effects of the occurrence of the single-phase fault.

According to the simulations, we notice that the active and reactive power generated by the IARC control strategy are perfectly constant (Fig. 3). However, in the presence of BPSC control strategy, the generated active and reactive powers are oscillating as soon the fault occurred. It oscillates around their reference values at twice the grid frequency (Fig. 4).

It is important to note that the existence of oscillations at twice the fundamental frequency in the active and reactive power is expected due to interaction between the current of the positive sequence voltage and the negative sequence.

Via results (Fig. 3), we show that since the fault occurs at t=0.2s, the injected currents become strongly deformed. In addition, it turns out the major advantage of this control strategy is that it ensures constant active and reactive powers even during the fault phase.

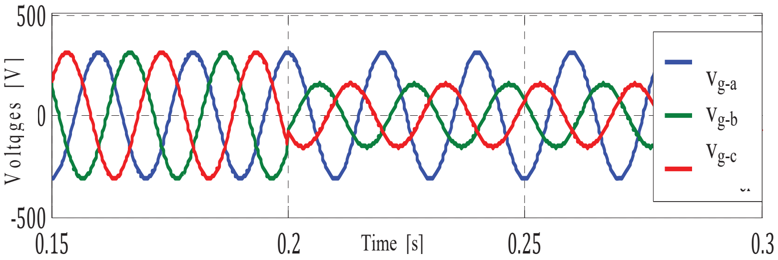

Fig. 2 Grid voltage system

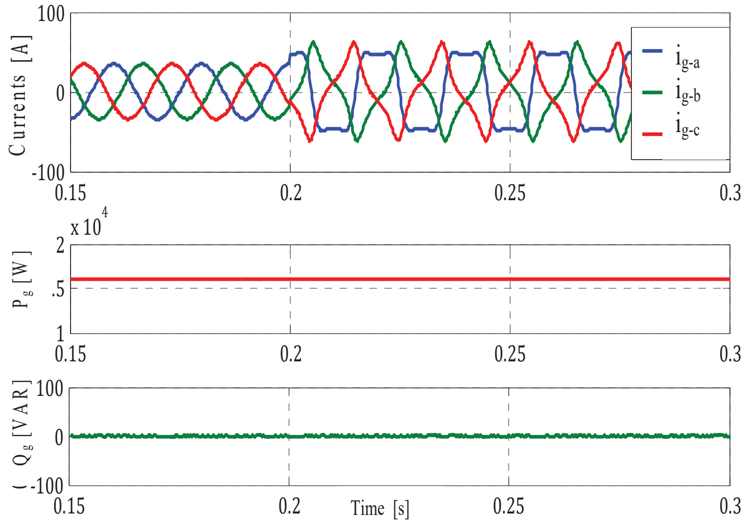

Fig. 3 Injected currents, active and reactive powers before and during the voltage sag: case of IARC strategy

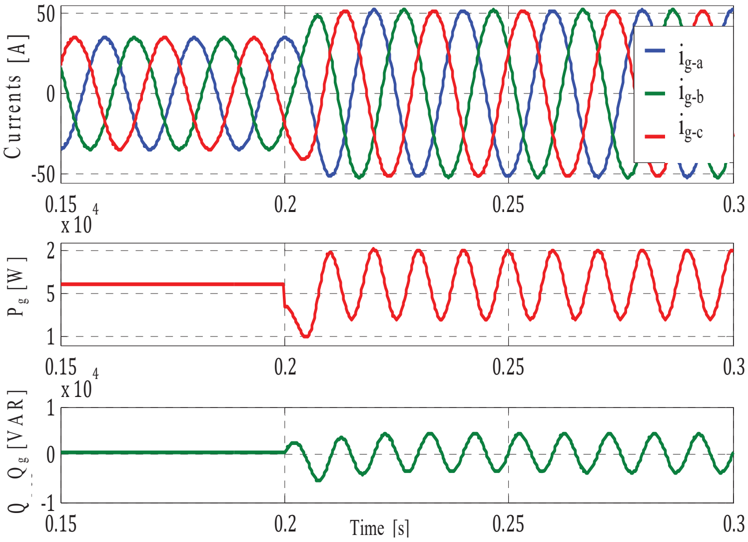

Fig. 4 Injected currents, active and reactive powers before and during the voltage sag: case of BPSC strategy

Faced with the same cited fault (Fig. 2) for pre-analyzed strategies, the simulations' results of the application of the BPSC control strategy show that the currents are balanced and sinusoidal (Fig. 4). We note that the current amplitude is increased to maintain the average active power injected into the network when the drop occurs at PCC voltages.

V. CONCLUSIONS

Photovoltaic energy systems are very promising for the use of renewable energy. In this work, we presented the optimized configuration of PV systems connected to the grid. We first defined the modeling methodologies specific to a PVS and its control to extract the maximum available power. We also studied two CCR control strategies.

We found that the two control strategies are not advantageous from the point of view that they do not allow the control of the exchanged powers and the injected electric current network together. Indeed, the technique IARC allows us to generate constant active and reactive powers but an unbalanced system of injected currents. However, the BPSC technique generates balanced and sinusoidal currents with fluctuating powers.

REFERENCES

[1] Marcantonini, C.; Ellerman, A.D., "The cost of abating CO2 emissions by renewable energy incentives in Germany," 10th International Conference on the European Energy Market (EEM) DOI: 10.1109/EEM.2013.6607312, 27-31 May, 2013, Stockholm, Sweden, pp.1-8,

[2] R. Abbassi, S. Chebbi, "Energy Management Strategy for a Grid–Connected Wind-Solar Hybrid System with Battery Storage: Policy for Optimizing Conventional Energy Generation", International Review of Electrical Engineering (I.R.E.E.), Vol. 7, N° 2, pp. 3979-3990, April 2012.

[3] Daniel, S.A.; Ammasaigounden, N., "A novel hybrid isolated generating system based on PV fed inverter-assisted wind-driven induction Generators," in Energy Conversion, IEEE Transactions on, vol.19, no.2, pp.416-422, June 2004.

[4] R. Abbassi, S. Chebbi, "Optimal Energy Management Strategy for Wind Photovoltaic Hybrid System with Battery Storage", 16th IEEE

Mediterranean Electrotechnical Conference (MELECON), pp. 810–813, Mars 2012.

[5] Yaow-Ming Chen; Yuan-Chuan Liu; Shih-Chieh Hung; Chung-Sheng Cheng, "Multi-Input Inverter for Grid-Connected Hybrid PV/Wind Power System," in Power Electronics, IEEE Transactions on, vol.22, no.3, pp.1070-1077, May 2007.

[6] M. Mohammadi, S.H. Hosseinian, G.B. Gharehpetian, “Optimization of hybrid solar energy sources/wind turbine systems integrated to utility grids as microgrid (MG) under pool/bilateral/hybrid electricity market using PSO”, *Solar Energy*, Vol. 6, pp. 112-125, 2012.

[7] J. A. Suul, A. Luna, P. Rodriguez, and T. Undeland, “Virtual-Flux-Based Voltage-Sensor-Less Power Control for Unbalanced Grid Conditions”, *IEEE Trans. Power Electronics*, vol. 27, pp. 4071-4087, 2012.

[8] Reyes, M.; Rodriguez, P.; Vazquez, S.; Luna, A.; Teodorescu, R.; Carrasco, J.M., "Enhanced Decoupled Double Synchronous Reference Frame Current Controller for Unbalanced Grid-Voltage Conditions," in *Power Electronics, IEEE Transactions on*, vol.27, no.9, pp.3934-3943, Sept. 2012.

[9] Jiabing Hu; Yikang He, "Modeling and Control of Grid-Connected Voltage-Sourced Converters Under Generalized Unbalanced Operation Conditions," in *Energy Conversion, IEEE Transactions on*, vol.23, no.3, pp.903-913, Sept. 2008.

[10] R. Abbassi, S. Saidi, M. Hamami, S. Chebbi, “Analysis and Operation of Renewable Energy Power Generation Systems: The Key to Optimizing Power System Reliability and Flexibility During Unbalanced Network Fault”, *Handbook of Research on Advanced Intelligent Control Engineering and Automation*: Pennsylvania (USA), Chapter 24, November 2014.

[11] Mohd Zainuri, M.A.A.; Mohd Radzi, M.A.; Soh, A.C.; Rahim, N.A., "Development of adaptive perturb and observe-fuzzy control maximum power point tracking for photovoltaic boost dc-dc converter," in *Renewable Power Generation, IET*, vol.8, no.2, pp.183-194, March 2014.

[12] Rajan Singaravel, M.M.; Daniel, S.A., "MPPT with Single DC–DC Converter and Inverter for Grid-Connected Hybrid Wind-Driven PMSG–PV System," in Industrial Electronics, IEEE Transactions on, vol.62, no.8, pp.4849-4857, Aug. 2015.

[13] P. Rodriguez, A. Luna, I. Etxeberria, R. Teodorescu, F. Blaabjerg, “A Stationary Reference Frame Grid Synchronization System for Three-Phase Grid-Connected Power Converters under Adverse Grid Conditions,” in *IEEE Transactions on Power Electronics*, Vol. 27, No. 1, pp. 99-112, January 2012.

[14] Abbassi, R.; Saidi, S.; Marrouchi, S.; Chebbi, S., "Novel flexible algorithm for the operation of renewable source grid interface VSCs under unbalanced voltage sags," in *Environment and Electrical Engineering (EEEIC), 2015 IEEE 15th International Conference on*, vol., no., pp.1414-1419, 10-13 June 2015.

[15] Kazmierkowski, M.P., "Theory (Instantaneous Power Theory and Applications to Power Conditioning; Akagi, H. et al; 2007) (Book Review)," *Industrial Electronics Magazine, IEEE*, vol.1, no.3, pp.46,46, 2007.

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