Regulation of HV Grid Connected to a 250 kW Photovoltaic Power Plant

Nasreddine ATTOU[1], Sid-Ahmed ZIDI[1], Samir HADJERI[1], Mohamed KHATIR[1]

[1]Electrical Engineering Department Intelligent Control & Electrical Power Systems Laboratory (ICEPS), Djillali Liabes University Sidi Bel-Abbes, Algeria

Email: nasreddine.attou@univ-sba.dz

Abstract-In this paper, our attention is focused on a system for the control and injection of photovoltaic energy into the high voltage (HV), to ensure efficient integration under different operating conditions while providing self-sufficient generation that satisfies various economic and operational constraints on the one hand, and further improving the performance and stability of the power system on the other. Different control mechanisms are considered in the injection process, such as P/Q control (Maximum Power Point Tracking (MPPT), Phase Locked Loop (PLL) design standards, and current/voltage control loops). The effects of varying load power, varying solar irradiance, and introducing harmonics are studied. The simulation results demonstrate the capability of the proposed control systems in net power injection, ensuring a good transfer of all the maximum power to the grid, better conversion quality, and fast dynamic response while preserving the voltage and frequency stability standards

Keywords - HV Battery Energy Storage System, Grid Power, Peak Management, Renewable Energy.

I. INTRODUCTION

Electrical grids are in a constant state of evolution because they are closely linked to demographic and economic changes, the development of new national and international energy laws and initiatives, the growing awareness of climate change, and the increasing change in consumption habits.

Environmental issues are now a major focus in the energy world. On the one hand, fossil fuel reserves are limited and on the other hand, the use of these resources is responsible for a certain number of consequences on the environment: local pollution or an increase in the concentration of greenhouse gases (GHG) in the atmosphere leading to global warming. The search for greater energy independence is therefore an environmental policy.

Currently, the European Union is establishing directives for the year 2030 which aim to ensure that at least 32% of the EU's final energy consumption will be from renewable sources.

These targets will fundamentally change the use of energy. However, the transition of these means of production integrating an increasing part of renewable resources, therefore, requires the implementation of new systems of management and control of these products means to bring sufficient operational flexibility [1].

The evolution of grid-connected PV systems worldwide represents a significant amount of installed capacity compared to stand-alone systems. Grid-connected PV systems without batteries are economical and require less maintenance, as the energy generated by the PV plant is directly transmitted to the transmission line and distributed. This eliminates the need for batteries and other energy storage devices, making the installation less cumbersome and reducing capital and maintenance costs compared to the stand-alone system.

But if PV penetration is high, photovoltaic systems can subject the grid to several negative impacts. These include voltage fluctuation and difficulty in controlling it, power quality problems, and frequency fluctuations [2-3].

capital and maintenance costs compared to the stand-alone system.

But if PV penetration is high, photovoltaic systems can subject the grid to several negative impacts. These include voltage fluctuation and difficulty in controlling it, power quality problems, and frequency fluctuations [2-3].

The random and intermittent injection of photovoltaic (PV) generation into a public power grid affects its stability and protection. This poses new challenges for grid management.

The potential impacts of PV installations on the electricity grid are:

- Local voltage variation
- Voltage imbalance
- Rapid power variation (intermittency)
- Harmonic injection
- direct current injection
- Protection blinding
- Impact of PV power on-grid investments

Grid-tied inverters (GTIs) used in the PV system are classified into two categories: small scale (several tens of kilowatts) and large scale (hundreds of megawatts). As a result, the standard of grid interconnection is highest, which improves the reliability, efficiency, and cost of the power system. In addition, the operation of the grid-connected inverter depends mainly on the robustness of the control strategy, even under abnormal grid conditions such as voltage and frequency deviation.

Grid-connected PV systems are designed to work in conjunction with other distributed generation resources (DERs) and the power grid, which has certain advantages. Grid-connected PV systems consist of a bi-directional inverter and PV panels. The bi-directional interface or features built into the system allow the energy produced by the PV panels to power loads directly connected to the AC bus system and to send excess energy to the grid when the PV system's output is greater than the power required by consumers. The reverse occurs when the power demand is higher than the PV system output [5].

II. RELATED WORK

In the literature, various strategies and systems for PV grid injection have been proposed. For example, in [4], the authors developed a grid-connected PV system with battery storage to limit fluctuations in PV output, other researchers in [6] focused on studying the importance of grid-connected photovoltaic (PV) systems about the intermittent nature of renewable generation, and on characterizing PV output concerning grid code compliance. The development of PV systems and related expansion plans for the future worldwide are elaborated. The most important impacts of grid-connected PV systems on distribution networks as well as the level of penetration of PV systems were investigated.

In reference [7], the authors proposed software computation methods (SC) to improve conventional techniques for grid-connected photovoltaic (PV) systems due to their ability to solve complex non-linear problems. These techniques are developed to handle adverse environmental conditions such as sudden changes in temperature and irradiance. In [8], the authors focus on three-phase, single-stage, high-power PV systems connected to a distribution grid with a modified control strategy, which includes grid voltage drop compensation and reactive power injection capability. Some authors propose in [9] and [10] methods for power quality improvement and analysis after PV grid integration.

In [11] the effects of the PV system installation location on the power quality of the distribution system are presented. The power quality of the distribution system, in terms of voltage, active power, total losses, and grid power factor, is studied.

Nevertheless, it's clear that the quality of power conversions in an inverter-based PV system, such as low THD, high power factor, and fast dynamic response, is largely determined by the control technique used by the inverters connected to the grid, and that fast dynamic response is largely determined by the control strategy adopted by the inverters connected to the grid.

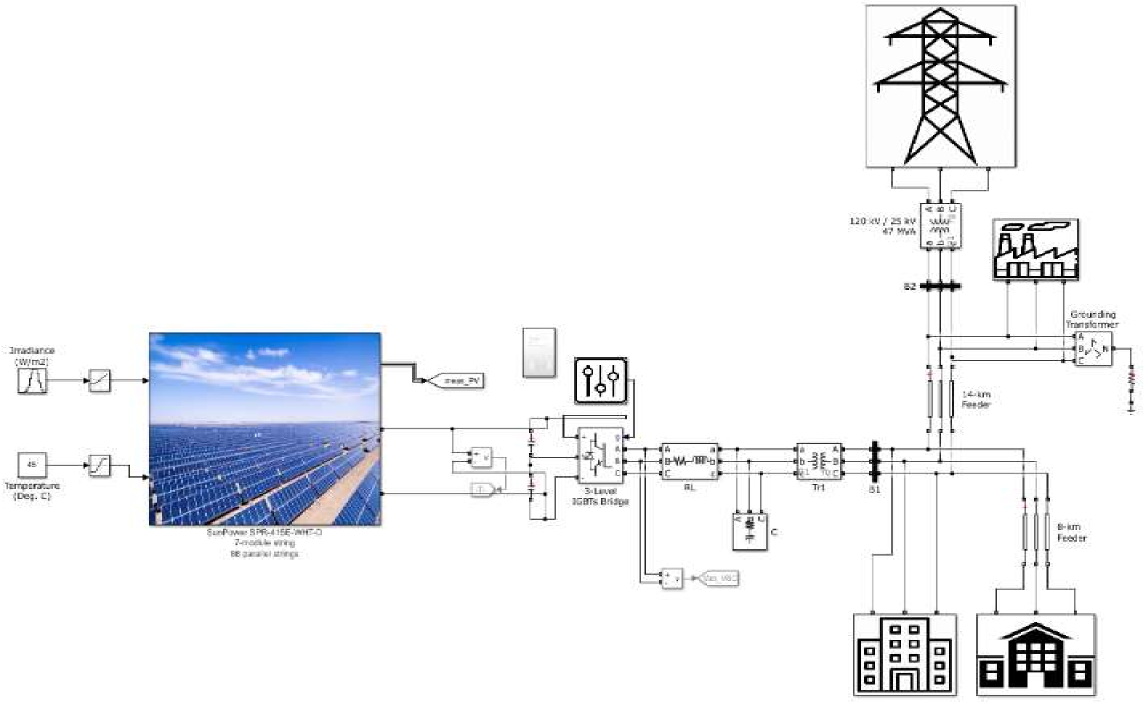

Fig. 1. Architecture of the connected Grid-connected system.

In this paper, we focused on the development of a robust decentralized control system applied to an HV grid-connected inverter (GTI) which can ensure an optimal transfer of any PV power and limit the negative impacts due to the intermittent nature of the PV production.

The implemented control strategy takes into account the P/Q control based on the MPPT maximum power point tracking, the PLL phase synchronizer, as well as the voltage and current regulation loops necessary for the correct operation.

III. SYSTEM DESCRIPTION

The proposed system structure includes residential and industrial loads with a rated power of 600 kW and a 250-kW photovoltaic (PV) array. A bi-directional connection between the PV system and the main grid (i.e., power can be delivered to the grid) is used to ensure voltage/frequency stability. The PV system consists of a PV array, a DC-AC inverter, and a control system (MPPT controller, VDC voltage and current controller, PLL and PWM generator) (MPPT controls are directly implemented for the inverters), as shown in Figure 1 [12].

The PV array feeds a power distribution network through a 25KV/480V step-down transformer [13].

Table 1 presents the parameters of the microgrid

Table 1. Microgrid Parameters.

Symbols	Description	Value	Unit
Ppv	PV POWER	235	KW
PL	LOAD POWER	600	KW
V bus 1	VOLTAGE BUS	25	KV
VDC	1	480	V
f	DC VOLTAGE	50	HZ
t	FREQUENCY	24	H
	SIMULATION		
	TIME		

The structure of the studied system is given in the following figure.

IV. CONTROL STRATEGY

The control strategy developed is used to ensure optimal power transfer while facilitating the insertion of intermittent generation into the grid (Fig. 2).

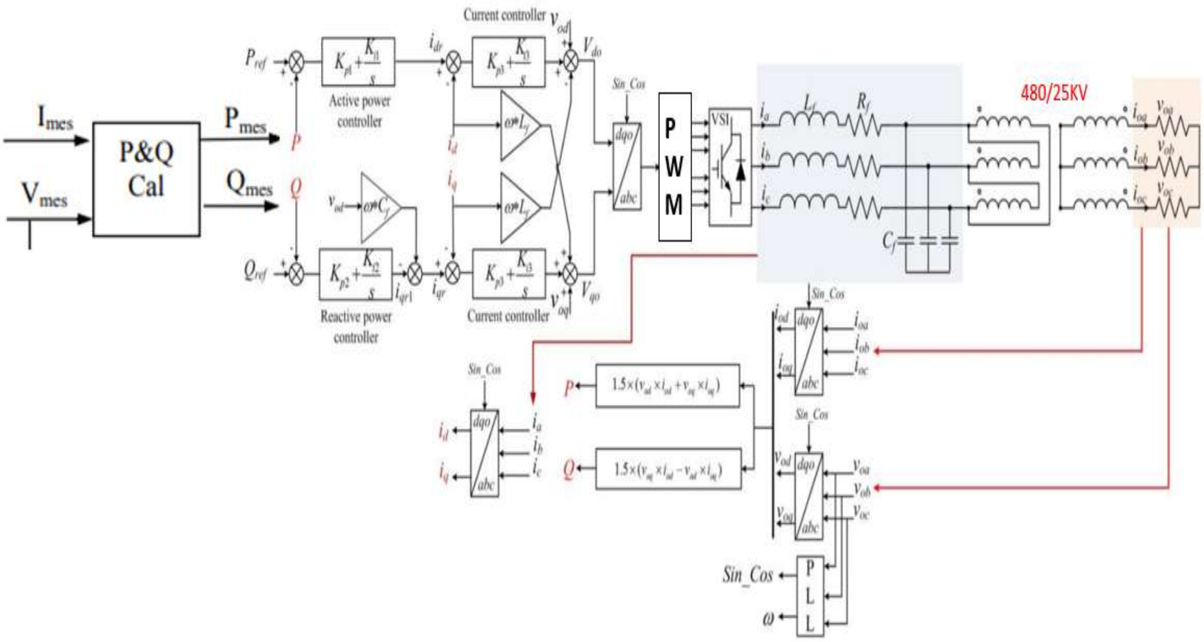

Fig. 2. Proposed grid tred inverter control.

The control structure is composed of 4 types of controllers:

MPPT control (Maximum Power Point Tracking): This control is linked to an inverter that allows the PV and load to adapt so that the generated power corresponds to its maximum value and is directly delivered to the grid. The Perturb and Observe (P & O) method is used in our study to establish the MPPT control. This controller automatically modifies the VDC reference signal of the inverter's DC voltage regulator to obtain a DC voltage that allows the PV array to produce the maximum amount of electricity [13].

Current and voltage control: V_{DC} controller: The V_{DC} voltage control system is used to regulate the PV array's output voltage and adjust it to the maximum power point value based on solar radiation, cell temperature, and load conditions.

This voltage controller ensures that the inverter receives steady active power. This is commonly accomplished by using a PI controller to compare the reference voltage to the present state of the DC link voltage. [13].

Current controller. The current control loop regulates the current Id and the current Iq in the reference dq0 using a PI controller. This DC current is intended to extract as much PV generation power as possible [1-13].

They are used to maintain the steady-state operation of a grid-connected PV system, as they can monitor the current to follow the reference current.

The reference active power and reactive power are decoupled into the reference current in the d- and q-axis in the Power Control block, and then the reference current is controlled by the PI Current Controller to make the steady-state error equal to zero.

Current and voltage control: The phase-locked loop (PLL) is used to synchronize the frequency and phase of the DG with the main grid.

The voltage outputs Vd and Vq of the current controller are converted into three modulation signals Uabc_ref used by the PWM generator [13].

First of all, the DC bus voltage of the inverter must be stabilized at a specific value because the output voltage of the PV modules varies according to temperature, radiation, and the effect of maximum power point tracking (MPPT). Second, the energy from the PV modules must be fed into the grid by inverting the DC current into a grid-synchronized sinusoidal waveform.

PV Control+ P/Q Control

In grid-connected operation, the PV system is under P/Q control, the grid provides U/f control to ensure a voltage and frequency reference.

The PV system model is given as a current source with P/Q control. Psp is determined by the MPPT of the PV module and Qsp is zero.

The purpose of this control (PQ) is to ensure that the active and reactive power output of the DG is always equal to its reference power.

It also follows the fluctuation of the load and therefore its output power must be controllable to some extent, and it must be able to react quickly enough to the load fluctuation.

In this system, the active and reactive power is appropriately controlled using the rotating synchronous frame approach dq. The dq components are defined as id and iq, proportional to the active and reactive power [1]:

$$i_{dref} = \frac{P_{ref}}{u_d} \tag{1}$$

$$i_{qref} = \frac{Q_{ref}}{u_q} \tag{2}$$

It can be seen that the purpose of active and reactive power control P and Q is equivalent to current control, i.e. as long as the PQ controller implements the tracking of the current reference iref, P and Q can be controlled. The current control is performed by the PI controller. Equation (3) gives the voltage equation of the inverter in the rotating reference frame d-q:

$$\begin{bmatrix} u_d \\ u_q \end{bmatrix} = \begin{pmatrix} LS & wL \\ -wL & LS \end{pmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} v_d \\ v_q \end{bmatrix} \tag{3}$$

Where u_d and u_q are the grid voltage, i_d and i_q are the inverter current, L is the filter inductance, and v_d and v_q are the control voltages. It can be seen from (3) that the inverter current is coupled in terms of the d and q axis, and id and iq are not only affected by vd and vq but also by the coupled voltage ωLi. Thus, to control id and iq independently, the coupled value must be cancelled, and current feedforward compensation is usually used to decouple the current in the d–q frame [14]. By introducing $-\omega L i_q$ and ωLid, the current controller with PI control is written as follows:

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = \begin{bmatrix} u_d \\ u_q \end{bmatrix} - \left(k_p + \frac{k_i}{S}\right) \begin{bmatrix} i_{d\_ref} \\ i_{q\_ref} \end{bmatrix} + \begin{pmatrix} -wL & 0 \\ 0 & wL \end{pmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} \tag{4}$$

By inserting (4) into (3), the relationship between the reference control current and the inverter current can be derived as follows:

$$\begin{bmatrix} i_{d\_ref} \\ i_{q\_ref} \end{bmatrix} = \left(\frac{LS}{k_p + \frac{k_i}{S}} + 1 \right) \begin{bmatrix} i_d \\ i_q \end{bmatrix} \tag{5}$$

Then the voltage outputs Vd and Vq of the current controller are converted into three modulation signals Uabc-ref used by the PWM generator.

The switching angles generated by the PWM controller are used to control the inverter and inject the PV power directly into the grid.

V. RESULTS AND DISCUSSION

Simulation results of a grid-connected photovoltaic field in Matlab/Simulink are presented to evaluate the effectiveness of the proposed control system.

The simulations were performed in discrete mode with a step size of 5µs in order to see the behaviour and accuracy of the control system in adjusting and tracking the reference voltage and power instantaneously at each variation of the solar irradiation.

In sunny weather, the PV system follows a normal distribution of solar irradiance during the day and reaches its maximum power at noon, as shown in Figures 3 and 4. The daily load curve shows an industrial load with a maximum power of 600 kW, the load profile varies throughout the day and shows periods of high demand in the evening and morning and lows during the night. The result of the simulation is presented in the following figures. The PV generator power and grid power, the voltages between the phases, the current at the output of the grid, and the PV systems are shown under different solar radiation systems (Fig. 3 and 4).

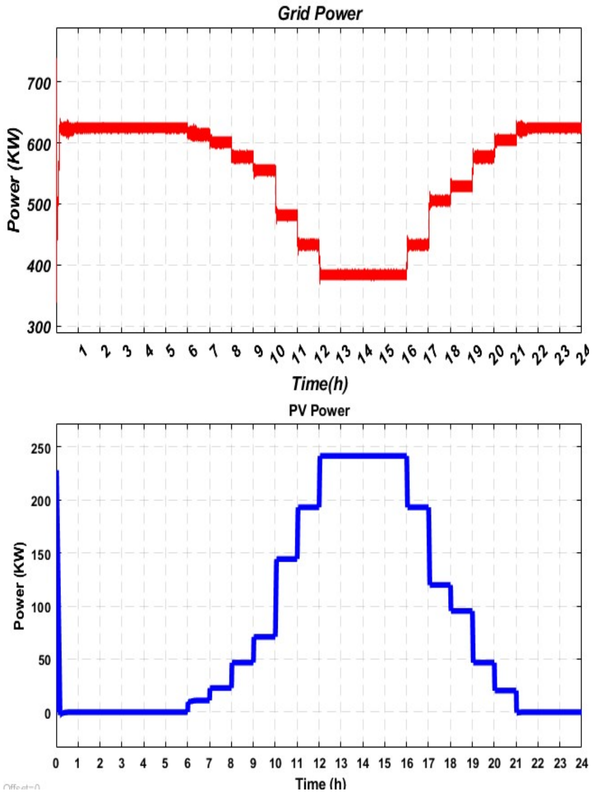

Fig. 3. Grid and Photovoltaic power variation during a day.

The active power variation of the PV system and the grid for one day is shown in Figure 3. It can be seen that all the power produced is injected directly into the grid. The PV system starts to produce energy to meet the demand. From 10:00 to 18:00 the (PV) system supplies the entire load and the excess power will be fed directly into the grid at a high price to also gain economic benefits. During the evening (18:00 to midnight) the energy demand reaches its maximum value at 21:00, and the grid supplies the full energy to meet the power demand.

As shown in Fig. 3. the proportional-integral (PI) current controller is used to keep the current injected into the grid sinusoidal and achieve high dynamic performance under rapidly changing atmospheric conditions because the current injected by the PV system fluctuates throughout the day due to changes in solar irradiation.

The grid regulates the voltage and frequency of the signal generated by the PV plant, illustrating the relevance of current and voltage regulators, PWM generators, and phase-locked loops in changing the power flow and refining the waveform fed into the grid. The three-level injection inverter (GTI) regulates the DC bus voltage to 500 V and maintains the unity power factor. The control solution uses two control loops: an exterior control loop that maintains a 250 V DC link voltage and an internal control loop that maintains grid currents Id and Iq (active and reactive components).

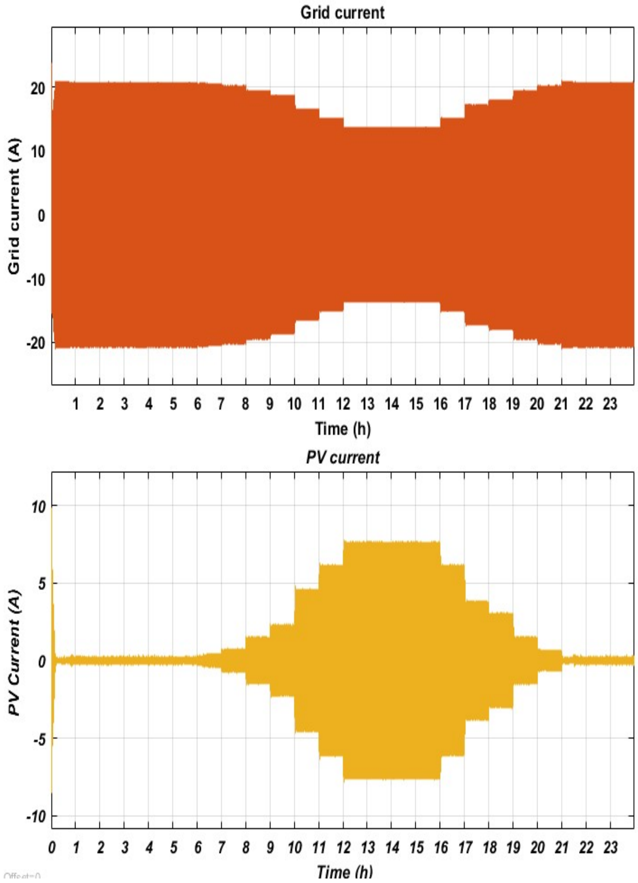

Fig. 4. Grid and Photovoltaic current variation during a day.

The DC link voltage is chosen to give the inverter a steady voltage. The output of the external DC voltage regulator serves as the current reference Id. The current reference Iq is set to zero to maintain the unity power factor.

The voltage outputs Vd and Vq of the current regulator are converted into three modulation signals U_{ref} abc used by the three-level pulse generator with pulse width modulation (PWM).
The phase-locked loop is used to orient the dq frame. Then, the PLL calculates the angular velocity of the charge voltage vector wl [13].

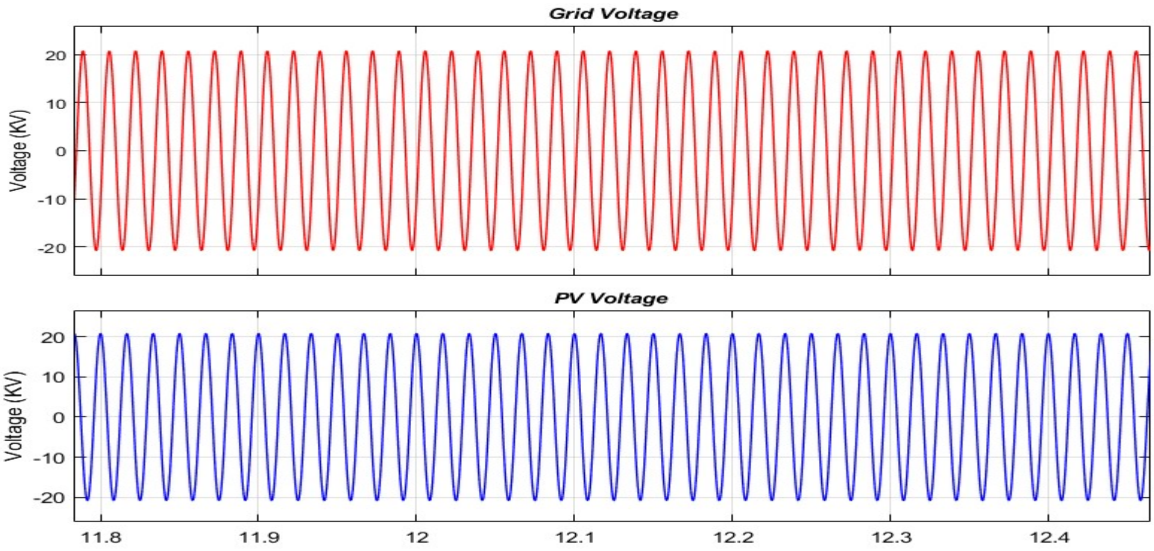

Fig. 5. Grid and Photovoltaic voltage during a day.

It can be seen that each time the solar irradiance changes, the voltage (Vdc_average) changes to allow the MPPT controller to extract the maximum average power Pdc from the array.

In the morning, as the irradiance increases, the DC control loop adjusts and increases its DC voltage value to inject the maximum power to the grid progressively as the irradiance changes. The irradiance reaches its highest value during midday, allowing the PV to inject the maximum amount of power. The MPPT controller begins tracking the maximum power by controlling the PV voltage to extract the maximum power each time the irradiance changes.

Figure 5 shows that the PWM control with the control blocks improves the quality ofthe voltage and current waveform of the PV system fed into the grid. When the solar irradiation decreases rapidly in the evening, the control system reduces the VDC reference to extract the maximumpower from the PV system as shown in Figures 3 and 4.

VI. CONCLUSION

In this paper, we focused on a control strategy and injection of photovoltaic power to the grid to facilitate the insertion of variable resources to the grid while ensuring better voltage and frequency quality. The simulation results demonstrated the effectiveness of the proposed control systems in controlling the energy flow during power injection to the grid, such as power system stability and power quality, and in improving system performance, including the fast dynamic response.

In addition, the use of control strategies capable of controlling active and reactive power ensures correct voltage amplitude and operating frequency generation of the reference signal.

VII. REFERENCES

[1] Attou Nasreddine. Contribution à l'étude des Réseaux Electriques Intelligents du futur (Smart-Grids). Thèse de doctorat. Faculté de génie électrique Université Djillali Liabes de Sidi Bel Abbes, Algérie 2022.

[2] Sreedevi, J., Ashwin, N., et Raju, M. Naini. A study on grid-connected PV systems. In: 2016 National Power Systems Conference (NPSC). IEEE, 2016. p. 1-6.

[3] Arulkumar, K., Palanisamy, K., et Vijayakumar, D. Recent advances and control techniques in grid-connected PV system–A review. International Journal of Renewable Energy Research, 2016, vol. 6, no 3, p. 1037-1049.

[4] Rallabandi, Vandana, Akeyo, Oluwaseun M., Jewell, Nicholas, et al. Incorporating battery energy storage systems into multi-MW grid-connected PV systems. IEEE Transactions on Industry Applications, 2018, vol. 55, no 1, p. 638-647.

[5] Tobnaghi, Davud Mostafa. A Review on impacts of Grid-connected PV system on Distribution Networks. International Journal of Electrical and Computer Engineering, 2016, vol. 10, no 1, p. 137-152.

[6] Adefarati, T. et Bansal, R. C. Energizing renewable energy systems and distributed generation. In : Pathways to a smarter power system. Academic Press, 2019. p. 29-65.

[7] Balamurugan, M., Sahoo, Sarat Kumar, et Sukchai, Sukruedee. Application of soft computing methods for grid-connected PV system: a technological and status review. Renewable and Sustainable Energy Reviews, 2017, vol. 75, p. 1493-1508.

[8] LAL, Vivek Nandan et SINGH, Sri Niwas. Control and performance analysis of a single-stage utility-scale grid-connected PV system. IEEE Systems Journal, 2015, vol. 11, no 3, p. 1601-1611.

[9] Kumary, SV Swarna, OO, V. Arangarajan Aman Maung Than, Shafiullah, G. M., et al. Modelling and power quality analysis of a grid-connected solar PV system. In : 2014 Australasian Universities Power Engineering Conference (AUPEC). IEEE, 2014. p. 1-6.

[10] Verma, Aran Kumar, Singh, Bhim, et SHAHANI, D. T. Grid interfaced solar photovoltaic power generating system with power quality improvement at AC mains. In : 2012 IEEE Third International Conference on Sustainable Energy Technologies (ICSET). IEEE, 2012. p. 177-182.

[11] Srisaen, N. et Sangswang, A. Effects of PV grid-connected system location on a distribution system. In : APCCAS 2006-2006 IEEE Asia Pacific conference on circuits and systems. IEEE, 2006. p. 852-855.

[12] Attou, Nasreddine, Zidi, Sid-Ahmed, Khatir, Mohamed, et al. Energy Management System for Hybrid Microgrids. Electrotehnica, Electronica, Automatica, 2021, vol. 69, no 2, p. 21-30.

[13] Attou, Nasreddine, Zidi, Sid-Ahmed, Khatir, Mohamed, et al. Grid-Connected Photovoltaic System. In : ICREEC 2019. Springer, Singapore, 2020. p. 101-107.

[14] Bai, Wenlei, Abedi, M. Reza, et Lee, Kwang Y. Distributed generation system control strategies with PV and fuel cell in microgrid operation. Control Engineering Practice, 2016, vol. 53, p. 184-193.