

Voltage Control of Grid-Connected PV System Facing Voltage Sags

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Abstract

There is an exponential growth of implementation of renewable energy generation systems in recent years. The photovoltaic system (PV system) takes an important place due to its simple integration to the grid. However, a disturbance in the grid could have a significant impact on PV system operation. Voltage sags are acknowledged to be one of the major power quality disturbances which can provoke the PV system disconnection due to the decoupling protection. With a less severe voltage sags, for example in case of a momentary faults or short circuits on the adjacent feeder, this disconnection is not desired. This results to the essential need of the development a voltage control at the connection point. This article presents the development an auto adaptative voltage control integrated into the PV inverters. Facing the voltage sags, this control system allows the voltage at the connection point greater than an admissible voltage threshold of decoupling protection, the connection of PV system is so maintained. The models and simulations are developed in Matlab-Simulink. The obtained results are satisfied.

Keywords: Voltage sags, auto-adaptative voltage control, PV system.

1. Introduction

Nowadays, most of the worldwide production of energy is ensured by fossil sources. The consumption of energy from the fossil sources faces to the exhaustion of these sources, the climate changes, and the emission of CO₂. This results in the exponential growth of implementation of renewable energy generation systems. Among the renewable energy sources, photovoltaic solar energy (PV) is a promising source. In the current economic context (tariffs of purchase, tax credit, national or regional aids, etc.), the number of requests for connection of PV is increasing in an exponential way. There are interactions between PV system and power network. The behavior of PV systems connected to the distribution grid has been reported by many groups [1], [2]. PV system can have a significant impact on the operation of the electrical system or may cause malfunctions [3]. Besides, a disturbance in the network could have an important impact on PV system operation. Voltage sags are acknowledged to be one of the major power quality disturbances. A low voltage caused by voltage sag can provoke the PV system disconnection due to the decoupling protection [4], [5].

Currently, almost inverters integrated with a classic regulation (P/Q regulation) cannot control voltages. In the worst case, if the voltage sags are very deep (i.e. the voltage can drop practically to a few V

for a few hundred milliseconds), it is impossible to maintain the PV systems in such conditions. But in less severe voltage sags, for example in case of a momentary faults or short circuits on the adjacent feeder, the maintenance of PV systems connected to the grid is achievable. The connection is maintained by a control system integrated into the inverters which allows the voltage at the connection point greater than an accepted threshold. This threshold voltage depends on the rules of each country and each type of the grid.

In this paper, the proposed method relates to the integration of an "intelligent" control/command system in the PV inverters. This control system allows participation in maintaining the voltage at the connection point during a voltage dip or voltage disturbances on the grid and participate in the optimal regulation of the grid voltage by using a "auto-adaptive voltage control". It permits to increase the rate of insertion, the performances, and the flexibility of operation of PVs in an intelligent and adaptive way.

Section 2 of the paper presents firstly building an auto-adaptative voltage control for PV system. Secondly, section 3 will evaluate the effectiveness of the proposed control through Matlab/Simulink software. Finally, the conclusions and perspectives will be presented in section 4.

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2. Development of auto-adaptative voltage control for PV system

PV inverters can be operated with different control schemes according to their operation mode [6],[7]. Three types of reactive power compensation schemes can be applied for grid-tied inverters: an active and reactive power control scheme (*P/Q*-control); a control of active power and power factor (*P/PF*-control); a control of active power and voltage (*P/V*-control). The voltage/frequency (*V/f*) control scheme is generally used for grid-forming inverters [8].

For the *P/Q* control scheme, the active and reactive power outputs of PV are fixed to set-point values $P_{setpoint}$ and $Q_{setpoint}$. Similarly, for the *P/PF* control scheme, the active power and the power factor are fixed to set-point values by changing the reactive power in order to maintain a constant power factor.

For the *V/f* control scheme, the voltage and the frequency are fixed to set-point values $V_{setpoint}$ and $f_{setpoint}$. The active and reactive powers are controlled in order to maintain a constant voltage and frequency. A “frequency-active power” and “voltage-reactive power” droop is used.

The energy source is represented by a PV-power source. The authors suppose that the dynamic of the entire system of the up-stream PV system (primary source) could be represented by a first-order response which enables to change the time constant according to the characteristics of the primary source. In addition to this dynamic part of the PV’s characteristics, the operation limits of active and reactive power are included. Only the described parameters, enhanced by primary energy availability, e.g. with variations of solar irradiation, define the characteristics of PV.

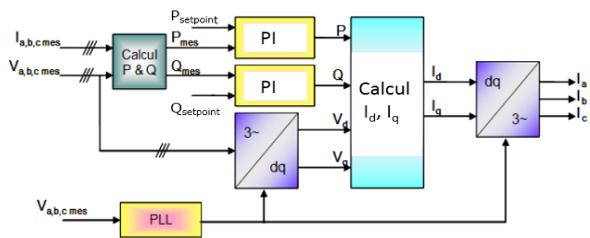


Fig 1. *P/Q* control scheme.

The operation principle of the *P/Q* control scheme is described as Fig.1. From the current and voltage measured at the connection point, the power (P_{mes} and Q_{mes}) and the corresponding voltage are determined. These powers will be adjusted by two proportional-integral (PI) controllers. The difference between the setpoint power $P_{setpoint}$ and $Q_{setpoint}$ and the measured power P_{mes} and Q_{mes} will be handled by the

ratio (K_p) and the integral (K_{ip}). From the output power through the PI, the desired current is calculated by the Park transformation:

$$\begin{cases} I_d = \frac{2(P \cdot V_d + Q \cdot V_q)}{3(V_d^2 + V_q^2)} \\ I_q = \frac{2(P \cdot V_q - Q \cdot V_d)}{3(V_d^2 + V_q^2)} \end{cases} \quad (1)$$

where I_d , I_q and V_d , V_q are Park transformation of currents and voltages at the output of the inverter; P and Q are the reference power (normally $Q=0$).

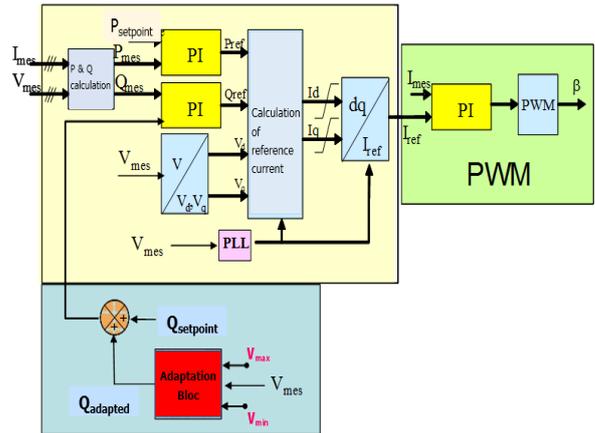


Fig.2. Auto-adaptive voltage controller of PV

Fig.2 presents the scheme of auto-adaptive voltage controller. The model of PV with this regulator is developed in three phases. It composes a *P/Q* control and a *P/V* control. In *P/V* control mode, the voltage setpoint is changed in an auto-adaptive way by using a fuzzy logic module or droop control. The change of setpoint voltage values is carried out, correlatively with the operation and location of PV, by respecting reactive power limits of each PV.

Three operating modes of the control are possible. They correspond to three possible states:

- **Normal state:** where the voltage is located inside a window of “desired” voltage ($V_{min_desired} \leq V \leq V_{max_desired}$). In this state, PV is in *P/Q* control (or *PF/VAR* control).

- **Disturbed state:** where voltage leaves the desired limits ($V > V_{max_desired}$ or $V < V_{min_desired}$). The goal of the adaptive control is to maintain, within the limits of the system, the voltage between these fixed values. Thus, under disturbed conditions, PV commutates in voltage regulation mode (*P/V* control). Here, only reactive power is used to control voltage at the PV connection point. The voltage set point is set at $V_{min_desired}$ or $V_{max_desired}$ according to whether the network voltage profile is too low or too high. If PV is in reactive power limitation ($Q=Q_{min}$ or $Q=Q_{max}$), it

cannot ensure any more the control in the desired voltage. The voltage moves and reaches critical state when voltage admissible limits are crossed.

- **Critical state:** where the voltage is out of the admissible limits ($V > V_{max_admissible}$ or $V < V_{min_admissible}$, in France $V_{max_admissible}=1.1$ pu, $V_{min_admissible}=0.9$ pu) and, as previously explained, PV cannot act any more by compensation of reactive power. In the critical state regulation of active power becomes necessary. So, PV commutates in active power regulation mode (Mode P). It means that PV changes active power generation in order to bring back the voltage in the admissible values.

The change of control operating mode is automatic and auto adaptive. Moreover, the proposed method only uses voltage or current measurements at the connection point and does not need any communication link with DNO or other PVs.

The control changes in an adaptive way the desired voltage value. The desired voltage depends on the voltage at the PV connection point, and the level of reactive power used compared to the Q_{limit} of each PV. The calculation of the desired limit is based on fuzzy logic as shown in equation (2), where

$$\begin{aligned}
 V_{mesure}(pu) &= V_{mesure}/V_{nominale} \text{ and} \\
 Q_{mesure}(pu) &= Q_{mesure}/Q_{limit}: \\
 V_{max} &= V_{max_admissible} - V_{nominale} \\
 V_{min} &= V_{nominale} - V_{max_admissible} \\
 V_{max_desired} &= V_{nominale} + C \cdot V_{max} \\
 V_{min_desired} &= V_{nominale} - C \cdot V_{min}
 \end{aligned}
 \tag{2}$$

After identifying the desired voltage in equation (2), the authors can calculate the reactive power required for voltage regulation. The coefficient C is identified by fuzzy logic as in the Fig. 3.

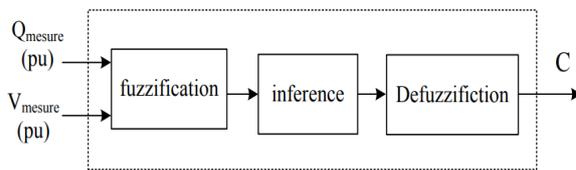


Fig. 3. Calculation of the coefficient C by fuzzy logic

Adaptive limits allow all PVs to contribute to voltage profile without communication system, even PVs located on not critical voltage feeders. In fact, the more the voltage measured is closed to 1pu the more voltage desired window will be narrow. This window moves according to the quantity of reactive power provided or absorbed compared with physical limits of the PV considered. More the contribution of reactive

power is important more the window of voltage will increase by respecting the limits ($V_{min_admissible} \leq V_{min_desired} \leq V_{max_desired} \leq V_{max_admissible}$).

3. Simulation results

This section evaluates the effectiveness of the proposed control through Matlab/Simulink software. In order to show the capacity of the proposed local voltage control of PVs, a medium voltage (MV) grid (Fig. 4) is used for the study. This MV network is supplied by a 110/22kV, 40 MVA transformer. It composes 53 and a 1000kW PV system.

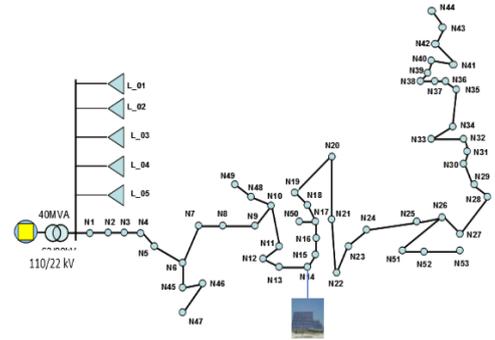


Fig.4. Medium voltage grid studied.

It assumes that the PV systems are disconnected facing a voltage dip $U \leq 85\%$ of the nominal voltage for PV systems connected in MV grid (such as French requirements [8]), this threshold voltage depends on the rules of each country and each type of the grid. A voltage sag caused by a momentary fault or a short circuit on the adjacent feeder appears at time $t = 0.5s$ for 500m. For PV system, two types of control are used: classical control (P/Q control) and Auto-adaptive voltage control.

With a short-circuit on the adjacent feeder L_{05} , in case of operating in P/Q control mode, Fig.5 illustrates the power of the 1000kW PV system and the voltage at the connection point

The simulation results show that the voltage at the connection point of PV systems exceeds the limit voltage normalized by the assumed recommendation (0.85pu), then this PV system can be disconnected by their associated protections and the reactive power remains zero at the time of voltage sags. The reactive power of PV systems should therefore be modified to keep the voltage within the admissible limits.

In case of using the auto-adaptive voltage control, the grid structure, parameters and scenario are identical to those of the above study. The Fig.6 shows that the PV inverters participate in the voltage regulation. For the P/Q control regulator, the reactive power always remains zero. Facing voltage sags, the PV system produces reactive power to restore the voltage in the admissible threshold by the decoupling

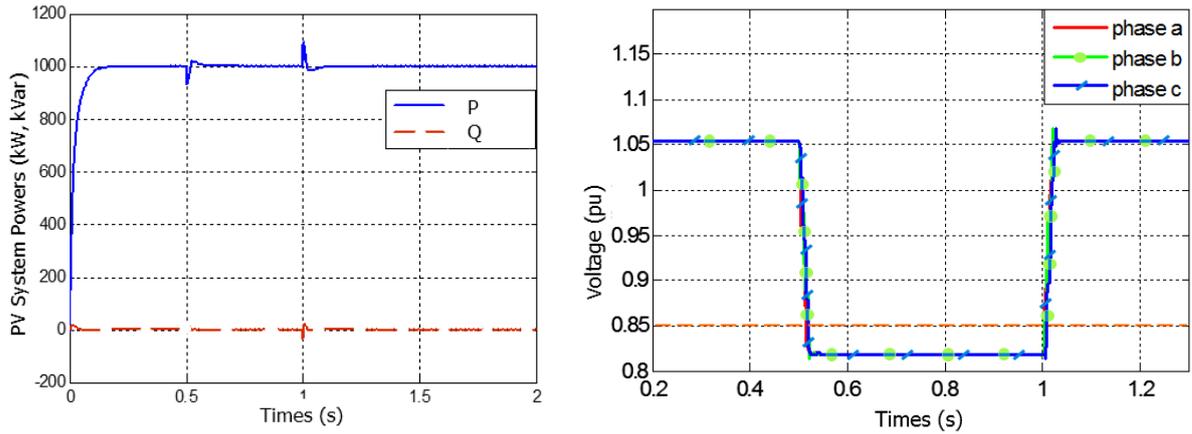


Fig 5. PV system powers connected to the MV grid and voltage variation with P/Q control.

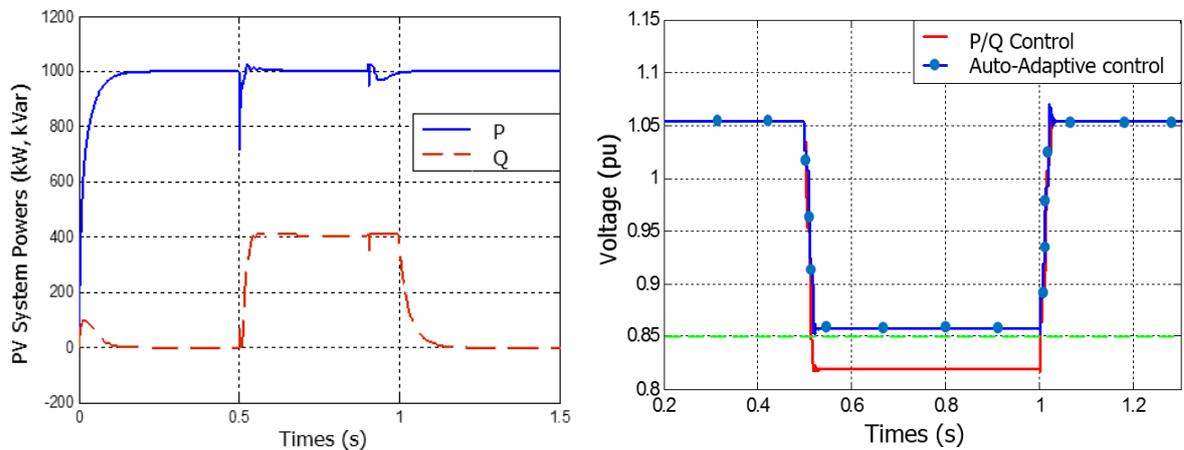


Fig 6. PV system powers and voltage variation with Auto-adaptative voltage control.

protections. Therefore, the voltage at the connection node (with auto adaptative voltage control) is greater than 0.85pu. In this case, this PV system remains connected to the grid.

The proposed voltage control is so capable to maintain the PV system connected facing the voltage sags and voltage disturbances on the grid. The degree of reactive production or absorption depends on different factors such as the connection location, the reactive supply capacity of PVs, grid voltage profile, and grid parameters.

4. Conclusion

This paper presents a local voltage control based on auto-adaptive voltage control integrated into PV inverter, this control uses local information. Based on absorption/production of reactive power, the voltage of PV systems at the connection is so improved and restored in the admissible threshold during a voltage sags (in case of momentary faults or short circuits on the adjacent feeder). A lot of advantages are brought by using such inverter control such as reducing

connection costs, increase the rate of insertion, the performances of operation of PV systems, the power quality of grid and without reducing the efficiency of the decoupling device of the inverters.

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