Modeling approach of a photovoltaic conversion in the PLC frequency range

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Abstract

This paper highlights a modeling approach of photovoltaic (PV) panels based on a single diode model and their conversion unit (buck-boost converter, DC/AC converter and LCL filter) in order to study the impact of their input impedance on the powerline channel transfer function in the frame of the study of Power Line Communication (PLC) technology performance. Hence, a single diode model is proposed and applied in order to simulate a photovoltaic panel by using the manufacturer datasheet. Also, the conversion unit associated with the PV installation is simulated using MatLab/Simulink. The input impedance of the global chain obtained by the model is finally used to study its impact on the powerline channel transfer function when connected to a given network topology.

1 Introduction

Since a few years, the presence of renewable energies in the electrical systems is booming. The reason of this emphasis is the necessity to find an alternative to fossil fuels whose ressources are dwindling. Hence, the installation of photovoltaic units, that are characterized by a fluctuating generation difficult to predict, is increasing especially to ensure the recommendations of the Horizon 2020 programme. Moreover, the associated conversion unit (boost converter, DC/AC converter...) generates harmonics that disturbe the network. In order to maintain the efficiency of power networks, the concept of the Smart Grid and Smart Metering in Low and Medium Voltage (LV and MV) networks has strongly been considered [1]. Power Line Communication is predisposed to become the technology used to exchange informations within the power network infrastructure. In this context of data transmission, these voltage fluctuations induce a variation of impedance which changes the transfer function of the PLC channel. These variations have to be controlled and predicted in order to allow the network manager to have an estimate of the PLC communication robustness in the current operating environment of distribution networks.

Power Line Communication are grouped into two families: Narrowband and Broadband PLC. Narrowband PLC is practically used for low bandwidth communication applications as control, command and monitoring. The frequency range is between 9 - 148.5 kHz in Europe (CENELEC standard) and 150 - 450 kHz in the USA. Broadband PLC uses a much wider frequency band (between 1.6 MHz to 30 MHz) and is employed for in-home high-speed data transfer applications.

In this paper, a single diode model is studied in order to simulate the behaviour of a photovoltaic panel (using MatLab). The parameters used for the simulation have been extracted from the manufacturer datasheet. Then the associated conversion unit composed of a boost converter, an DC/AC converter and a LCL filter is simulated using MatLab/Simulink and the resulting input impedance of the global chain is generated in the PLC frequency range. Finally, simulations are performed in order to study the impact of a voltage variation (and thus of an impedance variation) induced by the PV unit on the transfer function of a given network, including cables and transformers.

2 Modeling of a photovoltaic unit

Figure 1 shows a typical PV unit scheme which is composed of a photovoltaic panel followed by a buck-boost converter in order to adapt the voltage at the input of the DC/AC converter and a LCL filter. A Maximum Power Point Tracking (MPPT) algorithm is used to generate the maximum power from the PV. In this section, first, a single diode model is proposed to simulate the photovoltaic panel. Secondly, the associated con-

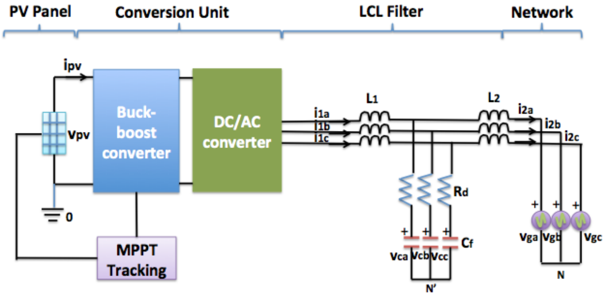

Fig. 1: *PV unit scheme*

version unit is simulated using MatLab/Simulink.

2.1 Single diode model

A photovoltaic cell is composed of a single p-n junction. The source used to excite electrons and holes is obtained thanks to light and the voltage through the cell depends on the gap energy. The generated voltage induces a current inside the cell. A photovoltaic cell can thus be modeled as a current source in parallel with a diode (Fig. 2). The output current of the PV is thus given by ([2]):

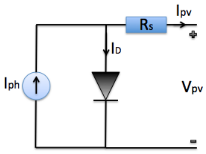

Fig. 2: *Single diode model*

$$I_{pv} = I_{ph} - \exp\left((V_{pv} + I_{pv} \cdot R_s) \cdot K_1 + K_2\right) \tag{1}$$

where $K_1 = \frac{q}{nKT}$ and $\exp(K_2) = I_o$. In this equation, n is the diode factor, K the Boltzmann constant [J/K], T the temperature [K] and q the electron charge [C]. I_{ph} is the photocurrent [A], I_o the diode saturation current [A], I_D the current through the diode [A], V_{pv} the PV cell voltage [V], I_{pv} the PV cell current [A] and R_s the series resistance which represents the resistive losses of material [Ω].

There are four unknowns in these equations: K_1, K_2, R_s and I_{ph}. They can be obtained by the knowledge of the short-circuit current (I_{sc}), the open circuit voltage (V_{oc}) and the current and voltage at the Maximum Power Point (I_m and V_m). The system of four equations (short-circuit, open circuit and maximum power) that have to be solved in order to obtain the four unknowns are:

$$\left\{\begin{array}{rl} I_{sc} = & I_{ph} - \exp((I_{sc}R_s)K_1 + K_2) \\ 0 = & I_{ph} - \exp(V_{oc}K_1 + K_2) \\ I_m = & I_{ph} - \exp((V_m + I_m R_s)K_1 + K_2) \\ \dfrac{dP_{pv}}{dV} = & 0 \end{array}\right. \tag{2}$$

and finally the solutions are given by:

$$\left\{\begin{array}{rl} K_1 = & -\dfrac{I_m}{V_m(I_m - I_{ph})} \\ R_s = & \dfrac{log(\dfrac{I_{ph} - I_m}{I_{ph}}) - V_m K_1 + V_{oc}K_1}{I_m K_1} \\ K_2 = & log(I_{ph}) - V_{oc}K_1 \\ I_{ph} = & I_{sc} + \exp((I_{sc}R_s)K_1 + K_2) \end{array}\right. \tag{3}$$

Note that V_{oc} and I_{sc} are dependent on the irradiance E_i and the temperature T_i:

$$V_{oc} = V_{oc(stc)} + TC_v(T_i - T_N) \tag{4}$$

$$I_{sc} = \frac{E_i}{E_{iN}} I_{sc(stc)}(1 + \frac{TC_i}{100}(T_i - T_N)) \tag{5}$$

where E_{iN} and T_N represent respectively the irradiance and the temperature in the standard test conditions stc ($E_{iN} = 1000W/m^2$, $T_N = 25^\circ C$). If a photovoltaic panel is composed of N_p cells in parallel and N_s cells in series and if an uniform irradiance and temperature are considered, we can write the following relationship:

$$I_{ph,tot} = N_p I_{ph}; I_{pv,tot} = N_p I_{pv}; R_{s,tot} = R_s \frac{N_s}{N_p} \tag{6}$$

2.2 PV Conversion unit and MPPT algorithm

Once the photovoltaic panel has been modeled, the associated conversion unit has to be defined. Fig.3 shows the complete chain composed by the photovoltaic panel, the buck-boost converter, the DC/AC converter, the LCL filter and the electrical network (modeled here as an ideal $230V$ voltage source). In order to generate the maximum power from the photovoltaic panel, a MPPT algorithm has been implemented in MatLab/Simulink. The MPPT algorithm is given in Fig.4. If $dP = P(t) - P(t-1) < 0$ and $dV_{ref} = V_{ref}(t) - V_{ref}(t-1) < 0$, V_{ref} is increased; If $dV_{ref} > 0$, V_{ref} is decreased. If $dP > 0$ and $dV_{ref} < 0$, $V_{ref} > 0$ is decreased; If $dV_{ref} > 0$, V_{ref} is increased. In these inequations, t represents the time.

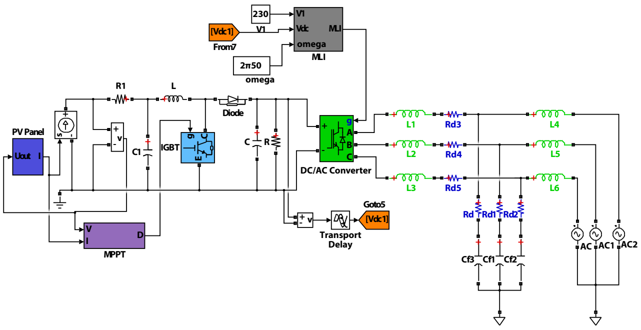

Fig. 3: *Complete chain of a photovoltaic unit*

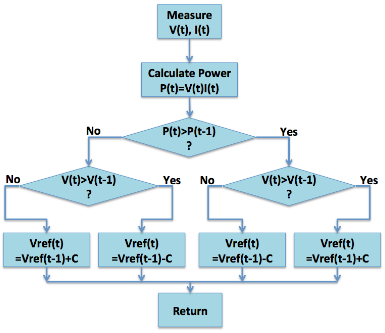

Fig. 4: *Explicative scheme of the MPPT algorithm*

The components values used for the simulation are given in Table 1 ([3], [4]).

Component	Value	Component	Value
f_{fund}	$50Hz$	L_1, L_2, L_3	$500\mu H$
$f_{DC/ACconv}$	$10kHz$	L_4, L_5, L_6	$130\mu H$
R_1	1Ω	R_d, R_{d1}, R_{d2}	0.3Ω
L	$100mH$	R_{d3}, R_{d4}, R_{d5}	0.1Ω
C_1	$500\mu F$	C_{f1}, C_{f2}, C_{f3}	$99\mu F$
C	$10mF$	AC voltage sources	$230V$
R	500Ω		

Table 1: Components values of the PV conversion unit

3 Simulation Results

3.1 Comparison between measurements and model for the PV module

In order to attest on the efficiency of the PV module modeling, the performance of a four PV modules unit connected in series from the DROBen Energy company has been studied. The measurement setup is illustrated in Fig.5. The PV unit charges a variable load and a multimeter (Agilent 34401A) is used to measure the current and voltage at the load position. By varying the load value, the evolutions of current, impedance and power versus voltage are obtained. The characteristics of a PV module are given in Table 2 [5]. An irradiance of $750W/m^2$ and a temperature of $40\,^{\circ}C$ were measured via a probe. Fig. 6 a, b and c show a comparison between the measured evolution of current, power and impedance versus voltage respectively and the simulated ones. The simulations and measurements are very close to each other. Consequently, it can be concluded on the efficiency of the single diode model. Hence, in the studied configuration (four PV modules in series, an irradiance of $750W/m^2$ and a temperature of $40\,^{\circ}C$), the installation provides a power of around 360 W at the MPP. At this point, the PV unit voltage and current are about $61V$ and $5.9A$ respectively.

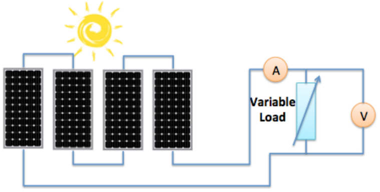

Fig. 5: *Measurement setup*

Parameter	Value	Parameter	Value
P_m	$130W$	$V_{oc(std)}$	$21.1V$
U_m	$17.1V$	TC_i	$0.08\%/^{\circ}C$
I_m	$7.6A$	TC_v	$-60mV/^{\circ}C$
$I_{sc(std)}$	$8.3A$		

Table 2: Components values of the PV module

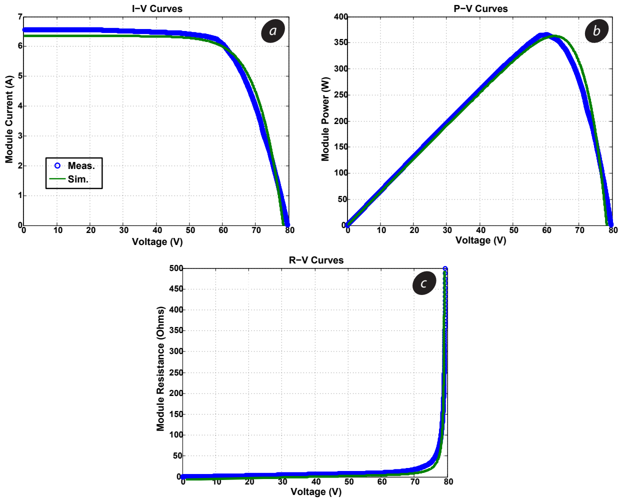

Fig. 6: *Comparison between the simulated performance of the PV unit and the measurements*

3.2 Simulation results for the PV conversion unit

Since the PV module model is validated, it can be used in the MatLab/Simulink environnement in order to simulate a PV conversion unit as shown in Fig.3. By imposing the parameters values of table 1 and table 2 in the simulation circuit, the evolution of the impedance between two phases (a and c) obtained at the output of the LCL filter is given in Fig.7 in the Narrowband PLC frequency range. This result has been obtained by choosing an irradiance step variation from $500W/m^2$ to $1000W/m^2$ at the time $t = 1s$. It can be seen that the impedance presents some frequency variations until $t = 0.5s$ with the most important ones at the time $t = 0.22s$. This time corresponds to the

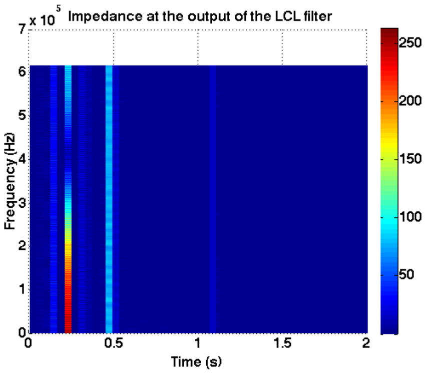

Fig. 7: *Evolution of the impedance at the output of the LCL filter*

end of the PV voltage and current transients due to the presence of the MPPT algorithm in the system. Moreover, at the time $t = 1.1s$ an increase of the impedance is observed. This time corresponds to the end of the transient due to the step variation of irradiance imposed from $500W/m^2$ to $1000W/m^2$. Once the impedance evolution in the frequency domain is obtained, it can be used in order to simulate its impact on the transfer function of a network. Hence, in [6], the authors have highlighted the possibility to use the two-port network model to simulate, with a reasonable consistency, the behavior of cables and transformers. A simulation tool using this model has been developed (using MatLab) in order to estimate the transfer function of an elaborate power network topology. In this paper, an example of topology that takes into account the presence of a photovoltaic unit is proposed (Fig.8) and its transfer function is simulated (Fig.9) in the Narrowband PLC frequency range (between 0 Hz and 500kHz). Note that each house is taken into account by the way of an impedance of 100Ω in the simulation proposed. It can be seen in Fig. 9 that the presence of the PV unit in the network leads to variations in the transfer function evolution. Some important variations are observed at the times corresponding to the end of each transient. Consequently, the higher the PV units number in the topology, the higher the attenuation. It is an important observation for the study of the PLC communication performance which can change according to these variations.

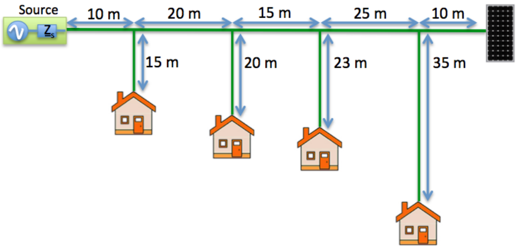

Fig. 8: *Example of a topology with 4 branches*

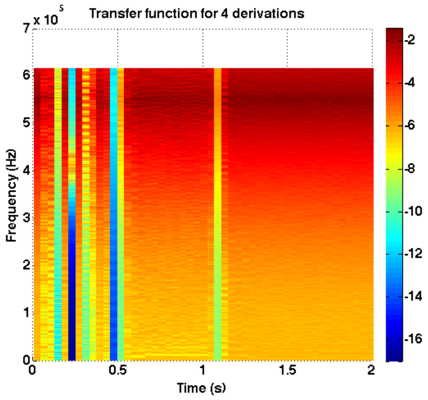

Fig. 9: *Transfer function for a topology with 4 branches and terminated with a PV unit*

4 Conclusion

In this paper, a method for performance modeling of a PV module based on a single diode model is applied. The parameters needed for the model have been extracted by the way of the manufacturer datasheet. The model has shown a good agreement between the measurements and the simulation. Then, the PV model has been implemented in a MatLab/Simulink simulator taking into account a bust-boost converter, a DC/AC converter and a LCL filter in order to simulate the global chain impedance of a PV unit. The component values of the model have been taken according to some references in the domain. Finally, the resulting impedance has been used in a transfer function model based on a two-port network modeling in order to simulate the impact of this impedance versus time and frequency on a simple topology composed with 4 branches. It has been concluded that the higher the PV units number in the topology, the higher the attenuation.

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