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Impact of the aging of a photovoltaic module on the performance of a grid-connected system

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ABSTRACT

Photovoltaic systems belong to the green energy dynamics which is an ambitious program based on energy efficiency and sustainable development. In this study, the impact of the aging of a photovoltaic module is investigated on the electrical performance of a grid-connected system. A photovoltaic conversion chain with MPPT (Maximum Power Point Tracking) control and LC (Inductor-Capacitor) filter is modeled and dimensioned according to the grid constraints. A method of hybridation detection of the MPPT coupling long-time aging evolution and short-time determination is proposed. Aging laws for the electrical and optical degradations of the photovoltaic module are introduced for the long-time evolution. Results display the lowering of the maximal power point with a rate of 1%/year and a slight augmentation of the THD over time even though it remains inferior to the IEEE standard STD 19-1992 maximum value of 5% for a usage of 20 years. Moreover, an equivalent scheme for the additional electrical resistance engendered by the aging of the photovoltaic module regarding other resistances of the photovoltaic system is given. Finally, the elevation of this resistance by 12.8% in 20 years may have non-negligible consequences on the power production of a large-scale installation.

1. Introduction

With demographics on ongoing surge, energy from fossil fuel resources (petroleum, coal, natural gas or nuclear energy) is becoming insufficient regarding the increasing worldwide energy needs. It is therefore essential to find a viable and sustainable solution such as the production of electricity with renewable energy sources which represent a solution for the future given that they are less polluting and economical. For example, as in Algeria which has a broad solar potential, photovoltaic installations are one of the best means to generate electricity (Semaoui, 2004; Bendjamâa, 2012).

The optimization of a photovoltaic system is difficult because its power varies as a function of temperature and illumination, the reason for which, the photovoltaic panel can provide maximum power only for well-defined voltage and current values (Laronde et al., 2010). Besides, a photovoltaic module suffers degradations over time which reduces its performance (Ndiaye et al., 2013; Laronde et al., 2012; Charki et al., 2012). The maximum power point is indeed dipped through time with a degradation rate which varies in an unlike manner according to the location and the technology of the photovoltaic installation (Phinikarides et al., 2014). The presence of defects such as LID (Light Induced Degradation), hot spots, corrosion or delamination affects the photovoltaic cells and the constitutive materials used for their protection. In an earlier study, optical and electrical degradations were distinguished in order to simulate these effects (Doumane et al., 2015).

MPPT techniques are still being improved so as to ameliorate the convergence speed and the stability to reach the maximum power point (Alik and Jusoh, 2018). However, these techniques use the I-V characteristics of photovoltaic modules which are lowered time wise (Dkhichi et al., 2016). Hence, recent studies have sought to refine the maximum power detection in the degraded operating mode by developing diverse approaches. Dkhichi et al. put to use an artificial neural network intelligent control to predict the duty cycle affected by the degradation of solar cells with the goal to provide an adequate

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command to the boost converter which controls the photovoltaic system (Dkhichi et al., 2016). Faba et al. presented a methodology to spot the degradation of a photovoltaic module measuring the divergence between the model and the device behavior (Faba et al., 2017). The degradation of the module can be represented by a progressive alteration of the equivalent one-diode circuit model for the device. Chine et al. proposed an automatic fault detection method for grid-connected photovoltaic plants which provides a diagnostic signal to indicate the possible faults and their locations (Chine et al., 2014). Among the defects, the designed software tool permits to identify the photovoltaic aging and the MPPT error. An adaptive thermal stress control (ATSC) is put forward by Alghassi et al. to adjust the reference input of the PI control to extend the life expectancy of the DC-DC converter of a photovoltaic system (Alghassi et al., 2017). They insist on the fact that the real-time early failure prediction necessitates to consider different aspects like the stress level, the reliability of components and the MPPT efficiency.

Additionally, the transformation of the photovoltaic energy into alternating current (AC) and voltage is done by means of a voltage inverter, with the issue of eliminating the harmonics that accompany this output voltage (Ayub et al., 2014; Çelebi and Çolak, 2011; Latheef, 2006). One of the solutions is to insert a filter between the inverter and the load (Djellad et al., 2013). Passive filters are an easy, robust and cost-effective solution when repetitive operating conditions are considered. They are more economical to implement than synchronous condensers and well designed passive filters can be deployed in large sizes of Mvars with almost maintenance free service. Their implantation allows a better power quality and a reduction of the total harmonic distortion (THD) at the output of the inverter for photovoltaic grid-connected or autonomous systems (Tali et al., 2014; Chtouki et al., 2016).

The aim of our work is to study a grid-connected photovoltaic installation by appreciating the influence of the MPPT (Maximum Power Point Tracking) control and of the aging of the photovoltaic panel on the performance of the produced power. First, the model of the conversion chain is detailed by describing the sizing of each element, the dimensioning of the LC filter and the different time scales involved in the hybridation approach. The latter takes into account the short-time detection of the maximum power and the dropping of its value due to long-time aging. Then, the aging laws used are defined prior to simulating the current and the voltage delivered to the load for the distinct usage periods. The THD, the maximum power degradation rate and the consequence of the equivalent resistance raise are determined and discussed.

2. Modeling of the photovoltaic system

The modeled conversion chain is presented in Fig. 1 (Chebana, 2014). It consists of a photovoltaic panel, a DC/DC (Direct Current) converter with MPPT control, a DC/AC converter with PWM (Pulse Width Modulation) control, a passive LC filter and, a grid or a load.

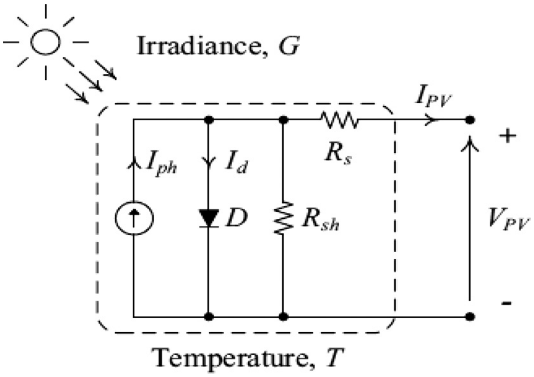

Fig. 2. Electrical equivalent circuit of the photovoltaic cell.

2.1. Photovoltaic cell

Fig. 2 shows the equivalent circuit of a photovoltaic cell. The current generator (I_{ph}) is connected in parallel with a diode, a series resistance (R_s) which is the internal resistance of the cell depending on the resistance of the semiconductor used and on the contact resistance of the collector grids, with a shunt resistor (R_{sh}) which corresponds to the leakage current at the junction (Yeung et al., 2017; Yahya and Mahmoud, 2008).

The mathematical equation for the current-voltage characteristic is deduced directly from Kirchhoff's law:

$$I_{pv} = I_{ph} - I_d - I_{sh}. \tag{1}$$

where I_d is the current of the diode (A) and I_{sh} is the shunt resistance current (A). Then, the expression of the electric current produced by the cell I_{pv} is (Rebei et al., 2015):

$$I_{pv} = I_{ph} - I_s\left(\exp\left(\frac{V_{pv} + I_{pv}R_s}{V_{tn}}\right) - 1\right) - \left(\frac{V_{pv} + I_{pv}R_s}{R_{sh}}\right) \tag{2}$$

where I_{ph} is the photo-current (A) with:

$$I_{ph} = (I_{ph,n} + K_1\Delta T)\frac{G}{G_n} \tag{3}$$

in which $I_{ph,n}$ is the nominal photocurrent (A), K_1 is the temperature coefficient of short-circuit current ($\mathrm{A\,K^{-1}}$), $\Delta T = T_m - T_n$ with T_m the module temperature (°C), $T_n = 25\,^{\circ}\mathrm{C}$ which is the nominal temperature, G is the irradiance ($\mathrm{W\,m^{-2}}$) and $G_n = 1000\ \mathrm{W\cdot m^{-2}}$ is the nominal irradiance. Besides, I_s is the reverse saturation current of the diode (A), V_t is the thermal voltage (V), V_{pv} is the voltage of the cell (V) and n is the ideality factor of the diode. In the case of a module, N_s cells are assembled in series.

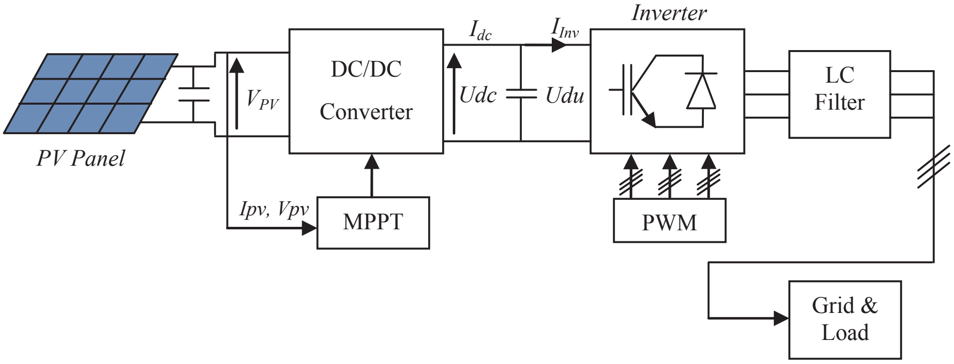

Fig. 1. Synoptic diagram of the photovoltaic conversion chain.