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ASPECTS REGARDING THE CORRELATION OF THE NUMBER OF SERIES/PARALLEL-CONNECTED PHOTOVOLTAIC MODULES WITH THE INVERTER INPUTS

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Abstract: *Because the photovoltaic system performance is significantly influenced by the environmental factors, particularly temperature and irradiance, a right correlation between the number of series/parallel-connected photovoltaic modules with the inverter inputs must be achieved to guarantee the safety of all components and the system in its entirety, and a high efficiency in electrical energy production. This paper addresses these issues and presents the results in a very simple and illustrative manner very easily to be implemented in the design procedure of a photovoltaic system,*

1. INTRODUCTION

According to the data published by the National Energy Regulatory Authority; Transelectrica - the transmission and system operator in Romania and the Romanian distribution companies, the number of prosumers at the end of October 2024 exceeded 175,000, and the installed power of the photovoltaic systems (PVS) among them was over 2 GW [1]. This explosion, from practically zero, occurred in 4 years and the pace continues to accelerate. This results in the need for increased attention to detail on the part of PVS designers and installers.

In this paper we point out the management of the correlation between the number of series/parallel-connected photovoltaic modules with the inverter inputs in terms of voltage and current.

2. METHODOLOGY

The main parameters of the PV modules used for the above analysis are:

- *Electrical data* under standard test conditions (STC), irradiance G_{STC} = 1000 W/m^2, spectrum AM 1.5 and cell temperature T_{STC} = 25°C: Nominal max. power (P_{max}), Opt. operating voltage (V_{mp-STC}), Opt. operating current (I_{mp-STC}), Open circuit voltage (V_{OC-STC}), Short circuit current (I_{sc-STC})
- *Temperature characteristics* under nominal module operating temperature (NMOT), irradiance of 800 W/m^2, spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s: Temperature coefficient of *Voc* (λ_V) expressed in %/°C, Temperature coefficient of I_{sc} (λ_I) expressed in %/°C, Nominal module operating temperature (NMOT).

The main parameters of the Inverter used for the above analysis are:

- Max. input voltage ($V_{max\ Inv}$), MPPT operating voltage range ($V_{min\ MPPT}$, $V_{max\ MPPT}$), Rated input voltage ($V_{r\ MPPT}$), Max. input current per MPPT ($I_{max\ MPPT}$), Max. short-circuit current ($I_{sc\ MPPT}$).

Due to the major impact of the environmental parameter (irradiance and ambient temperature T_a) on the PV modules output parameters, the simplified approach consisting of comparing the STC parameter with the inverter input ones is not an option.

The relations that express the above variabilities are presented in detail in [2-10] and are applied for the "worst case scenarios" that affect the PV module parameters, based on the actual slope, β and azimuth, γ, namely:

- for current and for operating voltage: that moment of a summer day with the greatest irradiance incident on the PV modules and the higher temperature of the modules which lead to the maximum values: $I_{sc\ max}$ and $I_{mp\ max}$ and to the minimum one: $V_{mp\ min}$:

$$I_{\mathrm{sc\ max}} = I_{\mathrm{sc}}\left(G_{max}, T_{max}\right) = I_{\mathrm{sc-STC}}\left[1 + \frac{\lambda_I}{100}\cdot\left(T_{max} - 25\right)\right] G_{max}/G_{STC} \tag{1}$$

$$I_{\mathrm{mp\ max}} = I_{\mathrm{mp}}\left(G_{max}, T_{max}\right) = I_{\mathrm{mp-STC}}\left[1 + \frac{\lambda_I}{100}\cdot\left(T_{max} - 25\right)\right] G_{max}/G_{STC} \tag{2}$$

$$V_{mp\,\mathrm{min}} = V_{mp}\left(T_{max}\right) = V_{mp-STC}\left[1 + \frac{\lambda_V}{100}\left(T_{max} - 25\right)\right] \tag{3}$$

$$T_{max} = T_{a\,max} + (NMOT - 20)G_{max}/800 \tag{4}$$

- for voltage: that moment of a winter day with the lowest irradiance incident on the PV modules and the lowest temperature which goes to the maximum value for $V_{OC\,max}$.

$$T_{min} = T_{a\,min} + (NMOT - 20)G_{min}\,/800 \tag{5}$$

$$V_{OC\,\max} = V_{OC}\,(T_{min}) = V_{OC-STC}\left[1 + \frac{\lambda_V}{100}(T_{min} - 25)\right] \tag{6}$$

The relations that must be fulfilled for a proper correlation between the number of series/parallel-connected photovoltaic modules with the inverter inputs are:

- maximum number of series connected PV modules, Ns_{max}:

$$Ns_{max} \leq V_{max-Inv}/V_{OC\,max} \tag{7}$$

- minimum number of series connected PV modules, Ns_{min}:

$$Ns_{min} \geq V_{min\,MPPT}/V_{mp\,min} \tag{8}$$

- maximum number of parallel connected PV arrays, Np_{max}:

$$Np_{max} \leq I_{max\,MPPT}/I_{mp\,max} \tag{9}$$

$$Np_{max} \leq I_{sc\,MPPT}/I_{sc\,max} \tag{10}$$

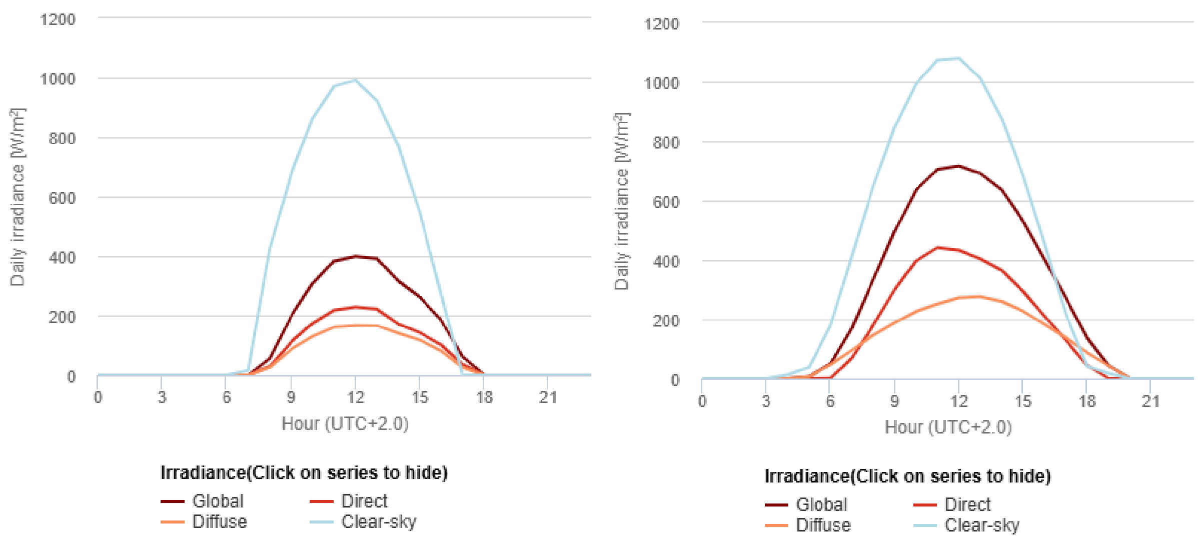
Inequalities (7-10) must be satisfied in all circumstances, but verifying them for the above mentioned “worst case scenarios” is sufficient for a good coordination between the PV module and inverter.

Another relation that ensures the optimum input d.c. voltage in the inverter, in terms of its efficiency, is very useful when the designer must select from multiple PV modules connection available. It should be noted that this condition is not mandatory to comply with.

$$N_{opt} \cong V_{r\,MPPT}/V_{mp\,STC} \tag{11}$$

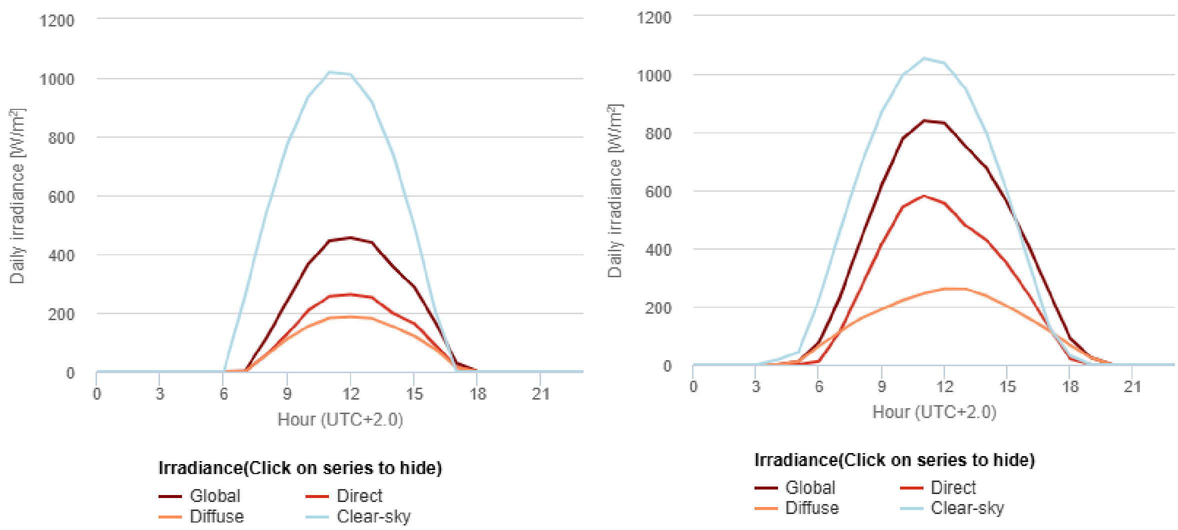
3. CASE STUDY FOR ROMANIA

The minimum and maximum values for G and T_a result from Photovoltaic Geographical System (PVGIS) [11]. As a case study, see *fig. 1* and *2* for Romania.



a. December *b. June*

Fig. 1. Daily average irradiance for the North of Romania



a. December *b. Jne*

Fig. 2. Daily average irradiance for the South of Romania

In Romania, the maximum values of clear-sky irradiance (considered for the G_{max} evaluation) and diffuse irradiance (considered for the G_{min} evaluation), have a variation of aprox. 100 W/m^2 between north and south and between winter and summer.

The values for environmental parameters for Romania taken into calculation are: G_{max} = 1100 W/m^2, $T_{a\ max}$ = 40°C, G_{min} = 100 W/m^2, $T_{a\ min}$ = -25°C.

Considering the usual ranges for the thermal parameters of the PV modules: $NOMT \in (40, 50)$ °C, $\lambda_V \in (-0.5, -0.25)$ %/°C and $\lambda_I \in (0.04, 0.08)$ %/°C, the graphical interpretation of $I_{sc\ max} / I_{sc\ STC} = I_{mp\ max} / I_{mp\ STC}$, $V_{mp\ min} / V_{mp\ STC}$ and $V_{OC\ max} / V_{OC\ STC}$ are depicted in *fig. 3* and *fig. 4*.

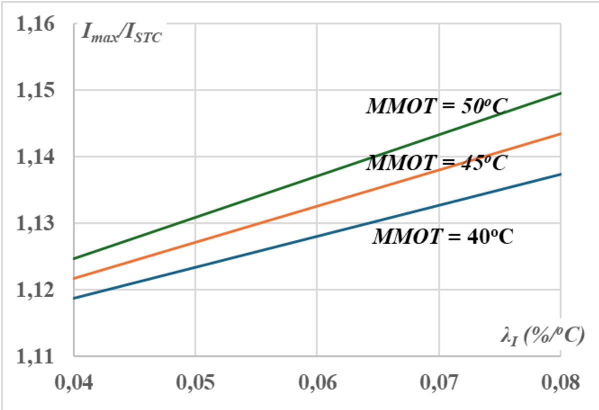
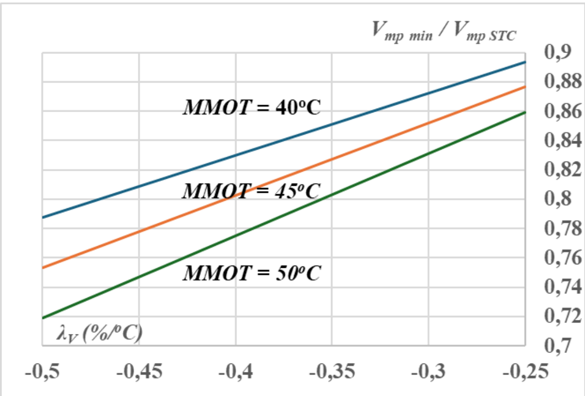
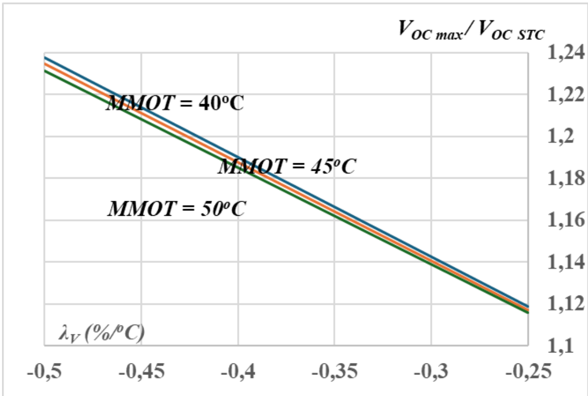


Fig. 3. $I_{sc\ max} / I_{sc\ STC} = I_{mp\ max} / I_{mp\ STC}$ *variations for different thermal parameters of PV modules*



a. $V_{mp\ min} / V_{mp\ STC}$



b. $V_{OC\ max} / V_{OC\ STC}$

Fig. 4. Voltages variations for different thermal parameters of PV modules

To avoid the calculation of the actual parameters of the PV modules according to (1) – (6), for a fast dimensioning of a PV system located in Romania, we recommend verifying the next inequations, derived from (7) – (10) and based on the results from *fig. 3* and *4*:

- maximum number of series connected PV modules, Ns_{max}:

$$Ns_{max} \leq V_{max-Inv}/(1.25 \cdot V_{OC\ STC}) \tag{12}$$

- minimum number of series connected PV modules, Ns_{min}:

$$Ns_{min} \geq V_{min\ MPPT}/\left(0.7 \cdot V_{mp\ STC}\right) \tag{13}$$

- maximum number of parallel connected PV arrays, Np_{max}:

$$Np_{max} \leq I_{max\ MPPT}/\left(1.15 \cdot I_{mp\ STC}\right) \tag{14}$$

$$Np_{max} \leq I_{sc\ MPPT}/(1.15 \cdot I_{sc\ STC}) \tag{15}$$

Of course, relations (12) – (15) should be used only in the pre-dimensioning stage, when the designer is dealing with the choice of the PV system components, e.g. has the module and is looking for the inverter or vice versa, and are not intended to be a shortcut in the design process, i.e. to replace the computation of the PV module parameters in the “worst case scenarios” (1) – (6) followed by the fulfillment of (7) – (10).

REFERENCES

[1] https://anre.ro/despre/rapoarte/, accessed October 2024.

[2] Villalva MG, Gazoli JR, Filho ER. *Comprehensive approach to modeling and simulation of photovoltaic arrays*. IEEE Trans.Power Electron, 94(5): 1198-1208, 2009.

[3] Brano V L, Orioli A, Ciulla G, Gangi A D. *An improved five-parameter model for photovoltaic modules*. Solar Energy Materials and Solar Cells, 94(8): 1358-1370, 2010.

[4] Mahmoud Y, Xiao W, Zeineldin H H. *A Simple Approach to Modeling and Simulation of Photovoltaic Modules*. IEEE Transactions on Sustainable Energy; 3(1): 185-186, 2011.

[5] Chatterjee A, Keyhani A, Kapoor D. *Identification of Photovoltaic Source Models*. IEEE Transactions on Energy Conversion; 26(3): 883-889, 2011.

[6] Siddique H, Xu P, De Doncker R. *Parameter extraction algorithm for one-diode model of PV panels based on datasheet values*. International Conference on Clean Electrical Power (ICCEP). 2013.

[7] Haider I, Nader A, *Variations of PV module parameters with irradiance and temperature*, Energy Procedia, Volume 134, Pages 276-285, 2017.

[8] L. D. Jathar, S. Ganesan, U. Awasarmol, K. Nikam, K. Shahapurkar, M. E. M. Soudagar, H. Fayaz, A.S. El-Shafay, M.A. Kalam, S. Bouadila, S. Baddadi, V. Tirth, A. S. Nizami, S. S. Lam, M. Rehan, *Comprehensive review of environmental factors influencing the performance of photovoltaic panels: Concern over emissions at various phases throughout the lifecycle*, Environmental Pollution, Volume 326, 2023.

[9] R. Bhol, R. Dash, A. Pradhan and S. M. Ali, *Environmental effect assessment on performance of solar PV panel, International Conference on Circuits, Power and Computing Technologies*, Nagercoil, India, pp. 1-5, 2015.

[10] A. A. Teyabeen, A. Algareu and F. Mohamed, *Assessment of Solar Photovoltaic System Performance,* 14th International Renewable Energy Congress (IREC), Sousse, Tunisia, pp. 1-5, 2023.

[11] European Commission, Joint Research Center, Photovoltaic Geographical Information System (PVGIS), https://ec.europa.eu/jrc/en/pvgis.