Analysis of the Sizing Factor Inverter in Brazilian Regions of Tropical Semiarid Climate

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***Abstract*—Designers of solar energy systems constantly opt for a photovoltaic generator power higher than the inverter power, considering the Sizing Factor Inverter (SFI) inferior to the unit to reduce costs. However, this can decrease inverter lifespan and increase inverter power clipping losses. The main goals of this research are to: determine a range of SFI values for wich higher values of annual average productivity and performance ratio of photovoltaic systems are obtained, in regions of semiarid climate, and analyze the influence of climatic factors - such as wind speed and relative humidity - in the SFI calculation. The methodology proposed for the execution of this research consists of: i) analyzing models for determining the output powers of photovoltaic modules and inverters; ii) study the effects of wind speed and relative humidity in the calculation of the operating temperature of photovoltaic cells; iii) use climate databases to calculate the FDI, to relate this parameter to geographic location; and iv) develop simulation programs and results analysis. The results of this research are the development of a methodology for calculating the SFI that considers the influence of relative humidity and wind speed on the operating temperature of photovoltaic cells; demonstrations that in semiarid climates it is appropriate to use SFI in the range of 0,9 to 1,1 and contributions to the construction of a map that contains intervals of FDI values for which better merit indexes of photovoltaic systems in the brazilian semiarid.**

Keywords-photovoltaic systems; semiarid climate; sizing factor inverter; productivity; wind speed.

I. INTRODUCTION

The Brazilian electric power generation system is historically characterized by presenting a predominantly hydroelectric matrix. However, due to the prolonged periods of water scarcity and the need to reduce pollutants and increase investments in renewable energy sources, photovoltaic solar energy systems have increasingly gained notoriety, installed capacity and contributed to the diversification of the Brazilian energy matrix. According to [1], the number of photovoltaic installations connected to the grid in Brazil reached the mark of 816,061, totaling 8,877,697.35 kW of PV capacity installed in January 2022.

Even with the tendency to increase investments and reduce taxes directed at photovoltaic systems, there is still a need for performance improvement of photovoltaic modules, inverters and batteries, and in the appropriate sizing of this equipment. Solar energy system designers frequently opt for a photovoltaic generator power higher than the inverter power, i.e., they consider the SFI lower than the unit, to reduce costs. According to [2], 72% of grid-connected photovoltaic systems in Brazil have the ratio between inverter nominal power and PV generator nominal power, known as SFI, lower than unity; 20% present inverter power higher than PV generator power; and only 8% of PV systems have unity SFI.

Several models for the prediction of SFI have been proposed in the literature, such as those presented by [3], [4] and [5]. These models disregard the effect of climatic factors such as relative humidity and wind speed on the performance of PV cells. The consideration of such factors, especially in tropical climate regions, directly impacts the operating temperature of photovoltaic cells [6]. Increased wind speed, e.g., contributes to the cooling of PV modules and the increase of their power output in real operating conditions [7]. In contrast, the increase in relative humidity causes the heating of PV cells and increases the power losses in the PV modules [8].

This paper presents the development of a methodology of prediction of the SFI for localities of semiarid tropical climate, taking into account the effect of climatic factors, like wind speed and relative humidity of the air, in the performance of photovoltaic modules. The methodology adopted for execution of this research consisted of the following steps: i) analysis of bibliographic works that include the modeling of PV modules, inverters and the determination of SFI; ii) study of impacts of ambient temperature, solar irradiance, wind speed and relative humidity on calculation of operating temperature of PV cells; iii) research of climatological databases of Brazilian Northeastern semiarid regions; iv) development of simulation programs and analysis of results.

The main contributions of this work include the analysis of sensibility of inverter efficiency and merit indexes of PV systems, such as productivity and performance ratio, to variations in SFI; the establishment of a range of SFI values that result in better merit indexes for locations with a semiarid tropical climate, using cities in Northeast Brazil as the basis for the analyses; and the verification of the influences of wind speed and relative humidity in predictions of SFI.

II. PHOTOVOLTAIC SYSTEM MODEL

A grid-connected photovoltaic system is defined as a set of equipment that allows the conversion of solar energy into electric energy connected in parallel with the energy distribution grid, in a way that the over energy produced is injected into the grid and accounted for by bidirectional energy meter [4]. In order to predict the SFI, it is necessary to use detailed mathematical model of PV modules and inverters. The simplified representation of the elements of a grid-connected PV system and the variables considered in simulations developed in this research are presented in Fig. 1.

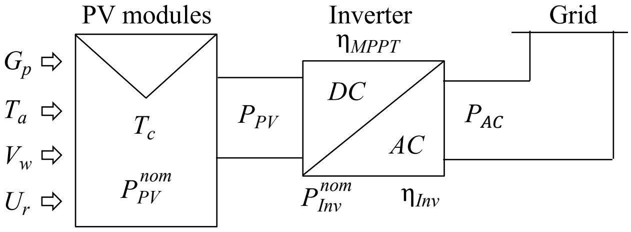

Figure 1. Simplified representation of a grid-connected PV system and simulation variables.

A. PV Modules

The initial step in PV system model consists in estimating the output power of the photovoltaic generator, which depends on factors such as operating temperature of PV cells, solar irradiance, ambient temperature, wind speed and relative humidity [9]. The models available in literature are based on the relationship between current and voltage of PV modules, which can be determined through iterative methods using non-linear equations [10]; meteorological data collected from PV systems in operation [11]; techniques based on Artificial Neural Network [12]; and linear regressions [13].

Since it is relevant to consider the influence of climatic factors in calculation of output power of PV generators, in this paper the effects of solar irradiance, ambient temperature, wind speed and relative humidity are considered in the prediction of SFI in PV systems.

B. PV Operating Cell Temperature

According to [14], the PV operating cell temperature can be calculated by

$$T_c = T_a + G_p \cdot K_t, \qquad (1)$$

where T_c (K) is the operating cell temperature; T_a (K) is the ambient temperature; G_p (W/m²) is the solar irradiance incident on the PV generator plane and K_t (K.m²/W) is the thermal coefficient of PV module, which depends on the ventilation capacity, the type of fixing structure and the technology employed in the manufacture of this equipment. The increase in solar irradiance levels and ambient temperature causes the operating cell temperature to rise.

The PV operating cell temperature can also be obtained as a function of solar irradiance, ambient temperature and wind speed [15], given that

$$T_c = T_a + \frac{(T_{NOCT} - 20)}{800} \cdot \frac{G_p \cdot 9,5}{(5,7 + 3,8 \cdot V_w)} \cdot \left(1 - \frac{\eta_{module}}{0,9}\right), \qquad (2)$$

where T_{NOCT} (K) is the nominal operating cell temperature, V_w (m/s) is the wind speed and η_{module} is the efficiency of PV module. From (2), the increase in wind speed contributes to decrease the PV operating cell temperature. This occurs due to convective heat exchanges between the PV modules and the air [6].

This paper also considers the effect of relative humidity on the PV operating cell temperature, which can be estimated, according to [8], by

$$T_c = 0,95 \cdot T_a + 0,03 \cdot G_p - 1,51 \cdot V_w + 0,16 \cdot U_r + 0,10, \qquad (3)$$

where U_r represents the relative humidity, whose increase contributes to the rise in PV operating cell temperature. According to [15], the PV module output power can decrease by approximately 35% when the relative humidity increases from 25% to 55%, considering a typical ambient temperature of 308 K.

C. PV Output Power

To calculate the DC power supplied by the PV modules to the inverter, the maximum power of the PV modules must be estimated considering the real operation conditions of the grid-connected PV system, taking into account factors such as solar irradiance, ambient temperature, wind speed and relative humidity. According to [16], the maximum power of PV module can be obtained by

$$P_{MPP} = P_{PV}^{nom} \cdot \frac{G_p}{1000} \cdot \left[1 - \gamma_{MP}\left(T_c - 25\right)\right], \qquad (4)$$

where P_{MPP} (W) is the maximum power of PV module; P_{PV}^{nom} (W) is the nominal power of PV module considering the irradiance of 1,000 W/m², cell temperature of 298 K and air mass spectrum of 1.5; and γ_{MP} (%/K) is the maximum power point temperature coefficient.

From PV module maximum power point, the DC power available at the inverter input can be estimated by

$$P_{FV} = P_{FV}^{nom} \cdot \frac{G_p}{1000} \cdot \left[1 - \gamma_{MP}\left(T_C - 25\right)\right] \cdot \eta_{MPPT}, \qquad (5)$$

where η_{MPPT} is the efficiency of maximum power point tracking.

D. Inverter Efficiency and AC Output Power

According to [17], the inverter output power can be estimated by the inverter efficiency model, that uses parameters such inverter nominal power, losses coefficient at no load and linear and quadratic current losses coefficients. The inverter efficiency is given by

$$\eta_{Inv} = \frac{p_{normal}}{p_{normal} + \left(k_0 + k_1 \cdot p_{normal} + k_2 \cdot p_{normal}{}^2\right)}, \tag{6}$$

where k_0 is the losses coefficient at no load, k_1 is the constant related to the voltage drop coefficients in diodes and switched devices, k_2 is the constant related to ohmic losses in conductors, inductors and resistances, and p_{normal} is the AC output power normalized in relation to the inverter nominal power.

The coefficients k_0, k_1 and k_2 can be estimated by

$$k_0 = \frac{1}{9} \cdot \frac{1}{\eta_{Inv_{100\%}}} - \frac{1}{4} \cdot \frac{1}{\eta_{Inv_{50\%}}} + \frac{5}{36} \cdot \frac{1}{\eta_{Inv_{10\%}}}, \tag{7}$$

$$k_1 = -\frac{4}{3} \cdot \frac{1}{\eta_{Inv_{100\%}}} + \frac{33}{12} \cdot \frac{1}{\eta_{Inv_{50\%}}} - \frac{5}{12} \cdot \frac{1}{\eta_{Inv_{10\%}}} - 1, \tag{8}$$

$$k_2 = \frac{20}{9} \cdot \frac{1}{\eta_{Inv_{100\%}}} - \frac{5}{2} \cdot \frac{1}{\eta_{Inv_{50\%}}} + \frac{5}{18} \cdot \frac{1}{\eta_{Inv_{10\%}}}, \tag{9}$$

where $\eta_{Inv100\%}$, $\eta_{Inv50\%}$ and $\eta_{Inv10\%}$ correspond to inverter efficiencies considering, respectively, the standardised AC output power equal to 100%, 50% and 10%.

The efficiency curves of different inverter models, used in simulations developed in this research, as a function of SFI, are shown in Fig. 2. Inverters with higher nominal power are generally more efficient.

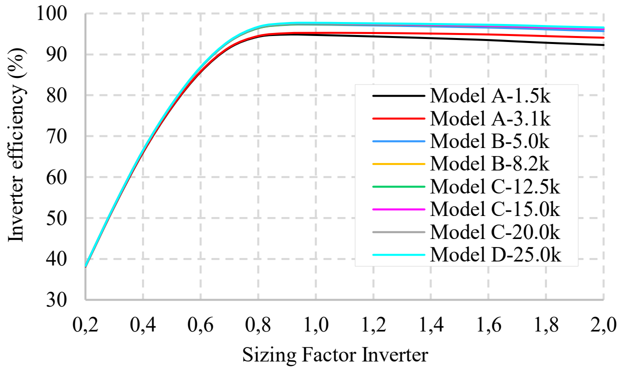

Figure 2. Inverter efficiency in function of SFI.

The power losses of the inverter DC-AC conversion process are calculated by

$$P_{Losses} = P_{PV} - P_{AC}\,. \tag{10}$$

Equation (10) can be standardised in relation to nominal power inverter and rewritten as

$$p_{Losses} = p_{PV} - p_{AC} = k_0 + k_1 \cdot p_{normal} + k_2 \cdot p_{normal}{}^2\,. \tag{11}$$

The inverter output power can be expressed as follows

$$P_{AC} = P_{Inv}^{nom} \text{ if } P_{AC} \geq P_{Inv}^{nom}, \tag{12}$$

$$P_{AC} = 0 \text{ if } P_{PV} \leq \left(k_0 \cdot P_{Inv}^{nom}\right), \tag{13}$$

$$P_{AC} = p_{normal} \cdot P_{Inv}^{nom} \text{ if } k_0 \cdot P_{Inv}^{nom} \leq P_{AC} \leq P_{Inv}^{nom}\,. \tag{14}$$

III. MERIT INDEXES

To analyze the performance of photovoltaic systems, the merit indexes used are productivity and performance ratio.

A. Productivity

Productivity corresponds to the ratio between the average value of energy produced by de grid-connected PV system in a time interval and the nominal power of PV generator [5], and can be estimated by

$$Y_F = \frac{\int_{t_1}^{t_2} P_{AC}\, dt}{P_{PV}^{nom}}\,. \tag{15}$$

B. Performance Ratio

The performance ratio corresponds to the index that considers all the losses inherent to the grid-connected PV systems and estimates the global performance of photovoltaic system. This indicator is calculated by

$$PR = \frac{Y_F}{\dfrac{\int_{t_1}^{t_2} G_{plane}\, dt}{1000}} \tag{16}$$

The denominator used in (16) corresponds to the number of hours that solar irradiance levels are equal to 1,000 W/m², in the local where the grid-connected PV system is installed.

IV. SIMULATION METHODOLOGY

The simulation methodology for predicting SFI proposed in this paper is based on the determination of the SFI that results in the best merit indexes, i.e., the SFI is calculated with the premise of obtaining the highest annual productivity and, consequently, the best performance ratio of grid-connected PV system.

It is necessary to choose PV module and inverter models and to access hourly data of Global Horizontal Irradiance (GHI), ambient temperature, wind speed and relative humidity to be used in the simulations, considering the cities of interest. As the purpose of this paper is to analyze the SFI in regions that have a semiarid climate, cities in the Brazilian semiarid region were selected, as shown in Table I. This region is characterized by high levels of irradiance, often greater than 1,000 W/m², and low latitudes. In simulations performed in this paper are simulated different models of inverter, whose parameters used are illustrated in Table II.

The SFI is initialized with the value of 0.2, considering that this value is sufficient to simulate the situation in which the maximum input power allowed by the inverter is supplied. After that, the PV generator nominal power is calculated from the ratio between inverter nominal power and the SFI value in current iteration. The inverter input power is estimated considering de power polynomial model, using (4) and (5). Posteriorly, are obtained: inverter output power, using (11); inverter power clipping losses, using (12); and merit indexes productivity and performance ratio, using (13) and (14), respectively. The value of 0.1 is added to the SFI value, the current iteration is finished and the iterative calculation process is repeated until the SFI equals 2.0. The SFI increment value is 0.1 to balance computational effort in developed simulations and precision in calculation of inverter nominal power.

TABLE I. NORTHEASTERN CITIES IN BRAZILIAN SEMIARID

State	City	Latitude
AL	Pão de Açúcar	09°44' S
AL	Piranhas	09°36' S
BA	Euclides da Cunha	10°30' S
BA	Uauá	09°50' S
CE	Quixadá	04°58' S
CE	Quixeramobim	05°11' S
PB	Itaporanga	07°19' S
PB	Patos	07°04' S
PE	Petrolina	09°23' S
PE	Serra Talhada	07°57' S
PI	Picos	07°04' S
PI	São João do Piauí	08°20' S
RN	Caicó	06°27' S
RN	Mossoró	04°54' S
PI	Carira	10°21' S
PI	Poço Verde	10°42' S

TABLE II. ELECTRICAL PARAMETERS OF INVERTERS USED IN SIMULATIONS

Lines: A and B				
Electrical Parameters	***Model A-1.5k***	***Model A-3.1k***	***Model B-5.0k***	***Model B-8.2k***
AC nominal power (W)	1,500	3,100	5,000	8,200
Efficiency at 10% of P_{nom}	0.897	0.933	0.948	0.960
Efficiency at 50% of P_{nom}	0.955	0.961	0.979	0.980
Efficiency at 100% of P_{nom}	0.959	0.952	0.979	0.977
MPPT efficiency	> 0.999			
Lines: C and D				
Electrical Parameters	***Model C-12.5k***	***Model C-15.0k***	***Model C-20.0k***	***Model D-25.0k***
AC nominal power (W)	12,500	15,000	20,000	25,000
Efficiency at 10% of P_{nom}	0.961	0.960	0.969	0.970
Efficiency at 50% of P_{nom}	0.980	0.981	0.981	0.982
Efficiency at 100% of P_{nom}	0.978	0.981	0.980	0.982
MPPT efficiency	> 0.999			

The iterative calculation process is done for all cities mentioned in Table I, to determine a range of SFI values, applicable to Brazilian northeastern locations with semiarid climate, for which bests productivity and performance ratio of grid-connected PV systems are obtained. The block diagram of proposed simulation methodology for estimation of SFI is shown in Fig. 3.

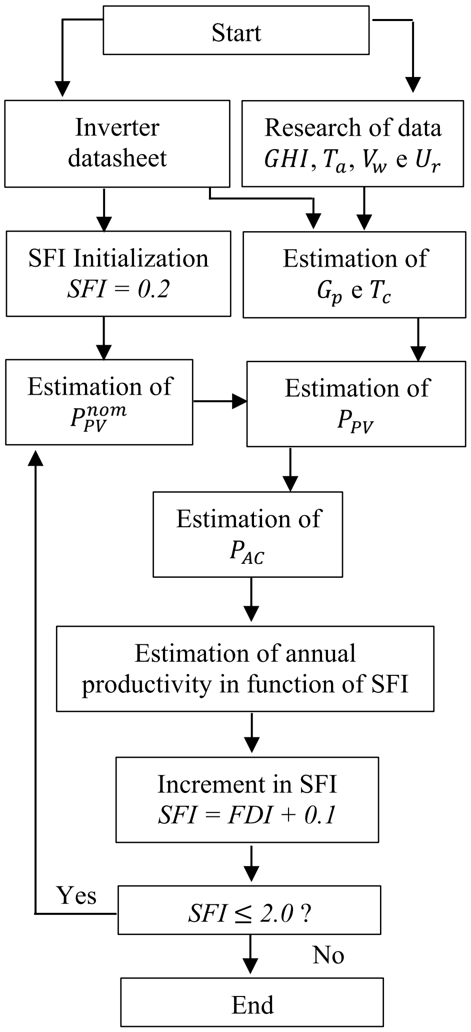

Figure 3. Block diagram of simulation methodology.

V. SIMULATION RESULTS

In order to determine a range of SFI values for which greater average annual productivity are obtained in Brazilian regions with a semiarid tropical climate, simulations were performed for different inverters and PV modules, considering the influences of irradiance, ambient temperature, wind speed and relative humidity on the operating temperature of photovoltaic modules.

A. Productivity

Considering the use of PV modules with 335 W of nominal power and 17.2% efficiency, installed in 10° inclination in relation to the horizontal plane and in 0° N direction, it is estimated the AC power produced by the grid-connected PV system, for all selected inverters. Fig. 4 shows the annual average productivity values obtained as a function of SFI, using (1) to calculate the operating temperature of PV modules. For all simulated inverters, PV systems present approximately equal annual average productivities, for SFI values lower than 0.6. The PV systems present maximum annual average productivity in a range of SFI values between 0.9 and 1.1. However, as Line A inverter models are less efficient than the others, the maximum annual average productivity of PV systems with inverters of this line are approximately 50 kWh/kW/year lower than PV systems with inverters models of Line B, Line C, Line D.

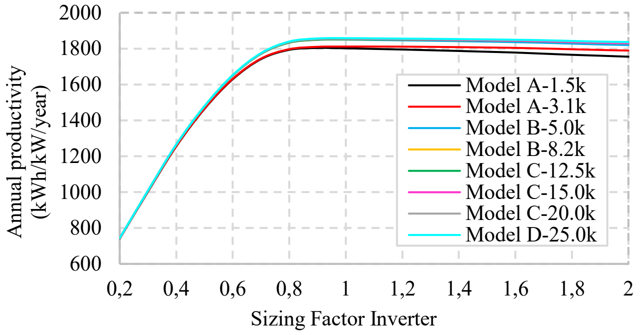

Figure 4. Annual average productivity in function of SFI, using (1) to calculate the operating temperature of PV modules.

Fig. 5 presents the effect of wind speed in the calculation of operating temperature of PV modules and in the prediction of a range of SFI values for which the greatest annual productivities of PV systems installed in Brazilian locations of semiarid climate are obtained. As the wind speed influences the decrease in operating temperature of PV modules, annual productivities of PV systems presented in Fig. 5 are greater than annual productivities showed in Fig. 4, for all analyzed inverters.

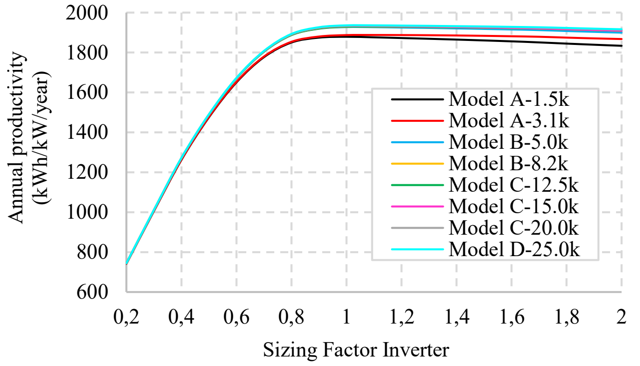

Figure 5. Annual average productivity in function of SFI, using (2) to calculate the operating temperature of PV modules.

In PV systems with A-1.5k inverter model, when disregarding the effect of wind speed on the operating temperature of PV modules, the maximum annual productivity obtained was approximately 1,804 kWh/kW/year for the SFI value of 0.9. When considering the effect of wind speed on operating temperature of PV modules, the maximum annual productivity obtained was approximately 1,879 kWh/kW/year for the SFI value of 1.0, proving that wind speed can influence the determination of the appropriate SFI value for a grid-connected PV system.

Fig. 6 presents the annual productivities of PV systems as a function of SFI, using (3) to consider also the effect of relative humidity of the air in operating temperature of PV modules. The annual productivities of PV systems obtained considering the influence of relative humidity of the air in operating temperature of PV modules were lesser than annual productivities obtained disregarding the effect of this climatic factor in estimations of operating temperature of PV modules. This occurs because relative humidity contributes to increase the operating temperature of PV modules and decrease the energy produced by photovoltaic systems. For SFI values higher than 1.1, it is noticed that annual productivities of simulated photovoltaic systems suffer decreases, for all forms to estimate the operating temperature of PV modules.

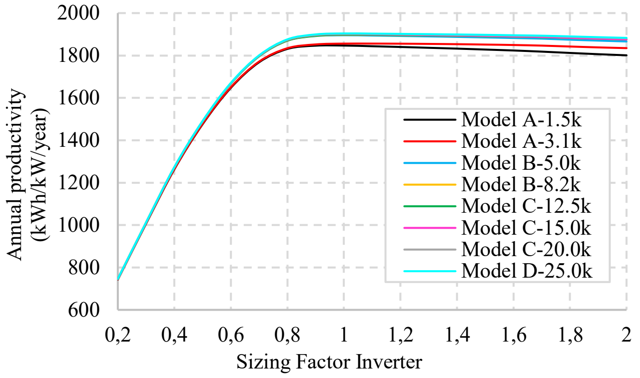

Figure 6. Annual average productivity in function of SFI, using (3) to calculate the operating temperature of PV modules.

As presented in Fig. 7, SFI values that resulted in maximum productivity of grid-connected PV system tend to increase with the decrease of latitude of the analyzed city. It is appropriate to use inverters with nominal power equal to or greater than the nominal power of PV generator, for most of cities considered in this paper: Quixadá, Quixeramobim, Itaporanga, Patos, Petrolina, Serra Talhada, Picos, São João do Piauí, Caicó and Mossoró. In the other cities analyzed, undersizing the inverter proved to be adequate, provided that the nominal power inverter corresponds, at least, to 90% of the nominal power of PV generator.

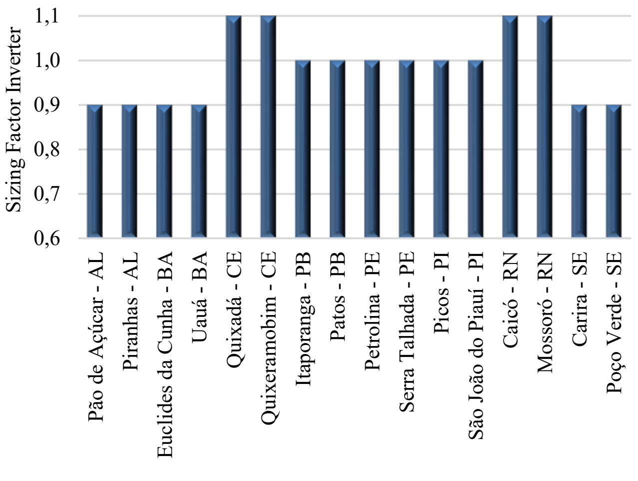

Figure 7. SFI that results in maximum annual productivity of grid-connected PV systems, by city.

In Fig. 8 is showed that annual productivity was greater in lower latitude cities, e.g., Mossoró, Caicó, Quixadá and Quixeramobim. In these locations, the annual average productivities obtained were higher than 1,825 kWh/kW/year. Cities with greater latitude presented lower annual productivity. In Bahia, the cities of Uauá and Euclides da Cunha obtained annual productivity of 1,718.6 kWh/kW/year and 1,690.4 kWh/kW/year, respectively. In Sergipe, the cities of Carira and Poço Verde obtained annual productivity of 1,694.1 kWh/kW/year and 1,679.8 kWh/kW/year, respectively.

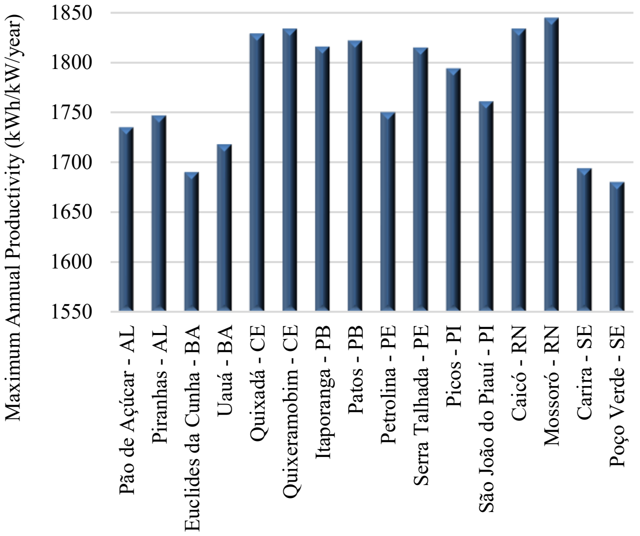

Figure 8. Annual productivity of grid-connected PV systems, by city.

The estimation of SFI can be generalized according to the map illustrated in Fig. 9, which shows the semiarid tropical climate area in Northeast Brazil. This generalization is based on similarity between climatic factors (irradiance, ambient temperature, wind speed and relative humidity) of distinct cities, but with latitudes close to each other. In cities with latitude greater than 10º S (yellow hatched area), it is observed that the greatest productivity indices of grid-connected systems are obtained for 0.9 < SFI < 1.0. In cities with latitude between 5º S and 10º S (orange and red hatched areas) it observed that the greatest annual productivities are achieved when SFI is equal to or greater than 0.9 and inferior to 1.1.

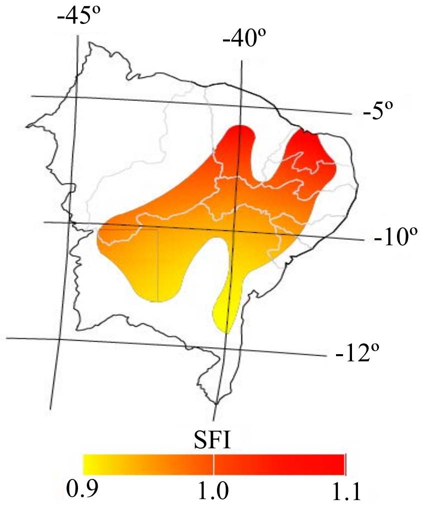

Figure 9. Map of SFI values that results in greater productivity indices in semiarid tropical climate area in Northeast Brazil.

B. Inverter Losses

The inverter power clipping losses in function of SFI are presented in Fig. 10. The power limitation phenomenon in all simulated inverters tend to zero for SFI values greater than 0.8. These losses are less than 5% for SFI = 0.7 and less than 10% for SFI = 0.6.

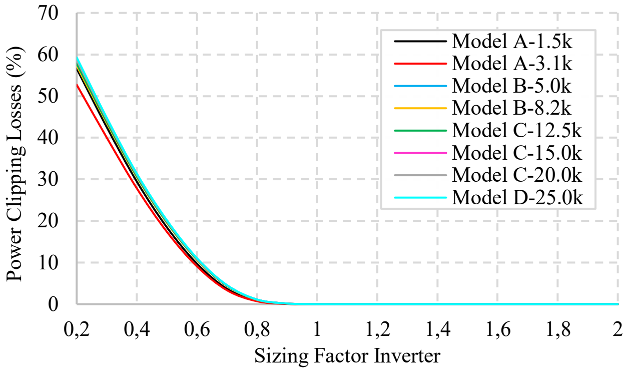

Figure 10. Inverter power clipping losses in function of SFI.

Inverter total losses are greater for SFI values lower than 0.6, mainly because of inverter power clipping losses, which is higher for low SFI values. Inverter total losses are less than 10% for SFI values equal to or greater than 0.7 and less than 6% for SFI values between 0.9 and 1.1. For SFI values greater than 1.1, inverter total losses gradually increase, mainly because of low loading of the inverter. Total losses have the lowest percentage values for the range of SFI values situated from 0.9 to 1.1, i.e., the productivity is maximum when total losses are minimum. Fig. 11 presents the inverter total losses in function of SFI.

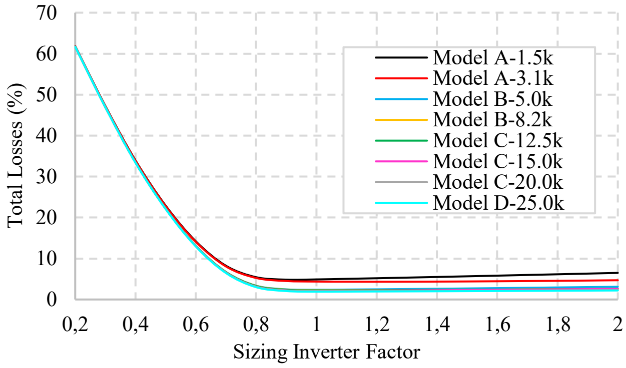

Figure 11. Inverter total losses.

C. Performance Ratio

Fig. 12 presents the performance ratio in function of SFI. The performance ratio reaches maximum percentages for SFI values situated in the range from 0.9 to 1.1 regardless of the type of inverter considered in the project of PV system. The maximum performance ratio obtained was 86.7% when SFI = 1.1.

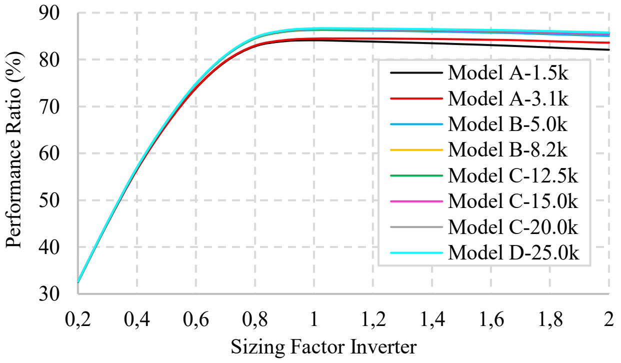

Figure 12. Performance ratio in function of SFI.

VI. CONCLUSIONS

Results obtained in this paper evidenced that factors as inverter efficiency, solar irradiance, ambient temperature, wind speed and relative humidity of the air can influence the calculation of SFI and the annual productivity of grid-connected PV systems. The simulations have demonstrated, for PV systems installed in locations with semiarid tropical climate, that: SFI values equal to or greater than 0.9 and inferior to 1.1 provide higher annual average productivity, for all considered inverters; SFI value for more efficient inverters is greater; although factors such wind speed and relative humidity influence SFI calculations, solar irradiance has more influence in determining this parameter; for locations with higher levels of solar irradiance, higher the SFI will be; and SFI value tends to be higher for locations with lower latitude. So the main contribution of this paper consisted in the determination of a range of FDI values for which the greatest annual productivity is obtained for grid-connected PV systems installed in semiarid tropical climate zones.

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REFERENCES

[1] Aneel (2022). *Superintendência de Concessões e Autorizações de Geração (SCG): Geração Distribuída*. Agência Nacional de Energia Elétrica.

[2] L. T. Scarabelot, "Influência do fator de dimensionamento de inversor no desempenho termoenergético de sistemas fotovoltaicos de geração distribuída", Technological Center, Federal University of Santa Catarina. Florianópolis, Santa Catarina, Brazil. Dec 2020.

[3] H. X. Wang, M. A. Muñoz-García, G. P. Moreda and M. C. Alonso-García, "Optimum inverter sizing of grid-connected photovoltaic systems based on energetic and economic considerations", *Renewable energy: an international journal*. Nov 2017.

[4] W. N. Macêdo, "Análise do fator de dimensionamento do inversor aplicado a sistemas fotovoltaicos conectados à rede", Tese de Doutorado, University of São Paulo. São Paulo, Brazil. 2006.

[5] G. Velasco, R. Piqué, F. Guinjoan, F. Casellas and J. de la Hoz,"Power sizing factor design of central inverter PV grid-connected systems: a simulation approach", *International Power Electronics and Motion Control Conference*. IEEE. 2010.

[6] G. A. R. Cantor, "Influência dos fatores climáticos no desempenho de módulo fotovoltaicos em regiões de clima tropical", Departamento de Energias Alternativas e Renováveis, Federal University of Paraíba. João Pessoa, Paraíba, Brazil. 2017.

[7] A. Q. Jakhrani, A. K. Othman, A. R. H. Rigit and S. R. Ramo, "Comparison of solar photovoltaic module temperature models", *World Applied Sciences Journal*, Vol. 14. 2011.

[8] G. TamizhMani, L. Ji, Y. Tang and L. Petacci, "Photovoltaic module thermal/wind performance: long-term monitoring and model development for energy rating", *NCPV and Solar Program Review Meeting*, pp. 936-940. 2003.

[9] J. A. A. da Silva, "Tratamento de dados meteorológicos e análise de desempenho do sistema fotovoltaico da EMC/UFG", Escola de Engenharia Elétrica, Mecânica e Computação, Federal University of Goiás. Goiânia, Goiás, Brazil. 2019.

[10] P. Rodrigues, "Extração dos parâmetros de módulos fotovoltaicos a partir da solução de um Sistema de equações não lineares utilizando técnicas da região de confiança", Faculdade de Engenharia Elétrica, Federal University of Uberlândia. Uberlândia, Minas Gerais, Brazil. 2019.

[11] I. G. P. Bastos et al., "Previsão de geração fotovoltaica a partir de dados meteorológicos utilizando rede LSTM", *VIII Congresso Brasileiro de Energia Solar*. 2020.

[12] H. He, "A power forecasting approach for PV plant based on irradiance index and LSTM", *Chinese Control Conference (CCC)*, pp. 9404-9409. 2018.

[13] A. J. Nascimento, "Contribuição à modelagem de módulos fotovoltaicos e proposta de uma técnica híbrida de seguimento do ponto de máxima potência com estimador de irradiância", Centro de Tecnologia de Geociências, Federal University of Pernambuco. Recife, Pernambuco, Brazil. 2018.

[14] J. A. Duffie and W. A. Beckman, "Solar engineering of thermal processes", *John Wiley & Sons*, Vol. 4. 2013,

[15] M. K. Panjwani and G. B. Narejo, "Effect of humidity on the efficiency of solar cell (photovoltaic)", *International Journal of Engineering Research and General Science*, Vol. 2. 2014.

[16] O. Gergaud, B. Multon and H. B. Ahmed, "Analysis and experimental validation of various photovoltaic system models", *International Electrimacs Congress*. Montreal, Canada, 2002.

[17] H. Schmidt, M. Jantsch and J. Schmd "Results of the concerted action on power conditioning and control", *European Photovoltaic Solar Energy Conference*. Montreux, Switzerland, 1992.