Grid Connected PV Systems in Dairy and Poultry Farms in Brazil: Evaluation of Different Installation Approaches

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Abstract

The aim of this paper is to evaluate three grid connected photovoltaic systems that were implemented in rural properties dedicated to the animal protein supply chain in the west of the State of Paraná, Brazil. PV modules with mono and multicrystalline Si solar cells from the same supplier were used. One of the PV arrays was ground mounted, faced to North, 18 ° tilted and the others were mounted on the north-facing rooftop of the farm buildings. On the roof of a cow-shed, PV modules were 18° tilted, azimuth angle of 9° NE and on the roof of a poultry house, PV array was 13° tilted (same slope of the roof) and with an azimuth of 52° NE. Two inverter brands were applied and two approaches to connect to the electrical grid were used. The results indicated that high difference in performance ratio and yield can be produced due to the position of the inverter inside the farm (distance to the main electric input) and the installation approach. The highest performance ratio (PR) was obtained for rooftop mounted with optimum slope angle, reaching an annual PR of 86 %. This PV array installed in an approximately 8 m high cow-shed presented the lower operating temperatures due to the high wind speed on the roof. Concerning the module temperature, the higher PV module effective temperatures were observed in ground-mounted array, that achieved and annual PR of 82 %. The worst average PR obtained was 69 %, in a farm where the inverter is located near the PV array but far away from the main electrical panel.

Keywords: photovoltaic systems, grid-connected systems, rural properties.

1. Introduction

The Brazilian electric matrix is mostly based on renewable sources, such as hydroelectric, biomass and wind power plants. Photovoltaic systems were firstly used in homes or isolated communities and only in 2012 the connection of micro and mini generation power systems to the electrical grid became legal. In 2018, the photovoltaic (PV) power capacity in Brazil was of around 2.6 GW and 0.6 GW were from distributed solar PV generation. The Brazilian market for distributed generation by using PV technology features a rapid growth, of around 3 to 4 times a year. Many PV systems are solar home systems or medium-size systems applied in commercial buildings, the majority in urban areas (Faria Jr. et al., 2017; Moehlecke and Zanesco, 2018).

The Brazil is a global leader in producing chicken, beef and pork meat. For instance, in 2017, the Brazilian production of chicken meat reached 13 million tons, being the second world production, below the United States (ABPA, 2018). The sector is represented by dozens of thousands of integrated producers, hundreds of processing companies and dozens of exporters. The States in the south region of Brazil are the largest producers of chickens and porks, and the Paraná (PR) is the first one producer of chicken (34.3% of the Brazilian production). Although the CO_2 emissions due to this production chain in Brazil are lower than that observed in countries such as USA, China or European Union due to the use of energy from hydroelectric plants, the expansion of the animal protein industry will need new sources of electrical energy, since the cost-effective hydroelectric plants already draw all the energy potential. Therefore, photovoltaic systems connected to the grid in farms will be an approach to reduce the need of electrical energy from the new farms to produce animal protein and, at the same time, can contribute to keep low the CO_2 footprint of this industry (Vida and Tedesco, 2017; Alexandratos and Bruinsma, 2012; Sobrosa Neto et al., 2018).

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To provide a detailed study of the insertion of PV systems in rural properties, a partnership was established between the PUCRS (Pontifical Catholic University of Rio Grande do Sul), the Itaipu Binacional (the largest hydroelectric power plant in America), three agricultural cooperatives in the state of Paraná (LAR, COPACOL and C. VALE), the association of the farm cooperatives of the Paraná as well as the Brazilian Micro and Small Business Support Service of Paraná (SEBRAE-PR). The objective of the project is to perform a technical and economic evaluation of PV systems in rural properties, assessing the problems of installation and operation, the advantages for farmers, the actual costs as well as other features.

The aim of this paper is to analyse three photovoltaic systems designed for rural properties of cooperatives in the Paraná State and the results of the operation during 2018 and 2019. The performance of the systems in different farms and with different mountings was analysed. Specifically, the yield and performance ratio as well as the average effective temperature of photovoltaic modules were compared. Two inverter brands were applied and two approaches to connect the devices to the grid were used. In two of the PV systems, PV array and inverter were settled in different buildings in order to have the inverter as close as possible to the electrical input of the farm (i.e., near to the utility power lines). In one system, the inverter was installed inside the building of the poultry farm, far away to the main electrical input of the farm. Therefore, different mountings, inverters and points of electrical connection can be compared.

2. Photovoltaic and Monitoring Systems

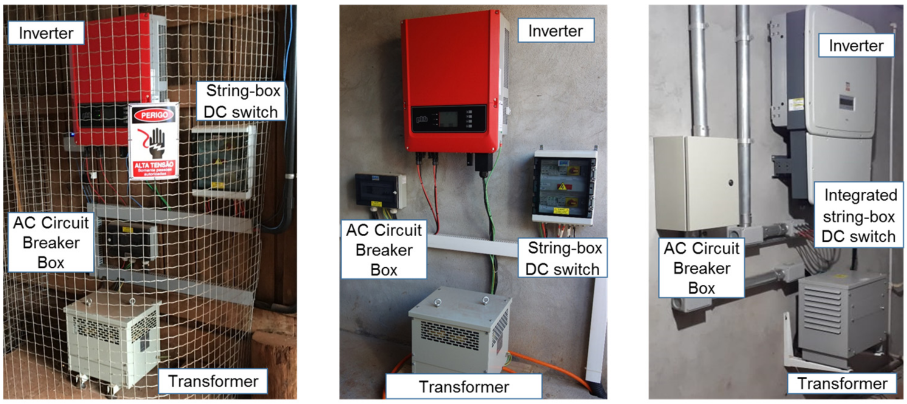
Three farms were selected to install PV systems connected to the grid: two poultry farms and one dedicated to milk production. To select the farms, the electrical energy consumption profile, the location, the owner availability as well as the kind of farm building were considered. The power of 20 kW_p for the systems was set bearing in mind the electrical energy consumption of the farms and the existence of 20 kW inverters produced by Brazilian industries.

One farm is located in Medianeira, PR (latitude: 25°16'32'' S, longitude: 54°3'14'' W), a dairy farm, and in the Fig. 1 (a) is shown the PV array. The property is associated to the LAR rural cooperative. The array was installed on the rooftop of a stable with the tilt angle of 18°, azimuth of 9° NE (orientation of the larger dimension of the rooftop). The tilt angle was set to take into account the higher yield of the PV system obtained from PV*Sol simulations. The building is relatively high for farms (height of 8 m), and PV modules were elevated 8° over the roof inclination to achieve the 18° tilt, as presented in Fig. 1(b). The PV array comprises 76 PV modules of rated power of 270 W_p +3%, with 60 multicrystalline silicon solar cells. The PV modules were characterized under standard conditions by using a PSS8 Bergerlichttechnik sun simulator in order to obtain the actual power. All the modules presented power above the nominal value and the average power was (278.9 ± 0.9) W_p. The modules presented an average efficiency of (17.04 ± 0.06) %. The standard installed capacity was 21.19 kW_p. Four strings with nineteen PV modules (series connected) were wired to the string box. Two strings were connected in parallel in the string box and the two panels were joined to the inverter (see Fig. 2 (a)). The solar inverter is produced in Brazil and it is a three-phase device (380 V, 220 V between each phase and neutral) with two maximum power point trackers (MPPT). The maximum efficiency presented in the datasheet is 98 %. The cooling system of the inverter is based on fans. A string box-DC switch, AC circuit breaker box and a transformer also compose the PV system. The latter device is needed in the West of Paraná because the voltage between phase and neutral is 127 V instead of 220 V. As Fig.3 (a) shows, the string box and inverter were not installed in the same building of the PV array due to the lack of a safe place to install them in the cow stable. Eight underground cables (two for each PV string) carried out the connection between the PV array and string box. Therefore, the power is transmitted by DC high voltage (of around 700 V, when irradiance on the array is near 1000 W/m^2), reducing the wiring losses. The data acquisition system consisted of a data logger, one piranometer to measure the in-plane of array solar irradiance, one anemometer, one ambient temperature sensor as well as a temperature sensor (PT100) installed on the rear face of a PV module. All the devices, except data logger, were installed on the stable roof, just behind the PV array (see Fig. 1 (b)). The data logger measures and storages the electrical parameters of the inverter (DC current, DC voltage, AC current, AC voltage, AC power, etc.) and the weather date in order to allow the performance evaluation of the PV system. The data have been obtained since May 2018.

Fig. 1: The 20 kWp PV systems installed and analysed: (a) dairy farm, PV array on a north-facing sloping roof, 18° tilted (8° above to the roof slope), azimuth of 8° NE (Medianeira-LAR); (b) detail of the PV module installation and weather station (WS), LAR; (c) PV system installed in a poultry farm, ground mounted PV, 18° tilted, north-oriented (Cafelândia-COPACOL); (d) detail of the position of weather station, COPACOL; (d) PV system installed in a poultry farm, PV array mounted on the rooftop, 13 º tilted, azimuth of 52° NE (Assis Chateaubriand – C.VALE) and (f) details of the PV module installation and weather station, C.VALE.

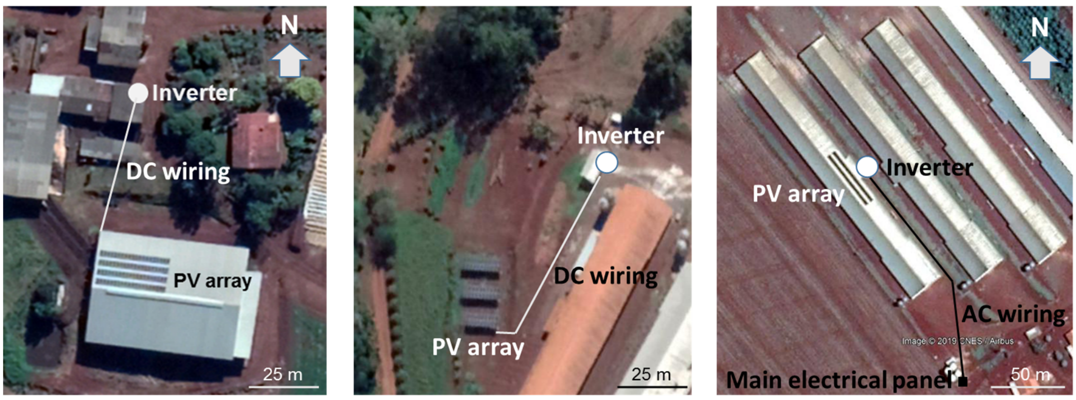
In the Fig.1 (c), we present the PV system installed in Cafelândia, PR (latitude: 24°38’38’’ S, longitude: 53°18’51’’ W), in a farm dedicated to producing chickens. The property is associated to the COPACOL rural cooperative. In this property, PV array was installed in the ground (1 m above ground) because the buildings do not have a structure to support the new load added from PV modules. At the same time, the region of the buildings had several trees nearby that produces shadowing on the roof. The PV modules were ground-mounted, inclined at an angle of 18°, facing north at an azimuth angle of 0°. The array comprises 62 PV modules of rated power of 325 W_p + 3%, with 72 multicrystalline silicon solar cells. The PV module power ranged from 334 W to 340 W and the average value was (336 ± 0.8) W, i.e., an average power of 3.5% above the nominal value. The PV modules presented an average efficiency of (17.34 ± 0.07) %. The installed standard power was 20.86 kW_p. The PV array is composed by four strings, two with 15 PV modules (series connected) and two with 16 modules connected in series. These strings were wired to the string box by underground cables. The solar inverter and DC-AC circuits are shown in the Fig. 2 (b) and the position of the PV array and the inverter is presented in Fig. 3(b). The data acquisition system was the same installed in the rural property of Medianeira, as above described. All the devices, except data logger and module temperature sensor, were installed in a pole, behind PV array, as Fig. 1 (d) shows. The data have been obtained since July 2018.

In the third rural property, in Assis Chateaubriand, PR (latitude: 24°23’10’’ S and longitude: 53°32’14’’ W), a poultry farm, the PV modules were mounted on the roof (13° tilted and with an azimuth of 52° NE), as Fig. 1 (e) and (f) show. The property is associated to the C.VALE rural cooperative. The PV array comprises 60 PV modules of rated power of 340 W_p + 3%, with 72 monocrystalline silicon solar cells. The PV module power ranged from 341 W to 351 W and the average value was (346.5 ± 2.1) W_p, that is, all the modules presented power above the rated power. It worth to mention that the standard deviation of the average power of the PV modules with monocrystalline Si cells was slightly higher than that with multicrystalline ones. The modules presented an average efficiency of (17.9 ± 0.1) %. The installed standard power was 20.79 kW_p. The PV array is composed by four strings with fifteen PV modules, series connected. The four strings were connected to the built-in string box of the inverter, producing two panels with two strings in each parallel. A three-phase inverter, produced in China, with two MPPTs, was installed near the roof where PV array was mounted. The maximum and the weighted efficiency (EURO/CEC) presented in the datasheet is 98.2% and 98 %, respectively. The Fig. 2 (c) shows the inverter, AC breaker and transformer. Unlike the inverter used in the farms associated to LAR and COPACOL cooperatives, this device has a passive cooling system, with a heat sink on the back. The inverter is connect to the internal grid of the building and is linked to the main input of the property by AC by using underground cables. In the Fig. 3 (c) the local of inverter and of the main electrical input of the property are shown. The monitoring system is composed by data logger and a weather station. The solar irradiance on the plane of PV array, ambient temperature, PV module temperature as well as direction and speed of the wind are measured. The data have been stored since November 2018.



(a) (b) (c)

Fig. 2: Inverter, string box-DC switch, AC circuit breaker and transformer installed in each rural property: (a) PHB inverter, Medianeira, LAR; (b) PHB inverter, Cafelândia, COPACOL; (c) ABB inverter, Assis Chateaubriand, C.VALE.



(a) (b) (c)

Fig. 3: Connection of the PV array to the string-box+inverter in each system: (a) Medianeira, LAR; (b) Cafelândia, COPACOL; (c) Assis Chateaubriand, C.VALE.

3. Methodology

3.1. PV module temperature

The effective temperature of the PV modules, T_{eff}, is defined as the weighted temperature with the solar irradiation on photovoltaic modules (Lorenzo, 2014). Therefore, during the day, the hours with higher solar irradiation will be more significant to analyse the PV array performance. The effective temperature can be calculated with:

$$T_{eff} = \frac{\int H_T(\beta,t).T_{Module}(t)dt}{\int H_T(\beta,t)dt} \qquad \text{(eq. 3.1)}$$

where $H_T(\beta,t)$ is the solar irradiation on the plane of PV array during a period and $T_{Module}(t)$ is the temperature of the PV modules.

The daily and monthly average T_{eff} as well as ambient temperature, T_{amb}, were calculated for each PV system. The difference between T_{eff} and T_{amb}, called ΔT, was used to analyse the influence of the mounting on the effective temperature of the PV array.

3.2. Performance analysis

To assess the performance of the PV systems, the final yield, Y_F, and the performance ratio, PR, were used (IEC, 1998; Khalid et al., 2016; Marion et al., 2005).

The final yield of the system is the ratio between the average value of the electric energy produced in a period and delivered to the load and the nominal power of the photovoltaic system. The unit is kWh/kWp or hours. The Y_F indicates how a PV system in a given location can produce electrical energy, being a good parameter to compare locations (ambient temperature and irradiation) and installation. Final yield can be described by the equation 3.2 as follows:

$$Y_F = \frac{1}{P_{Std}}\left[\frac{1}{T}\int_T P_{FV}(t)dt\right] \qquad \text{(eq. 3.2)}$$

where $P_{FV}(t)$ is the instantaneous AC power output, P_{Std} is the power of the PV array at standard conditions and T is the integration period.

The reference yield, Y_R, is the total in-plane solar irradiation (kWh/m^2) divided by the reference irradiance (1 kW/m^2). It is the number of peak sun-hours and can be calculated by:

$$Y_R = \frac{\frac{1}{T}\int_T G(t)dt}{1\ kW/m^2} \qquad \text{(eq. 3.3)}$$

where G(t) is the solar irradiance on the plane of the PV array (kW/m^2) and T is the integration period.

The performance ratio, PR, is defined by the following equation as:

$$PR = \left(\frac{Y_F}{Y_R}\right) \times 100\% \qquad \text{(eq. 3.4)}$$

The higher the PR of the system, the better the performance of it as compared to other systems with similar climatic conditions. A PR of 0.8 and above is an indicator of a good performing system (Khalid et al., 2016). These losses can be classified as non-temperature related factors (e.g., inverter inefficiency, wiring, mismatch, soiling, system's availability and component failures as well as shading) and temperature related factor (Quansah et al., 2017).

4. Results and Analysis

4.1. Effective temperature

Fig. 4 shows the monthly average daily total solar irradiation on the PV arrays. During the year of 2018, the monitoring system in the COPACOL and LAR rural properties presented instabilities and date were not recorded. In the summer months (December, January and February), PV array installed on the roof of the building in the C.VALE associated property presented the higher in-plane solar irradiation because the angle of incidence of beam irradiance was lower than the angle in the other installations. The high irradiation was observed in December 2018, achieving near 6.8 kWh/m^2.day, value above the maximum of 6.6 kWh/m^2.day, observed in summer months and presented by Tiepolo et al. (2016) in the Solar Energy Atlas of the State of Paraná.

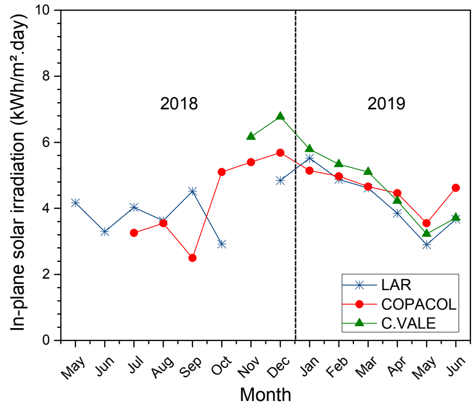
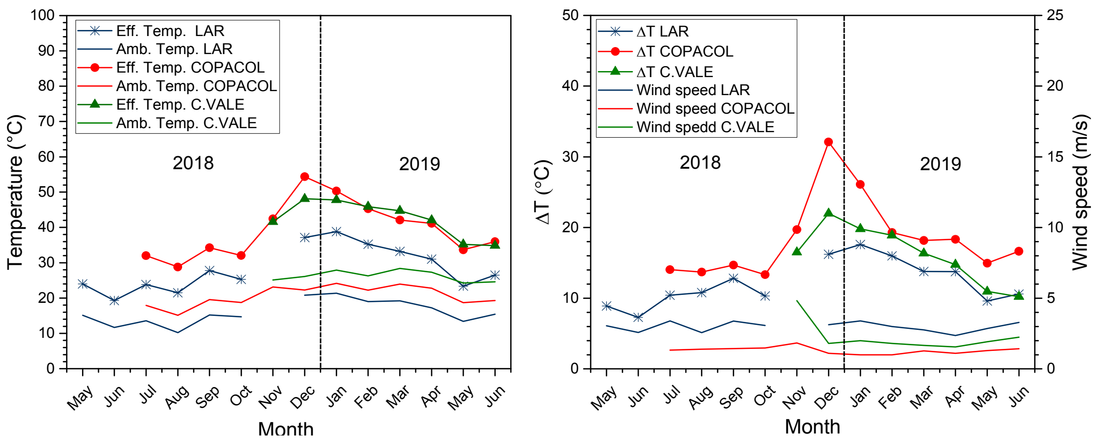


Fig. 4: Monthly average daily total in-plane solar irradiation on the three PV arrays.

Fig. 5 (a) presents the monthly average daily ambient temperature and effective temperature of a PV module. The higher monthly average ambient temperatures were observed in Assis Chateaubriand, in the rural property associated to C.VALE cooperative, reaching 28.4 °C, that is, 4 °C and 7 °C higher than those measured in Cafelândia-COPACOL and Medianeira-LAR, respectively. The lower effective temperatures were presented in the PV module installed on the roof of the cow stable (Medianeira-LAR), where the wind speed was higher, as we can conclude from the date presented in Fig. 5 (b). For instance, for January 2019, the monthly average wind speed near PV arrays were: LAR, 3.4 m/s, COPACOL, 1 m/s and C.VALE, 2 m/s. The instantaneous wind speed achieved values as high as 8 m/s in the roof of cow stable at Medianeira-LAR, and this reduces strongly the PV module temperature (Schwingshackl et al., 2013). Besides the higher wind speed observed in the 8 m high cow stable, PV modules are inclined at an angle of 8 ° to the roof, allowing the heat transfer by the back face of the modules. Therefore, the lower ΔT was observed in the PV array installed in the rural property in Medianeira. The higher ΔT was observed in the COPACOL associated property, achieving approximately 32 °C, for the ground-mounted PV array. From winter to summer months, the ground-mounted system always presented the higher ΔT.



(a) **(b)**

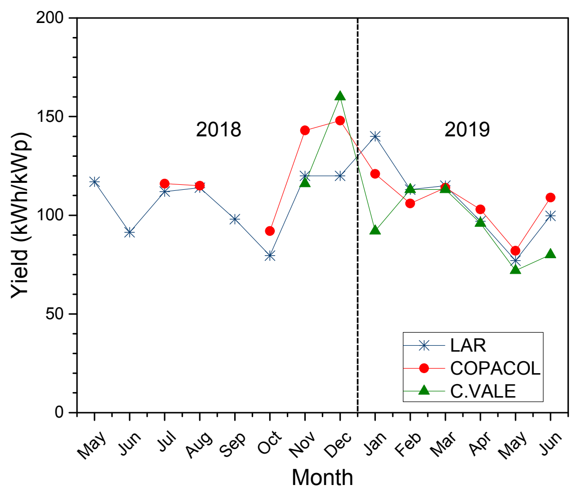
Fig. 5: (a) Monthly average effective and ambient temperatures and (b) monthly average ΔT and wind speed.

4.2. Performance analysis

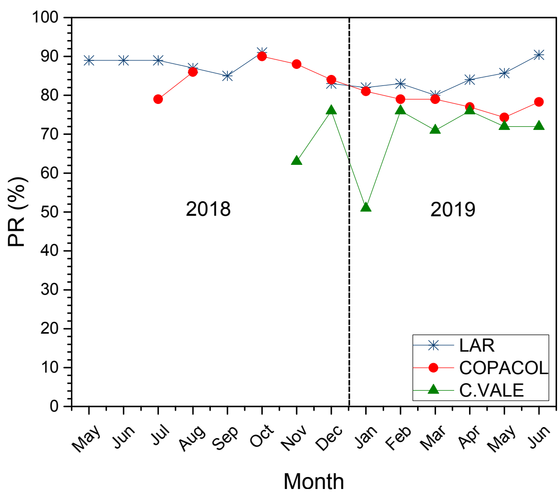
In the Fig. 6 are presented the monthly final yield and monthly performance ratio of the three PV systems analysed. The PV system installed in Medianeira, monitored during 14 months, presented a yearly performance ratio of around 86 %, and the monthly PR always remained above 80 %, indicating that the system is operating in a proper way and PV array is kept in relatively low operating temperatures (due to high wind speed and mounting that allow convection on the back of the modules). The high PR observed is similar to that obtained in PV systems installed in 12 m high buildings in cold climates like Ireland, as reported by Ayompe et al. (2011). For instance, in a region of the India, the average annual PR of a PV system with multicrystalline silicon modules achieved 82 %, in a climate hot and dry for about eight months and moderate-cool during four months (Kumar et al., 2014). The yearly final yield achieved 1287 kWh/kW$_p$, a value of around 13 % lower than that obtained by simulation with the PV*Sol computer program due to the low solar irradiation observed in 2018-2019 when compared to the historic date of solar irradiation in cities of the west of Paraná (Araujo et al., 2018).

The ground-mounted PV system in the rural property associated to COPACOL was monitored during 12 months and presented an average PR of 82 % and an Y_F of 1140 kWh/kW$_p$. The worse PR was obtained in February 2019, reaching 74 %, but it is not due to the higher module temperatures because this month had several cloudy/rainy days. The final yield was 24 % lower than the value estimated by PV*Sol simulations (Araujo et al., 2018). Bearing in mind that the monitoring system did not collect date in several periods in 2018, the results of PR and Y_F can be considered a first result of the performance evaluation.

The PV system installed in rural property in Assis Chateaubriand was monitored since November 2018. During the eight months, the average PR was 69 % and the Y_F was 762 kWh/kW$_p$. Final yield was 20 % below the estimated value (Araujo et al., 2018) due to lower solar irradiations and due to the inverter disconnections to the grid or the power reduction in several days, mainly in November 2018 and January 2019. In this farm, PV array and inverter were installed in the same building, far away to the main electrical input of the rural property, where electrical noises (due to the fans, illuminating control system, etc.) can disable the inverter, problems that we are now identifying by installing PV systems connected to the grid in farms. The Fig. 7 shows the solar irradiance and the AC power injected by the inverter to the grid and the periods of disconnection are easily observed. Besides, the system has an inverter with passive cooler, an issue in hotter rooms ("standard" in farms in Brazil). In summer days, the temperature of the inverter can achieve 60 °C and this may promote also disconnections or the reduction of the power injected to the grid. If we disregard the two worse performance months, the average PR increases to 74 %, but remains low when compared to the value obtained in the others PV systems. In humid tropical climate, Quansah et al. (2017) reported low annual PR of 68 % and 76 % for multicrystalline and monocrystalline PV modules, but the high operation temperature of the modules mounted directly in contact with roof was the main issue.



(a)



(b)

Fig. 6: (a) Monthly final yield (Y_F) and (b) monthly performance ratio (PR) of the PV systems over the monitored period.

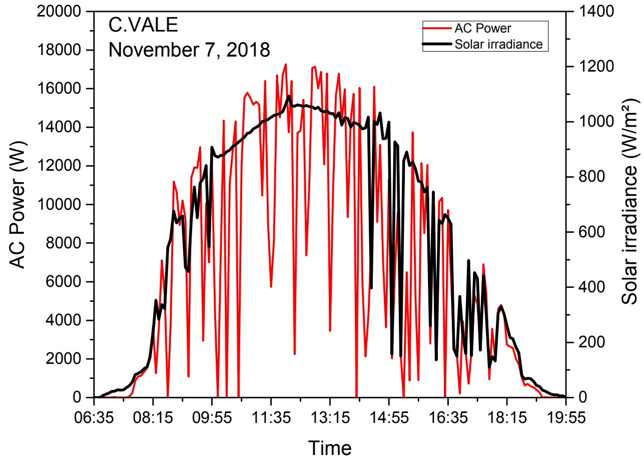


Fig. 7: AC power output of the inverter and solar irradiance in a sunny day of November 2018 in the farm associated to C.VALE agricultural cooperative, in Assis Chateaubriand, Paraná.

5. Conclusions

Three 20 kW_p photovoltaic systems were installed in farms in the West of Paraná, Brazil, and monitored during 2018 and 2019. Multicrystalline and monocrystalline silicon modules were used and three installations approaches were implemented: ground-mounting, rooftop mounting with optimum tilt angle (with an elevated structure over the roof) and just on-roof mounting following the inclination of the roof.

PV modules were characterized under standard conditions in order to obtain the actual installed power. All the modules presented power above the nominal value and the average power was: 1) LAR associated farm, PV module rated power of 270 W_p and average power of (278.9 ± 0.9) W_p, and average efficiency of (17.04 ± 0.06) %; 2) COPACOL associated rural property, nominal power of 325 W_p and average power of (336 ± 0.8) W and average efficiency of (17.34 ± 0.07) %; 3) C.VALE poultry farm, nominal power of 340 W_p and an average value of (346.5 ± 2.1) W_p and average efficiency of (17.9 ± 0.1) %.

The PV system installed in Medianeira, in a dairy farm associated to LAR agricultural cooperative, was monitored during fourteen months and presented a high annual performance ratio of 86 %, a value that corresponds to the best PV systems installed around the world. The monthly average daily effective module temperature were the lower of the systems compared in this work due to the greater wind speed on the 8 m high roof. The final yield was 13 % lower than the expected due to the lower solar irradiation observed during 2018-2019.

The ground-mounted PV system installed in the COPACOL associated property, in Cafelândia, was monitored during twelve months and presented an average PR of 82 % and the final yield was 24 % lower than the predicted by the simulations. The higher difference between effective module temperature and ambient temperature was observed in this PV array, achieving approximately 32 °C.

In Assis Chateaubriand, the rooftop PV system installed in a poultry farm associated to C.VALE was monitored by eight months, and the average PR was low, reaching 69 %, due to the disconnections or power reductions of the inverter in sunny days, mainly in November 2018 and January 2019. This shortcoming was attributed to the electrical noises due to the fans or illumination controls in the building of the poultry farm.

6. Acknowledgments

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7. References

ABPA – Brazilian Association of Animal Protein, 2018. Annual Report 2018. Available at: http://abpa-br.com.br/

Alexandratos, N., Bruinsma, J., 2012. World agriculture towards 2030/2050: the 2012 revision. ESA Working

Paper No. 12-03. FAO, Rome.

Araujo, N.D., 2019. Implementation and analysis of electrical energy production system in rural property with photovoltaic modules of multicrystalline silicon. Master Thesis. Graduation Program in Materials Engineering and Technology, PUCRS. In Portuguese.

Araujo, N.D., Osorio, E.A.A., Ramanauskas, L.F.C., Moehlecke, A., Zanesco, I., 2018. Photovoltaic systems in rural properties associated with cooperatives in the West of Paraná – Brazil. Acta de la XLI Reunión de Trabajo de la Asociación Argentina de Energías Renovables y Medio Ambiente, Argentina, v. 6, pp. 03.63-03.72. In Portuguese.

Ayompe, L.M., Duffy, A., McCormack, S.J., Conlon, M., 2011. Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland. Energy Conversion and Management, 52, 816-825.

Faria Jr, H., Trigoso, F.B.M., Cavalcanti, J.A.M., 2017. Review of distributed generation with photovoltaic grid connected systems in Brazil: Challenges and prospects. Renewable and Sustainable Energy Reviews, 75, 469–475.

IEC, 1998. Photovoltaic System Performance Monitoring-Guidelines for Measurement Data Exchange and Analysis. IEC Standard 61724. Geneva, Switzerland.

Khalid, A.M., Mitra, I., Warmuth, W., Schacht, V., 2016. Performance ratio – crucial parameter for grid connected PV plants. Renewable and Sustainable Energy Reviews, 65, 1139-1158.

Kumar, K.A., Sundareswaran, K., Venkateswaran, P.R., 2014. Performance study on a grid connected 20 kW_p solar photovoltaic installation in an industry in Tiruchirappalli (India). Energy for Sustainable Development, 23, 294–304.

Lorenzo, E., 2014. Ingeniería Fotovoltaica, Ed. Progensa, 275 p.

Marion, B., Adelstein, J., Boyle, K., Hayden, H., Hammond, B. et al., 2005. Performance parameters for grid-connected PV systems. In: Proceedings of the 31st IEEE Photovoltaic Specialists Conference, Florida, USA, pp. 1601-1606.

Moehlecke, A., Zanesco, I., 2018. Current status of photovoltaic systems for distributed generation in Brazil Energías Renovables y Medio Ambiente, 41, 79-85. In Spanish.

Quansah, D.A., Adaramola, M.S., Appiah, G.K., Edwin, I.A., 2017. Performance analysis of different grid-connected solar photovoltaic (PV) system technologies with combined capacity of 20 kW located in humid tropical climate. International Journal of Hydrogen Energy, 4(2), 4626-4635.

Schwingshackl, C., Petitta, M., Wagner, J.E., Belluardo, G., Moser, D., Castelli, M., Zebisch, M., Tetzlaff, A., 2013. Wind effect on PV module temperature: Analysis of different techniques for an accurate estimation, Energy Procedia, 40, 77-86.

Sobrosa Neto, R.C, Berchin. I.I., Magtoto, M., Berchin, S., Xavier, W.G., Salgueirinho, J.B., Guerra, O.A., 2018. An integrative approach for the water-energy-food nexus in beef cattle production: a simulation of the proposed model to Brazil. Journal of Cleaner Production, 204, 1108-1123

Tiepolo, G.M., Urbanetz Júnior, J., Pereira, E.B., Pereira, S.V., Alves, A.R., 2016. Generation potential of electricity through connected photovoltaic systems in Paraná State - partial results. In: VI Congresso Brasileiro de Energia Solar, Belo Horizonte, Brazil, pp. 1-8. In Portuguese.

Vida, E., Tedesco, D.E.A., 2017. The carbon footprint of integrated milk production and renewable energy systems – A case study. Science of the Total Environment, 609, 1286–1294.