Remote Monitoring and Analysis of Productivity Indicators of Photovoltaic Energy Generation Systems

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Abstract- A Photovoltaic (PV) System is a technology that converts sunlight into electricity through photovoltaic cells, mainly composed of solar modules and an inverter. The Federal Institute of Minas Gerais has 25 photovoltaic plants that generate sustainable energy and have a total installed capacity of 867.88 kWp. However, continuous monitoring of these systems has become a challenge due to a lack of specialized teams and availability on campuses. To overcome this limitation, a research project at IFMG was developed to monitor the plants daily. This involves analysis using the PVsyst software, implementation of dashboards for productivity indicators visualization, measures to streamline monitoring, and maintenance practices at the plants. The PVsyst software made it possible to model the plants that make up IFMG's photovoltaic generation. To this end, our models for each plant took into account several factors, namely: meteorological data, load profile, feeder tariffs, etc. Among all IFMG plants, theoretical data obtained through the PVsyst software can be cited, whose annual values are: Total horizontal irradiation (GlobHor) of 1765.9 kWh/m^2, Diffuse horizontal irradiation (DiffHor) of 836.49 kWh/m^2, Ambient temperature of 23.79 °C, Global incidence on the sensor plane (GlobInc) of 1770.9 kWh/m^2, Global effective (GlobEff) of 1724.1 kWh/m^2, Effective energy at the exit of the group of 64.87 MWh, Energy injected into the grid of 63.33 MWh and Performance Index (PR) of 0.797. PVsyst is simulation software used to model photovoltaic systems, from small residential sizes to large utilities, which is why its use is justified.

Keywords: Pholtovoltaic plants; Continuous monitoring; dashboards; reports; maintenance.

1. Introduction

A Photovoltaic (PV) System is a technology that converts solar energy into usable electricity through photovoltaic cells. The fundamental elements of a photovoltaic system include solar panels, inverters and, occasionally, energy storage devices such as batteries. Solar modules capture sunlight and generate electricity, while the inverter converts this electricity into a format that can be used by conventional electrical devices [1].Grid-connected photovoltaic power generation and independent photovoltaic power generation which are suitable for different occasions are all important application field in photovoltaic system technology [2]. For the grid connected PV System, the energy which is absorbed by the solar cell array is converted into standard sinusoidal AC voltage through the inverter in order to supply the grid directly [3],[4].

With the increasingly serious fossil energy crisis and environmental pollution, a target of “Carbon Peak and Carbon Neutrality” was proposed in China [5]. Solar energy is a clean energy to reduce carbon emissions, it has been intensively developed in Qinghai Province which has rich solar energy resources [6].

The PV system can be divided into the DC part and the AC part. The DC part is then divided into a PV module that generates power and a junction box that integrates PV modules connected in series and parallel. The AC part includes inverters and power distribution facilities [7]. The performance of photo voltaic modules depends on temperature and irradiance. It is necessary to translate the measured I-V characteristics to standard test condition for assessing degradation, and such translations require temperature coefficients for voltage and current [8].

Global PV capacity is expected to reach 2.2 [TW] by 2030, which means the Operation and Maintenance(O&M) of the PV system will grow rapidly over the next decade. This indicates the need for the management of PV systems [9]. The life of the PV system is 20 to 30 years so the optimal technology through O&M for maximum power generation is needed [10]. Regarding the inverter, when the voltage of the photovoltaic array and string does not reach the Maximum Power Point Tracking (MPPT) operating voltage, the overall power generation stops and the useful life of the inverter is 7 to 10 years [11], [12].

The predicted life model of the PV system can be used to calculate the degradation rate and to identify or classify potential defects [13]. Basically, silicon PV modules have an annual degradation rate of 0.5%, and 80% of power output is ensured for 20 to 25 years [14].

When PV power generation is connected to a power system, power quality problems like the harmonic problem should be considered because harmonics are generated in the process of converting DC to AC. In addition, the PV system is weather-varying power generation, which causes voltage fluctuations. According to IEEE, the voltage inequality is recommended to be within 1 ~ 4 % based on the asymmetry of phase angles between voltages of different phases [15].

This work consists of analyzing the monitoring of 25 photovoltaic plants distributed on the campuses of the Federal Institute of Education, Science and Technology of Minas Gerais (IFMG) with an installed capacity of 867.88 kWp. In order to evaluate performance, identify potential improvements and contribute to the strategic management of solar energy, this project aims to provide a comprehensive view of the energy panorama of these installations. By exploring the data collected and the strategies implemented throughout monitoring, we seek to highlight the importance of these practices for sustainability and operational efficiency. The level of the monitoring system must be determined by the size and type of the PV power plant and the effect of environmental variables must be considered as well [16].

In order to obtain a comparison of real generation, a survey of theoretical production was carried out to calculate the performance indicators of all 25 plants. For the analysis, the types of equipment used were investigated, the checking of projects in the PVsyst software and a detailed survey of the theoretical generation that is used to determine the generation indicators. One of the activities of this work consists of daily monitoring of photovoltaic plants and sending alert emails if generation and/or communication problems are tested. During the year, several emails were sent to those responsible for each campus in order to notify anomalies that occurred during the monitoring period. In order to facilitate the sending process, automated spreadsheets were created to send emails notifying about the monthly generation of each campus.

In studies [17], [18], [19], the use of efficient methodologies to quantify the generation of photovoltaic plants is noticeable. However, none of these approaches presents a proposal for notification to those responsible for photovoltaic plants. In [20] was also developed a notification system that determines, based on luminosity, whether the modules are dirty or clean, sending this information to those responsible. However, the proposed work does not focus only on specific problems, but on the entire set of variables that can affect energy generation, to then send information in a clear and objective way, in addition to producing a generation history of the plants. to evaluate production throughout the year. The automated notifications carried out in this work offer those responsible for managing plants a real-time view of solar energy performance and production. Through intuitive dashboards, it is possible to access detailed information about energy generation, including data on current production, generation history, and even alerts about possible failures or operational problems. This transparency and immediate access to data allows those responsible to make quick and informed decisions to optimize the operation of photovoltaic plants. For example, by identifying variations in energy generation, those responsible can adjust preventive maintenance, optimize the distribution of generated energy and even implement corrective measures to maximize efficiency and minimize losses. Furthermore, automated notifications ensure effective communication between the different parties involved in the operation and maintenance of photovoltaic plants. From technicians responsible for maintenance to managers and investors, everyone can receive updated and relevant information about the performance of the facilities, allowing efficient coordination of efforts and resources.

2. Merit Indicators

Merit indicators play a crucial role in the efficient evaluation and management of photovoltaic plants, highlighting their performance and operational effectiveness. The indicators that stand out in this context are the Performance Yield and the Performance Ratio. According to [17], Performance Yield can be defined as an indicator that provides a quantitative measure of the overall efficiency of a photovoltaic plant.

It calculates the relationship between the actual electrical energy generated by the system ($E_{PV,AC}$) and the maximum theoretical power that could be produced under ideal conditions ($P_{\max,STC}$). A high Performance Yield indicates a high level of efficiency in energy generation in relation to ideal conditions [18].

$$Y_f = \frac{E_{PV,AC}}{P_{\max,STC}} \quad (1)$$

Where:

$P_{\max,STC}$ represents the nominal photovoltaic power, $E_{PV,AC}$ is the energy injected into the system during the evaluation period, and Y_f is expressed in kWh/kWp or simply in hours.

The Performance Ratio (P_R), or Performance Ratio, is another indicator widely used in the context of photovoltaic plants, being crucial for evaluating the efficiency and performance of these systems. This metric is calculated as the ratio between the actual electrical energy generated by the solar modules and the maximum theoretical electrical energy that could be produced under ideal conditions. The real electrical energy generated refers to the amount of electricity actually produced by the photovoltaic system in a given period, expressed in (kWh). The maximum theoretical electrical energy represents the maximum theoretically possible energy that the system could generate under ideal conditions. This takes into account solar irradiation, panel temperature, availability of the electrical network, size of the opening area, nominal power and temperature correction values. A Performance Ratio close to one indicates efficient performance, while lower values may indicate problems in the system that may require maintenance or optimization [18], [21]:

$$P_R = \frac{E_{PV,AC}}{E_{AC,PV\_Syst}} \quad (2)$$

Where:

E_{AC,PV_Syst}, in kWh, is the estimated energy generation scaled by the PV Syst. And it is often represented as a percentage.

The campuses of the Federal Institute of Minas Gerais have a total of 25 plants, contributing to a total generation capacity of 867.88 kWp. In total there are 34 inverters and 2.663 photovoltaic modules of different models. Eight plants have been recently designed and are currently in operation. Photovoltaic systems are supervised by different platforms so that each one presents daily, monthly and annual production data.In Tables 1 and 2 it is possible to observe the data and equipment relating to each campus.

Table 1. Data regarding the photovoltaic system for campuses.

Campus	kWp of Plants	Inverter Model	No. of Inverters	Module Model	No. of Modules
Ipatinga	44,88	Renovigi RENO-20K	2	Risen RSM144-6-340P	132
Congonhas	28,6	SMA Sunny Tripower 25000TL (SIW500)	1	Canadian Solar CS6P-260P	110
Conselheiro Lafaiete	20,47	Growatt 20000 TL3-S	1	Canadian Solar, modelo CS6U-325P	63
Governador Valadares	28,6	SMA Sunny Tripower 25000TL (SIW500)	1	Canadian Solar CS6P-260P	110
Piumhi	44,88	Renovigi RENO-20K	2	Risen RSM144-6-340P	132
Ouro Branco	20,47	Growatt 20000 TL3-S	1	Canadian Solar, modelo CS6U-325P	63
Ouro Preto	28,6	SMA Sunny Tripower 25000TL (SIW500)	1	Canadian Solar CS6P-260P	110
Itabirito	20,47	Growatt 20000 TL3-S	1	Canadian Solar, modelo CS6U-325P	63
Ribeirão das Neves	28,6	SMA Sunny Tripower 25000TL (SIW500)	1	Canadian Solar CS6P-260P	110
Ponte Nova	20,47	Growatt 20000 TL3-S	1	Canadian Solar, modelo CS6U-325P	63
Sabará	20,47	Growatt 20000 TL3-S	1	Canadian Solar, modelo CS6U-325P	63
Formiga	28,6	SMA Sunny Tripower 25000TL (SIW500)	1	Canadian Solar CS6P-260P	110
Santa Luzia	20,47	Growatt 20000 TL3-S	1	Canadian Solar, modelo CS6U-325P	63
Bambuí	25,75	SMA Sunny Tripower 25000TL (SIW500)	1	Canadian Solar CS6P-260P	99
São João Evangelista	28,6	SMA Sunny Tripower 25000TL (SIW500)	1	Canadian Solar CS6P-260P	110
Betim	28,6	SMA Sunny Tripower 25000TL (SIW500)	1	Canadian Solar CS6P-260P	110
Arcos	20,47	Growatt 20000 TL3-S	1	Canadian Solar, modelo CS6U-325P	63
Ibirité	20,47	Growatt 20000 TL3-S	1	Canadian Solar, modelo CS6U-325P	63

Table 2. Information about the plants recently implemented at IFMG.

Campus	kWp of Plants	Inverter Model	No. of Inverters	Module Model	No. of Modules
Bambuí	55,64	GW15KLV-MT, GW30KLV-MT	2	JA SOLAR, modelo JAM72S30-535/MR	104
Formiga	55,105	GW15KLV-MT, GW30KLV-MT	2	JA SOLAR, modelo JAM72S30-535/MR	103
Ibirité	36,915	GW15KLV-MT	2	JA SOLAR, modelo JAM72S30-535/MR	69
Ouro Preto	55,64	GW50KLV-MT	1	JA SOLAR, modelo JAM72S30-535/MR	104
Ribeirão das Neves	55,64	GW15KLV-MT, GW30KLV-MT	2	JA SOLAR, modelo JAM72S30-535/MR	104
São João Evangelista	55,64	GW15KLV-MT	3	JA SOLAR, modelo JAM72S30-535/MR	104
Sabará	18,19	GW15KLV-MT	1	JA SOLAR, modelo JAM72S30-535/MR	34
Santa Luzia	55,64	GW50KLV-MT	1	JA SOLAR, modelo JAM72S30-535/MR	104

3. Results

To confirm the accuracy of the plants' generation, use the PVsyst software to calculate the theoretical generation of the systems. The PVsyst software is a specific tool gathers all the constraints relating to the sizing of a specific system:

I) For the number of modules in a series: the upper diagram shows the I/V curve of the PV array, together with the MPPT range, voltage, power, and current limits of the inverter.

II) For the inverter sizing: the second graph displays the annual distribution of the array power, with the array and inverter nominal power.

III) The optimal sizing of the inverter is based on the acceptable overload loss throughout the year. It usually leads to over-size the power ratio (array nominal power with respect to the inverter nom. AC power), by a factor of 1.25.

IV) different losses can be defined, such as near and far shading. Specialized tools are also provided to evaluate different losses due to wiring, module quality, incompatibility between modules, dirt, thermal behavior, mechanical assembly, system unavailability, etc.

PVsyst software allows users to enter specific data about their solar systems, for example, data about solar photovoltaic modules and inverters. Furthermore, PVsyst offers a range of advanced customization options for the design of photovoltaic systems. This includes modeling different panel technologies, incorporating shading and other site-specific factors, and optimizing system performance based on various criteria. The following diagra, Fig. 1, shows an outline of the project organization and simulation process.

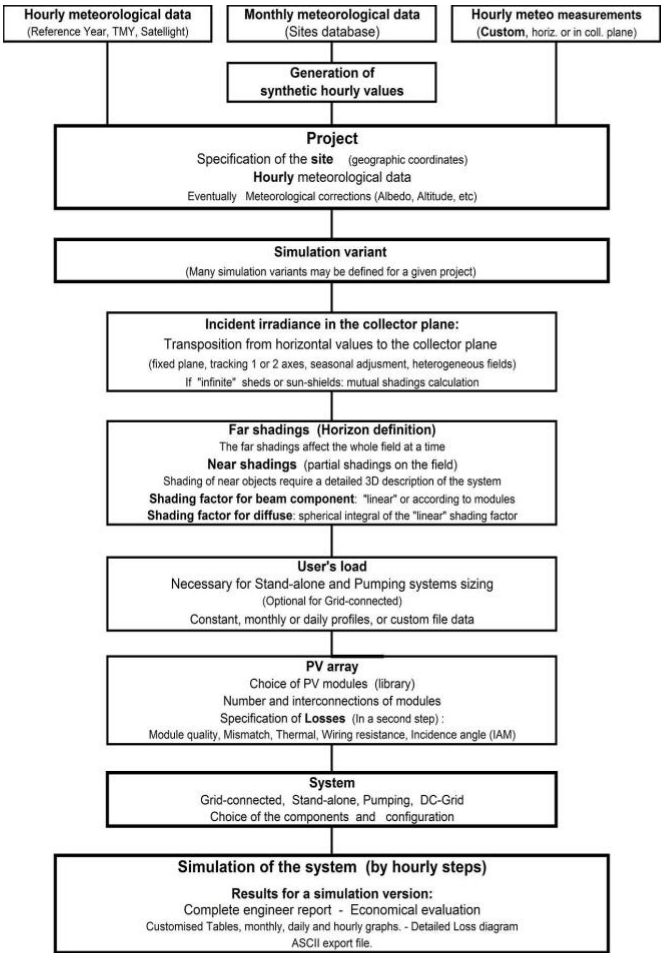


Figure 1. Organization of the project and the simulation process.

To execute the program, meteorological data from each region, number, configuration and orientation of photovoltaic modules, power required for the operation of the system, number of investors and, finally, the model of each equipment used in the project were considered [22].

To carry out the sizing in PVsyst, specific meteorological data for the region is initially inserted. The program offers the functionality of an interactive map, allowing you to enter the desired region using a search bar. When entering the location, the program calculates all the dimensions that will be used as a basis to estimate the amount of solar energy that will be received by the plants. In Fig. 2 it is possible to observe the meteorological data referring to the Itabirito region calculated by PVsyst [22].

	Irradiação horizontal total	Irradiação difusa horizontal	Temperatura	Velocidade do vento	Turvação de Linke	Humidade relativa
	kWh/m²/dia	kWh/m²/dia	°C	m/s	[-]	%
Janeiro	5.43	2.38	22.9	2.79	3.309	73.9
Fevereiro	5.65	2.50	23.0	2.70	3.317	72.5
Março	4.83	2.32	22.4	2.59	3.204	76.6
Abril	4.49	1.85	21.1	2.60	2.986	77.9
Maio	4.01	1.57	19.2	2.40	2.848	73.9
Junho	3.89	1.27	17.9	2.40	2.768	75.1
Julho	4.13	1.25	17.8	2.59	2.802	68.6
Agosto	5.01	1.54	19.5	3.00	3.117	60.4
Setembro	5.18	1.97	20.7	3.20	3.960	62.3
Outubro	5.19	2.33	22.5	3.30	3.842	62.9
Novembro	4.88	2.58	21.5	3.01	3.448	78.6
Dezembro	5.28	2.26	22.4	2.80	3.378	77.8
Ano	**4.83**	**1.98**	**20.9**	**2.8**	**3.248**	**71.7**

Figure 2. Meteorological data from the PVsyst program.

After calculating the meteorological data, the system orientations such as plane inclination and azimuth are included. In this option, which can be seen in Fig. 3, the program calculates the influence that the position of the photovoltaic modules can have on the system, highlighting the losses depending on the chosen orientation [22].

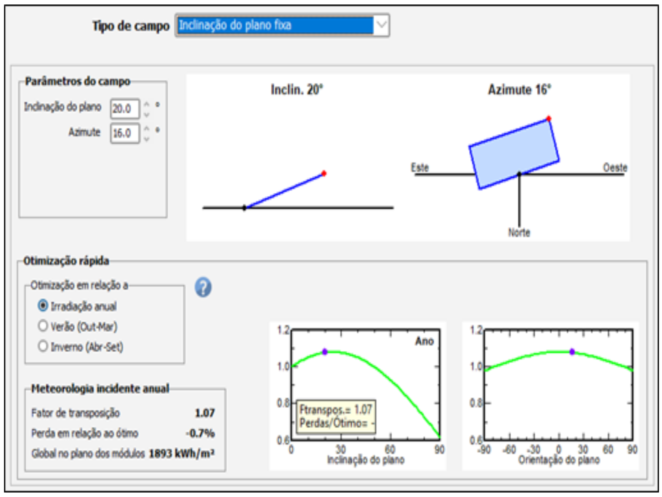


Figure 3. Setting the orientation of the photovoltaic system.

Finally, as seen in Fig. 4, the equipment is added along with its respective configurations. Furthermore, the program also offers the possibility of adjusting more advanced options, such as the individual specifications of each device [22].

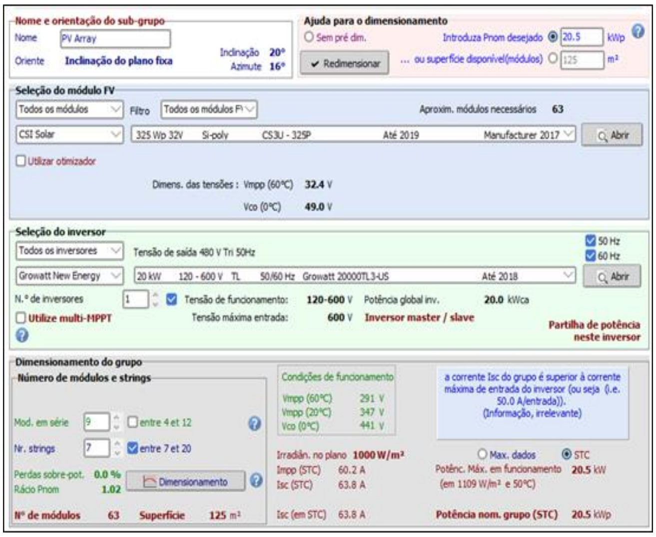


Figure 4. Configuration of photovoltaic systems.

After configuring the entire system, the program makes it possible to generate a report with data relating to the system's annual theoretical production, as well as all the information included in the project such as: Meteorological data, components, losses, etc. The reports generated served as a basis for certifying whether the projects and descriptive memorials made for each campus were in accordance with the data generated by the program, in addition to providing basic information on the theoretical generation of each plant. In Fig. 5 it is possible to observe the theoretical data for the Ipatinga campus obtained using the PVsyst software.

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR rácio
Janeiro	179.2	83.20	26.10	176.9	172.7	6.415	6.264	0.789
Fevereiro	171.9	81.80	26.40	171.6	167.7	6.226	6.082	0.790
Março	157.8	76.00	25.60	157.3	153.3	5.727	5.590	0.792
Abril	138.3	62.30	24.30	139.9	136.4	5.133	5.011	0.798
Maio	120.3	56.40	22.50	123.0	119.1	4.540	4.432	0.803
Junho	111.0	43.90	20.90	114.1	110.1	4.221	4.121	0.805
Julho	120.9	53.10	20.70	123.7	119.6	4.582	4.477	0.806
Agosto	141.1	58.80	21.90	143.3	139.6	5.303	5.179	0.805
Setembro	148.5	68.80	23.00	148.8	145.1	5.481	5.351	0.801
Outubro	158.7	83.00	24.20	157.9	154.1	5.782	5.643	0.797
Novembro	144.6	79.40	24.80	143.0	139.4	5.203	5.074	0.791
Dezembro	173.6	89.80	25.20	171.5	167.1	6.256	6.105	0.793
Ano	1765.9	836.49	23.79	1770.9	1724.1	64.870	63.330	0.797

Legendas

GlobHor	Irradiação horizontal total	EArray	Energia efetiva à saída do grupo
DiffHor	Irradiação difusa horizontal	E_Grid	Energia injetada na rede
T_Amb	Temperatura ambiente	PR	Índice de performance
GlobInc	Incidência global no plano dos sensores		
GlobEff	Global efetivo, corrigido para IAM e sombras		

Figure 5. Ipatinga campus theoretical performance report.

After ensuring that the theoretical data for each plant is consistent with the reports and descriptive memorials, dashboards were created using the Power Business Intelligence software (PBI), incorporating the monthly generation data for each plant. The integration of data into PBI was automated through the PBI website, allowing the desired time and date to be inserted. Subsequently, report links were generated for each campus, which were distributed automatically to the respective plants through Google Sheets automation. This process ensures that each campus has updated and direct access to the performance conditions of its plants, promoting more effective and informed management. In Fig. 6 it is possible to see the dashboard built on the Ipatinga campus as a model.

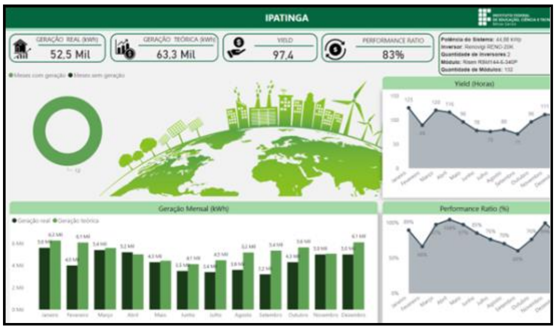
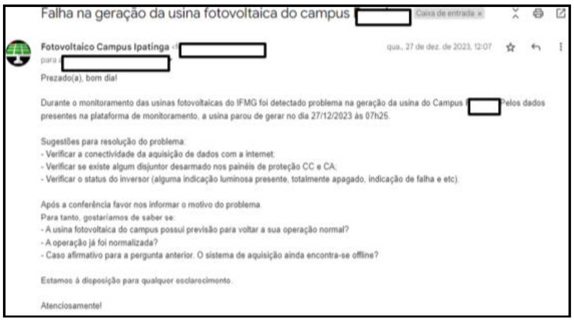


Figure 6. Performance dashboard of the Ipatinga campus plant.

Throughout the year, several discrepancies in the generation of some plants were detected, resulting in emails being sent to those responsible for each campus to notify them of the problems identified in the energy production of these facilities. In total, 29 emails were sent throughout 2023 notifying each campus about problems in the generation and/or communication of the plants. In Fig. 7 shows the e-mail with general guidelines developed for sending to campuses, where the main problems were highlighted and the guidelines provided. It is also worth highlighting that the main problem encountered is a failure in the campuses' internet. This way, the photovoltaic plant does not stop operating, but data sending is interrupted.


Falha na geração da usina fotovoltaica do campus [redacted] Caixa de entrada

Fotovoltaico Campus Ipatinga [redacted] qua., 27 de dez. de 2023, 12:07
para [redacted]

Prezado(a), bom dia!

Durante o monitoramento das usinas fotovoltaicas do IFMG foi detectado problema na geração da usina do Campus [redacted] Pelos dados presentes na plataforma de monitoramento, a usina parou de gerar no dia 27/12/2023 às 07h25.

Sugestões para resolução do problema:
- Verificar a conectividade da aquisição de dados com a internet;
- Verificar se existe algum disjuntor desarmado nos painéis de proteção CC e CA;
- Verificar o status do inversor (alguma indicação luminosa presente, totalmente apagado, indicação de falha e etc).

Após a conferência favor nos informar o motivo do problema.
Para tanto, gostaríamos de saber se:
- A usina fotovoltaica do campus possui previsão para voltar a sua operação normal?
- A operação já foi normalizada?
- Caso afirmativo para a pergunta anterior. O sistema de aquisição ainda encontra-se offline?

Estamos à disposição para qualquer esclarecimento.

Atenciosamente!

Figure 7. Alert email developed during the project.

On January 12, 2024, a report for the year 2023, in spreadsheet format, containing access links to the dashboards developed for all photovoltaic plants and their maintenance status was sent to IFMG management. This report highlighted items to be observed in the 25 IFMG plants, such as: adding the plants on the Arcos and Ribeirão das Neves campuses to the portal common to the others, inserting the plants on the Ipatinga and Piumhi campuses into the same portal and correcting maintenance problems observed.

A series of maintenance activities at the Ipatinga campus plant were triggered due to the finding of a lack of generation during the daily monitoring process. After an analysis, it was identified that energy production was not reaching expected levels, which led to the need for immediate interventions.

Cleaning activity was identified as a crucial measure to optimize the functioning of equipment, such as solar panels. Considering this context, on January 05, 2023, possible obstructions and accumulations that were affecting generation efficiency were removed. This intervention aimed to restore ideal conditions for capturing sunlight, thus maximizing energy production.

On January 9, 2023, it was observed that the alternating current circuit breaker of the second inverter began to trip repeatedly. The circuit breaker was reset twice, where the plant operated normally for a few days and the circuit breaker tripped again. Subsequently, phase C of the circuit breaker opened, resulting in a constant failure in the operation of the second inverter. To resolve this issue, on February 06, 2023, the circuit breaker was replaced, thus restoring the normal operation of the plant. Furthermore, the performance of some surge protection devices (DPSs) on the direct current side of the photovoltaic plant was identified, resulting in the replacement of these components on May 19, 2023. Furthermore, the opportunity was taken to conduct a general retightening of the panel. In Fig. 8 and Fig. 9 the DPS's actuated in the DC protection panels of the two inverters are highlighted and in Fig. 10 and Fig. 11 the panels are shown after changing the devices.

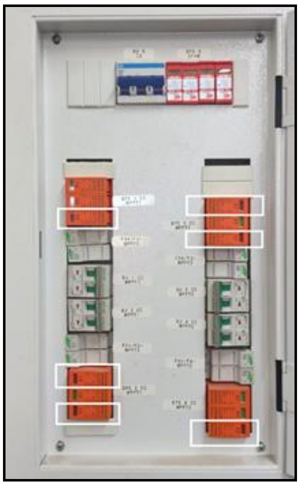


Figure 8. Actuated negative pole of DPS 1 and 4, actuated positive and negative poles of DPS 2 and 3 of Inverter 1.

Figure 9. DC protection boxes after changing the SPDs of Inverter 1.

Fig. 10. Negative and ground pole of DPS 2 and actuated positive pole of DPS 3 of Inverter 2.

Figure 11. DC protection boxes after exchanging the SPDs of Inverter 2.

4. Conclusion

Considering the information presented, the work aimed to offer a significant contribution to the efficient management of photovoltaic plants throughout IFMG. The ability to generate alerts in the face of potential abnormalities represented a crucial result, allowing quick and effective interventions. This project also aimed to improve management by offering support in the implementation of preventive/corrective maintenance and cleaning strategies in photovoltaic plants, actions that are currently present in only a few IFMG units.

The modeling of the plants located on each campus was carried out using the PVsyst software, where the system design is based on a quick and simple procedure, that is, specification of the desired power or available area, definition of the photovoltaic module and definition of the inverter. Furthermore, the software took into account losses such as close and distant shading, losses due to wiring, module quality, incompatibility between modules, dirt, thermal behavior, mechanical assembly, system unavailability and meteorological data.

By providing real data, the project contributes to planning future investments and optimizing the management of the institution's plants. The results generated include not only the identification of irregularities and improvement of maintenance, but also the validation of the return on investments made and guidance for future strategic decisions in the management of IFMG's photovoltaic plants.

References

[1] C. Machado, F. Miranda, (2014). “Energia Solar Fotovoltaica: Uma breve revisão”. Revista Virtual de Química Outubro. Rio de Janeiro.

[2] W. Wu, C. Zhang, J. Su e H. Wang, "The Design of New High Efficiency Photovoltaic Grid and Independent Power Supply Inverter", Conferência Internacional de 2015 sobre Inteligência Computacional e Redes de Comunicação (CICN) , Jabalpur, Índia, 2015 , pp.

[3] "Wang Haining. Research on the photovoltaic Grid-connected Power Conditioner System and Its Control Strategy", Hefei: Hefei University of Technology, 2005.

[4] Zhao Jinbin, Zhang Yuanji, Qu Keqing, Li Fen and Fujio Kurokawa, "Overview of Control Strategy for Single-Phase Grid-Connected Inverter with LCL Filter", Transactions of Transactions of China Electrotechnical Society, vol. 28, pp. 134-142, Oct. 2013.

[5] G. Tong, "Construction of smart energy system based on dual carbon goal", Smart Power, vol. 49, pp. 1-6, May 2021.

[6] X. Fu, M. Miao, F. Li, X. Yang and Z. Wang, "Study on photovoltaic acceptance ability in Qinghai power

grid", Shanxi Electric Power, vol. 45, pp. 21-25, Nov. 2017.

[7] T. G. Klise, R. John Balfour and T. J. Keating, "Solar PV O&M standards and best practices—Existing gaps and improvement efforts", Nov. 2014.

[8] R. Dubey, "Measurement of temperature coefficient of photovoltaic modules in field and comparison with laboratory measurements," 2015 IEEE 42nd Photovoltaic Specialist Conference (PVSC), New Orleans, LA, USA, 2015, pp. 1-5

[9] I. D'Adamo, M. Mammetti, D. Ottaviani and I. Ozturk, "Photovoltaic systems and sustainable communities: New social models for ecological transition. The impact of incentive policies in profitability analyses", Renew. Energy, vol. 202, pp. 1291-1304, Jan. 2023.

[10] L. G. da Fonseca, Solar O&M Market Opportunity by Activity 2020–2030, Edinburgh, U.K:Wood Mackenzie, Feb. 2022.

[11] P. Xu, J. M. Hou and D. K. Yuan, "Fault diagnosis for building grid-connected photovoltaic system based on analysis of energy loss", Advanced Materials Research, pp. 8-93, 2013.

[12] I.-S. Kim, "Fault detection algorithm of the photovoltaic system using wavelet transform", Proc. India Int. Conf. Power Electron. (IICPE), pp. 1-6, Jan. 2011.

[13] A. Colli, "Failure mode and effect analysis for photovoltaic systems", Renew. Sustain. Energy Rev., vol. 50, pp. 804-809, Oct. 2015.

[14] A. Mellit, G. M. Tina and S. A. Kalogirou, "Fault detection and diagnosis methods for photovoltaic systems: A review", Renew. Sustain. Energy Rev., vol. 91, pp. 1-17, Aug. 2018.

[15] "Standard 929–2000, Institute of Electrical and Electronics Engineers Inc", IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems, 2000.

[16] U. Jahn, Guidelines for Operation and Maintenance of Photovoltaic Power Plants in Different Climates, Oct. 2022.

[17] Almerão, Eduardo da Silva e Rampinelli, Giuliano Arns. (2022). "Análise de um Sistema Fotovoltaico de Geração Distribuída Instalado em uma Edificação com Arquitetura Bioclimática: Medição, Modelagem e Simulação". Anais do XIII CBPE. Itajubá.

[18] Shiva Kumar, B. E Sudhakar, K. (2015). "Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India". Energy Reports, v. 1, p. 184–192. Índia.

[19] Araújo Cavalcanti, Alvaro e colab. (2019). "Performance Evaluation of Micro-and Minidistributed Photovoltaic Systems Using Data Envelopment Analysis". IEEE Journal of Photovoltaics, v. 9, n. 6, p. 1806–1814. Pernambuco.

[20] Jhefsson Gabriel Targino da Silva Santos e Waltemberg Silva Limeira. (2022). "Sistema de Monitoramento de Impurezas aplicada à sistema de energia solar fotovoltaico". Repositório Universitário da Ânima (RUNA). Paraíba.

[21] G. G. Kim, J. H. Hyun, J. H. Choi, S.-H. ahn, B. G. Bhang e H.-K. Ahn, "Análise de qualidade de sistema fotovoltaico usando estatísticas descritivas de índice de desempenho de energia", em IEEE Access , vol. 28427-28438, 2023

[22] Leonardo Nery Carrijo dos Santos, Gerson Flávio Mendes de Lima. (2022). "Dimensionamento prático de um sistema fotovoltaico – estudo de caso utilizando o software Pvsyst". Brazilian Journal of Development. Minas Gerais.