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# 5G based data acquisition system applied to photovoltaic plants

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**Abstract.** This paper brings the state of the art of the Internet of Things (IoT) technology and 5G, emphasising their potential and combined use. Based on the review, we propose a monitoring system based on an AVR-IoT microcontroller, known for its 5G connectivity and energy efficiency, applied to decentralised photovoltaic (PV) plants. The combination of 5G connectivity, precise sensors and efficient microcontroller makes this option a robust and affordable choice for PV plants monitoring.

**Key words.** 5G, Internet of Things , Photovoltaics.

## 1. Introduction

5G stands as the 5th-generation technological standard designed for mobile networks, serving as the intended heir to 4G networks, granting connectivity to the majority of today's mobile devices. 5G is essentially a mobile network of the 5th generation, introducing a fresh network paradigm, aimed at linking nearly everyone and everything, encompassing machinery, objects, and various devices. This assertion draws parallels with another technological standard: the Internet of Things (IoT) technology. The primary objective of mobile networks, i.e., the continuous evolution and enhancement of mobile technologies, focus on facilitating rapid access to desired information for users. Hence, the foremost advantage of 5G lies in its exceptional speed.

5G offers wider coverage, helping to resolve coverage issues that frequently occur in rural areas. Furthermore, 5G offers high-speed services used for automatic, connected and remote medical services, mass communication used in digital factories, and smart cities. The application of IoT technologies in smart grids for use in smart cities allows real monitoring of generation and response to failures. This integration facilitates the exchange of infrastructure and data between smart grids and smart city systems, leading to enhanced efficiency and coordination of operations. By uniting these two systems, cities can simplify energy management, elevate public services, boost sustainability efforts, and establish a more interconnected and agile urban environment [1]. Additionally, due to 5G's low latency, IoT resources can be used to automate equipment and connect more quickly, efficiently and stably.

While 5G was deployed for commercial use in 2020, the industry is already actively engaged in forging novel global standards and products that extend 5G capabilities, benefiting industries worldwide [2]. The convergence of 5G and IoT fosters the growth of a smart urban ecosystem, empowering businesses, whether large or small, to establish IoT services without the need for developing their own network infrastructure. Numerous smart city services can leverage 5G power, advancing the integration of 5G and IoT. Hence, 5G can promote innovation in many industries and provide a platform that allows new technologies such as IoT to become an integral part of our economy and lifestyle. In such a context, we propose in this paper the use of 5G technology for monitoring a photovoltaic (PV) plant with IoT.

The paper has the following division: section 1 is the introduction, section 2 brings the state of the art, section 3 is the proposal of a monitoring system and section 4 brings our conclusions.

## 2. State of the art

According to the state of the art proposed in [3],[4], IoT is an emerging and promising technology with the potential to revolutionise the world through connected physical objects, involving low-power devices that interact with each other through the Internet. In this context, examples like home automation, assisted living, e-health, are application scenarios where the new paradigm will take a better role in the near future. In the same way, from a business user's perspective, the most apparent outcomes will be equally visible across domains such as automation in industrial manufacturing, logistics, business and process management, as well as the intelligent transportation and smart grids. Smart grid refers to the next-generation power grid, where the distribution and management of electricity are enhanced by integrating advanced two-way communications and pervasive computing capabilities to achieve better control, efficiency, reliability, and safety. A smart grid facilitates the transmission of electricity between suppliers and consumers through digital technologies, managing intelligent equipment to conserve energy, lower costs, and enhance reliability, efficiency, and transparency [5],[6],[7]. Over time, significant domestic and business applications will be attributed to IoT, generating an impact on improving the quality of life and mainly on the growth of the world economy [8], for example, in smart homes, controlling climate systems, all made available to residents. To realise this potential growth, emerging technologies and innovations need to be developed to meet user requirements to ensure anywhere, anytime availability.

In this context, IoT emerges as a potent enabler, offering a diversity of sophisticated applications adapted for the dynamic demands of smart cities. Nevertheless, this proliferation of IoT applications has led to an increasing energy consumption, a pressing challenge that necessitates the development of smart city solutions that optimise energy usage while effectively tackling the attendant complexities. Hence, energy management emerges as a pivotal paradigm essential to realise the potential of intricate energy systems of smart cities. In [9] an overview of the surrounding energy management in the context of smart cities is proposed, developing a comprehensive framework designed for energy-efficient optimization and IoT-centric smart city infrastructures. The investigated case studies serve to emphasise the impact of energy-efficient scheduling optimization and the integration of wireless power transfer, highlighting their transformative influence on the performance dynamics of IoT in smart cities.

5G has the function of allowing reliable communication, where data is sent and received with integrity. guaranteed transmission with low latency as 1 ms and low failure rate, allowing safe continuity of equipment connection to the network [10]. Massive Machine-Type Communication is a strategy that aims to offer efficient wireless connectivity for sensor devices in the IoT [11]-[12]. Furthermore, for communication that requires ultra-reliable connection services, it is possible to use ultra-reliable low-latency communication (URLLC), which includes real-time management of the intelligent electrical grid and remote control of real-time operations.

In this context, Release 14 is the start of 5G, developed by the 3rd Generation Partnership Project (3GPP) [13]. In addition to the continued progress of Long Term Evolution (LTE) , it was standardised to offer extensive connectivity for massive machine-type communications within the IoT. A capability analysis is proposed in [14] for various combinations of latency-reducing and reliability-enhancing features in the LTE system.

Recent technological advancements have positioned Massive MIMO as the top choice for large-scale implementations in 5G mobile networks [15]. Massive MIMO harnesses cutting-edge beamforming and MIMO techniques, serving as potent instruments for enhancing the end-user experience, capacity, and coverage. Consequently, Massive MIMO substantially elevates network performance in both the uplink (UL) and downlink (DL) directions. In the context, beamforming represents the capability to gather signal strength from a particular transmitter [16]. During reception, beamforming involves gathering signal power from a particular transmitter. These beams are continuously adjusted to the environment to deliver optimal performance for both UL and DL communications, according to Fig 1. In Fig 2 it is shown that a generalised beamforming serves a single user by transmitting the same data stream in multiple directions.

Beamforming is a technique through which an array of antennas can be steered to transmit radio signals in a specific direction. Instead of merely scattering the Wi-Fi signal in all directions, antenna arrays employing beamforming ascertain the direction of interest and transmit/receive the signal more strongly in that specific direction. Consequently, in 5G technology, where exceedingly high data rates are imperative, the only way to achieve this is by maximising transmission and efficient reception, employing beamforming; in this technique, each antenna element is separately fed with the signal to be transmitted [17] , [18].

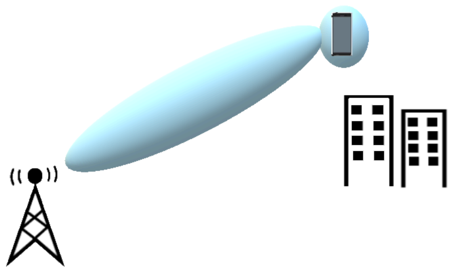

Fig. 1. Beamforming for individual users.

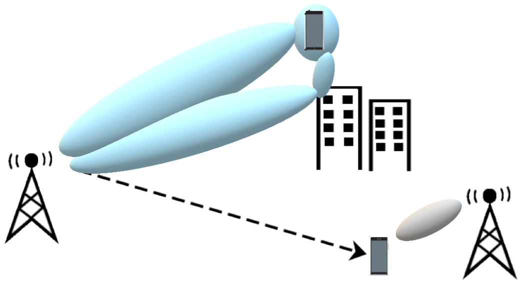

Fig 2. Generalised Beamforming.

A project is proposed in [19] to implement a flexible beamforming (FBF) antenna system capable of efficiently meeting diverse application demands. IoT domain promises a connected existence characterised by robust interactions between a variety of densely packed devices, while advances in 5G wireless technologies present an opportunity to address the scalability and interoperability challenges inherent in emerging devices, applications and services. The approach involves integrating FBF antenna architecture with cutting-edge 5G technologies, meticulously designed to meet the diverse requirements of a connected ecosystem. By dynamically scaling transmission power and implementing adaptive strategies, the authors in [20] ensure flexible spectrum coverage, connectivity and enhanced throughput, all achieved in an energy-efficient manner. The simulation results highlight the superiority of the proposed FBF antenna architecture, exhibiting substantially improved data rates, higher link capacity, reduced latency and greater energy efficiency when compared to other potential deployment scenarios.

According to [20] enabling massive access for IoT in networks beyond the scope of 5G poses a formidable challenge for conventional bandwidth-limited technologies. Millimetre-wave technologies (mmWave), while offering substantial bandwidth advantages, necessitate more intricate wireless processors to operate efficiently in challenging radio environments. Although mmWave presents a promising solution for facilitating massive IoT, the associated costs and power requirements currently impede widespread adoption in practical implementations.

Beamforming has the potential to significantly enhance communication and sensing capabilities across a broad spectrum of IoT applications [21]-[22]. The configuration of radiofrequency beams in the radiative far-field, focusing on WPT (Wireless Power Transfer), is investigated in [23]. The study shows an analytical model depicting channel fading, along with the adaptation of a blind model adaptive beamforming algorithm to suit the specific requirements of WPT. The findings underscore the positive impact of implementing this variant of beamforming, notably leading to an enhancement in the harvested power. The algorithm demonstrates convergence at varying distances ranging from 50 cm to 1.5 m, with the gain increasing proportionally as the number of antennas is augmented to two, three, and four. These significant findings hold substantial implications for the domain of supplying wireless power for IoT devices.

IoT based sensors have already been used for monitoring and prediction [24]. The free and customizable web application for SIoT, named Wireless Monitor, aims to offer a solution for secure online, real-time data visualisation [25]. Users can create a personalised web environment with Wireless Monitor to monitor IoT sensor devices, and the collected data is stored in a cloud server bank, allowing for real-time chart viewing. Experiences of monitoring and data acquisition systems (DAS) are described in [26]-[27], and a new concept of a low-cost DAS applied to decentralised renewable energy (RE) plants with a USB interface is proposed. Such systems contribute to the dissemination of RE plants, recognition of local energy resources in real time, monitoring of energy conversion efficiency, and sending of information concerning failures.

According to [28]-[29], the adoption of PV systems in Brazil is increasing as a consequence of the decreasing cost of PV modules and the electric power compensation mechanism; hence, consumers are increasingly focusing investments on PV decentralised generation to reduce power expenditures. In these papers an integrated system in the IoT is developed, using an IoT surveillance system adapted for a grid-connected PV setup within an educational institution, serving as an effective pedagogical tool to transmit knowledge on IoT and PV generation. The system core is the ESP32, facilitating data transmission to a cloud-based database. In [30], it is shown that to facilitate a comprehensive assessment of temperature differentials in the central and peripheral regions of grid-connected PV modules it is essential to develop and implement an IoT monitoring system. The proposed IoT embedded system is built on open source software and hardware, leveraging the ESP32 development board, which enables wireless communication with a cloud-based server via WiFi, offering unrestricted accessibility and distribution. A dedicated web interface, called 'Web Monitor', is created to enable real-time data monitoring and online querying of PV temperature. The main objective, behind monitoring individual modules, is to collect crucial data for assessing electricity generation efficiency and timely detection of possible failures arising from overheating of PV cells. Complementary meteorological data, covering solar irradiance, ambient temperature, relative humidity and wind speed, are collected and monitored simultaneously, enriching the analysis by clarifying the impact of these variables on the thermal response of the modules.

Throughout different phases of the microgeneration process, including the assessment of energy resources, prognosis of generation failures, and practical validation of project data and generation efficiency, monitoring and data acquisition systems find broad applicability [31]. To facilitate this, an online monitoring and DAS is proposed, employing a WiFi modem integrated with a microcontroller board operating on open-source software [32]. The system is designed to establish wireless communication with an online server, enabling the transmission of microgeneration data to the central database. Utilising open-source hardware and software, an online monitoring system is implemented, employing a WiFi embedded modem. This system is specifically applied to an electrical microgeneration plant that relies on thermoelectric microgenerators. The primary aim is to conduct an in-depth analysis of plant variables through a custom-developed online monitoring software. This software is designed to facilitate data storage in an online database and generate graphical representations, all accessible remotely for comprehensive plant oversight.

## 3. Proposal of a monitoring system for PV plants

We propose a monitoring system based on an AVR-IoT microcontroller, known for its 5G connectivity and energy efficiency. Specific sensors have been incorporated to obtain relevant data on the local environmental conditions. PT100 sensors are used to measure PV modules temperature, informing about harmful temperatures, preventing damage and improving the lifespan of components. The pyranometer is used to measure incident solar irradiance, providing valuable data for performance analysis. The anemometer monitors wind speed, which is crucial for evaluating the panels' heat dissipation and optimising electricity production. AVR-IoT is the system brain, responsible for collecting data from the sensors, processing the information and transmitting the results to a remote server. A DHT11 sensor provides information on the ambient temperature and humidity, allowing correlation analyses between these factors and the efficiency of the solar panels.

AVR-IoT uses 5G connectivity to transmit the collected data to a remote server. This methodology enables plant operators to access the system's operating conditions and performance in real time. In addition, it is possible to implement automatic alerts in the event of abnormal conditions, enabling a rapid response to critical events.

Our proposed monitoring system, based on the integration of AVR-IoT and a variety of specialised sensors, offers a comprehensive solution for monitoring and optimization of PV plants. Continuous data collection and analysis enable the implementation of sustainable practices, maximising operational efficiency and extending the life of components. The combination of 5G connectivity, precise sensors and efficient microcontroller makes this system a robust and affordable choice for PV plant monitoring. In Fig. 3 is shown the AVR-IoT Cellular Mini Development Board, a small and easily expandable demonstration and development platform for IoT solutions based on the AVR® microcontroller architecture using cellular technology. It is designed to demonstrate that the design of a typical IoT application can be simplified by partitioning the problem into three blocks: secure, connected, smart.

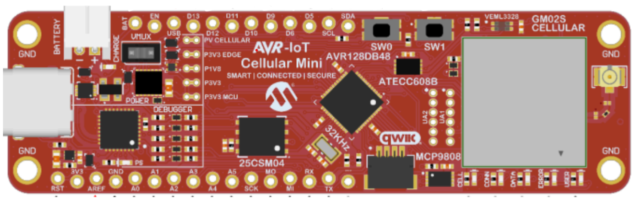

Fig. 3. AVR-IoT Cellular Mini Development Board

The monitoring system of the Laboratory of Alternative Energies (LEA) constitutes a comprehensive approach for the collection and analysis of relevant PV modules performance data. This system encompasses the temperature measurement of 12 modules of a PV plant, with focus on the temperatures of the upper, lower, and central edges of the extreme modules, along with the monitoring of environmental variables such as solar irradiance, ambient temperature, wind speed, and relative humidity. The technological system core is the ESP32 microcontroller, whose programming allows for the continuous collection of data at one-second intervals, followed by the computation of the average of these readings every minute. This procedure not only ensures a more precise analysis but also contributes to the optimization of the system efficiency by reducing the burden of transmitted data.

Data communication and transmission are carried out through a wifi connection to the IoT application server, named ThingSpeak. This server has dedicated APIs for data writing and reading, enabling effective integration with the monitoring system. Through the written API, a customised link is generated on the ESP32, where the averages of the sensor readings are aggregated. When the ESP32 sends an HTTP request to the ThingSpeak server, it proceeds with the processing and insertion of data into the designated channel and field. Thus, ThingSpeak performs the storage and exposure of the received data, making it accessible for analysis and download. This methodology simplifies data management, allowing authorised users to conveniently access the collected information. In summary, LEA's monitoring system is a comprehensive solution for the collection, processing, and provision of critical data related to the performance and operational environment of PV modules. This integrated approach provides a detailed and well-founded analysis, aligned with current scientific requirements and standards. Some examples of measured data are shown in Figs. 4, 5, 6, and 7: ambient temperature, wind speed, irradiance and PV module temperature, respectively.

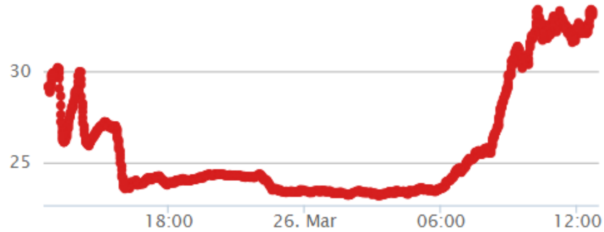

Fig. 4 Ambient Temperature (°C)

Fig.5 Wind Speed (m/s)

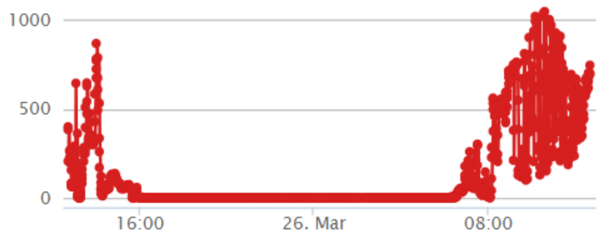

Fig. 6 Daily Irradiance (W/m²)

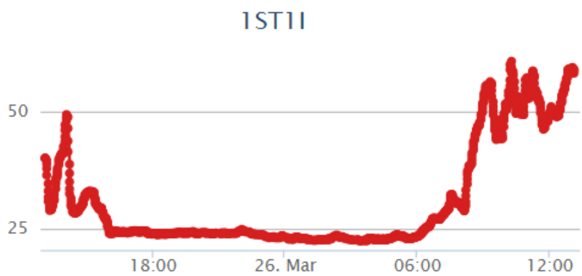

Fig 7. PV Module Temperature (°C)

## 4 . Conclusions

This paper presented and analysed the exciting potential of Internet of Things (IoT) technology and 5G, specifically highlighting their key features and potential for synergy. Leveraging the insights from this review, we proposed a monitoring system for decentralised PV plants, built around the AVR-IoT microcontroller. This choice stands out for its efficient 5G connectivity and low power consumption, making it a robust and cost-effective solution for real-time PV plant monitoring. We plan to further validate our approach by applying it to real-world PV plants and showcasing the results in future works.
In Fig. 8 is illustrated a possible 5G based monitoring system configuration applied to a PV plant.

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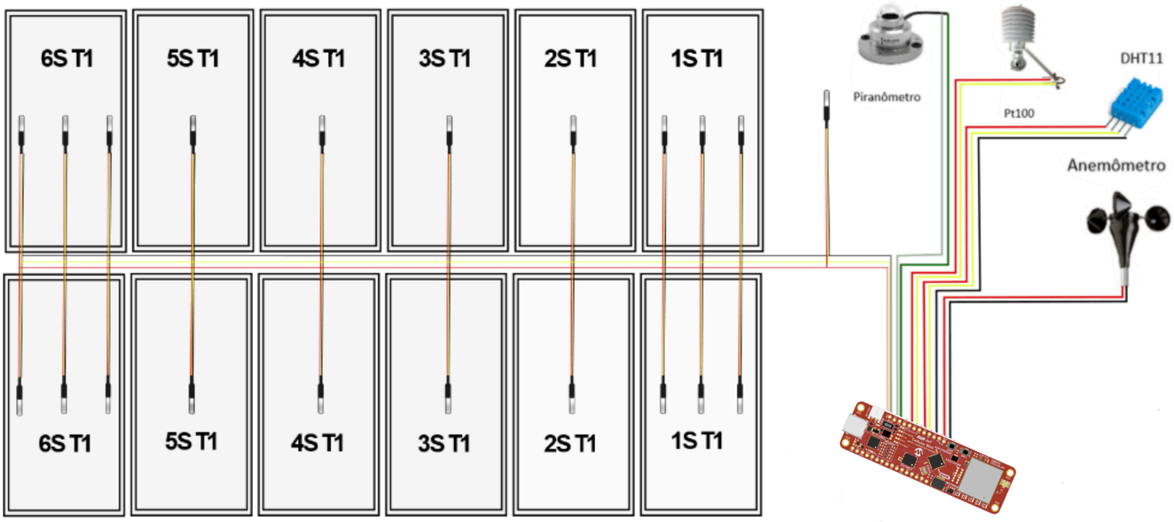

Fig. 8 5G based monitoring system configuration.

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