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POST-CLOUD SOLUTIONS IN THE HIGH-DEFINITION DIAGNOSTICS OF SOLAR FARMS

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Purpose: The aim of this article is to demonstrate the benefits of using post-cloud solutions in the monitoring and servicing of large photovoltaic farms.
Design/methodology/approach: This article analyzes current problems with maintaining high generation of large photovoltaic farms, discusses the limitations of current service methods and indicates the direction of development and possible applications of new IT tools in the field of the Internet of Things to solve these problems and limitations.
Findings: This article presents a revolutionary fog computing method and as a tool for building IT infrastructure for monitoring large photovoltaic farms.
Originality/value: The information contained in the article concerns the operation of large photovoltaic farms and the next step in the development of monitoring and service tools in terms of maintaining production efficiency at a high level thanks to the use of the latest IT technologies. The author indicates the possible direction of development of IT architecture based on the latest revolutionary methods of collecting and processing data as a solution to the limitations of currently used methods.
Category of the paper: General review, Technical paper.
Keywords: high resolution monitoring, cloud computing; fog computing; resource management, Solar Power Plants, Large-scale Photovoltaic, private blockchain.

1. Introduction

Will the operation of solar farms take advantage of the opportunities offered by the fourth industrial revolution? The new accelerating industrial revolution is primarily about the exponential increase in the amount of data processed and analyzed, allowing us to make business decisions faster and in a more reasonable way. This data will be the main component of modern monitoring solutions for power grid systems. They include large solar farms, sometimes called photovoltaic power plants. Procedures related to processing, storing, transmitting and securing the data should be the basic determinant supporting the decision-making process for choosing specific technologies or the architectural model of such systems.

It is of paramount importance to choose the right basic technology to digitalize the sector. The result of the digitalization will make it impossible for many years to change the adopted solution and introduce a new one. This will have a significant impact on the pace of changes, local market simulations and, first of all, on the performance and security of IT infrastructure, and will also make a starting point for creating a new paradigm for building IT systems for the infrastructure of large-scale photovoltaic power stations.

2. Current state

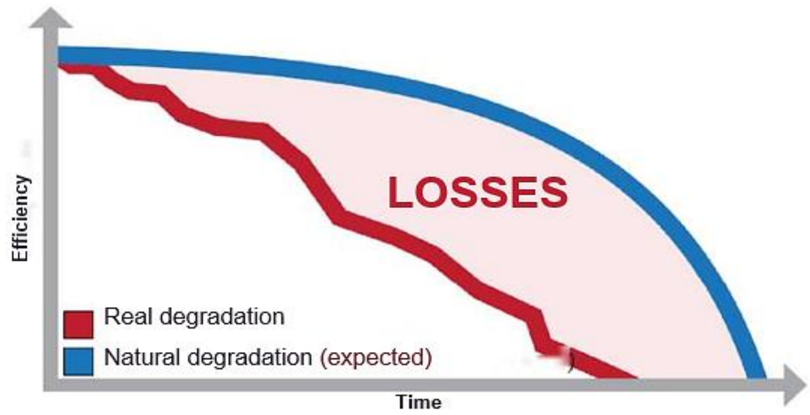

Figure 1. Decrease in efficiency due to degradation of photovoltaic panels.
Source: Own elaboration.

Solar farms degrade over time – it's natural. But, if poorly managed, they degrade at a much faster pace than expected (Figure 1). Investors do not achieve the expected ROI. As a result, they incur O&M costs or have to accept lower power generation performance and reduced revenues. There are several phenomena described in the literature (Garcia et al., 2014) that affect it. It results from the superimposition of the following phenomena:

1. Production mismatch: differences in solar module performance resulting from generation variations.
2. Thermal gradients: differences in temperature between solar modules within a system.
3. Uneven soiling: environmental contamination of solar modules.
4. Cloud shading and refraction: power surges (both power increase and power drops) resulting from clouds passing over the panel.
5. Defected bypass diodes: solar modules delivered from factory with defected bypass diodes.
6. Voltage drops: voltage mismatch in chain, resulting from voltage drop on home run lines leading to inverters.

7. Variable degradation: silicon solar cells age at different rates; their mismatch increases over time.
8. Cumulative wear: serious problems with the system that increase over time, e.g. mechanical or electrical faults.

Detecting these phenomena and their effects in large-scale solar farms with a power of 1 MWp or bigger is costly and time-consuming. A significant limitation of the study is the fact that the life cycle of a photovoltaic farm is 10-25 years. In the currently rapidly changing financial and technological environment, accurate observation of the installation's behavior in such a period is also devoid of research and financial sense. The observed cascading degradation phenomena are a problem in the long-term operation of photovoltaic farms, however, a precise presentation of the scale of this problem requires further observations. At the current stage of research, the phenomenon shown in Figure 2 occurs in every installation, but its scale depends on many factors such as: geographical location, age of the installation, generations of photovoltaic panels used, and service quality. In the long term (10-25 years) achieving a reasonable level of profitability of the photovoltaic business will largely depend on the introduction to the market of a new O&M service mode based on a remote high-definition/resolution diagnostics and monitoring (according to the International Energy Agency, the progress in the efficiency of photovoltaic generation depends on the rapid introduction of the so-called High Resolution Monitoring Systems (Figure 2).

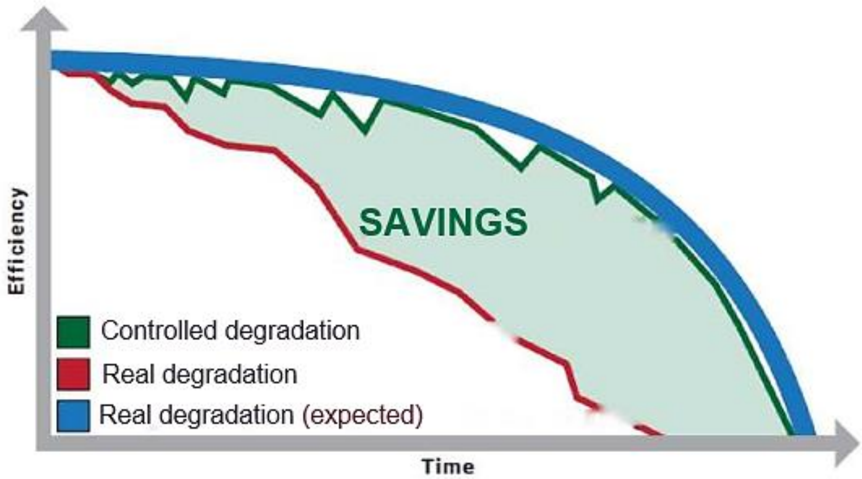

Figure 2. The scope of savings that can be achieved in the new monitoring and service model.
Source: Own elaboration.

Currently, due to rising labor costs and limited availability of technicians, monitoring of each solar panel in real time or near real time will allow the utility-scale (with a power over 5 MWp) farms to be maintained.

3. High-definition monitoring

Network monitoring is a critical IT process to discover, map, and monitor photovoltaic panels and other photovoltaic farm components.

The high-definition (HD) monitoring adopts the principle of monitoring in real time basic operating parameters, including voltage, current, power, temperature of all farm components, i.e. panels, inverters and power output systems. Such a significant amount of data requires a highly efficient data collection system and an intelligent processing system using AI elements (Benadale et al., 2023).

The solution should also be scalable, i.e. enabling to build higher-level monitoring stations, common to many sites.

4. Business aspect of high-definition diagnostics.

The basic trend is moving away from string-based monitoring systems. They are replaced with data acquired from inverters, offering the same diagnostic value without requiring additional expenses. However, data from inverters, similarly to string systems, does not solve the basic problem: the lack of indication of places and reasons for generation losses. This does not eliminate the need to conduct expensive field diagnostics by competent technicians using specialized measuring instruments. The costs of such diagnostics constitute 60% of the costs in the traditional O&M model (Figure 3). The main problems of the traditional O&M model include the growing labor costs and a shortage of qualified electrical technicians on the market. This has led to a widespread trend of not providing the required scope of services for utility-scale farms. The average percentage of panels covered by diagnostics does not exceed 30% (Figure 3) of the objectively required quantity and, in addition, the percentage of not completed scheduled service work is about 20% (Figure 3). All these adverse factors collectively result in structural losses of electricity generation (saw problem), practically impossible to make up for, and their removal requires stopping the farm's operation and involves additional large financial outlays. This fact also results in losses of electricity generation, which could be avoided by increasing the density of diagnostic measurements and optimizing the operation of service teams.

Service based on the model of traditional diagnostics

Service based on the model of HD diagnostics in an on-line system

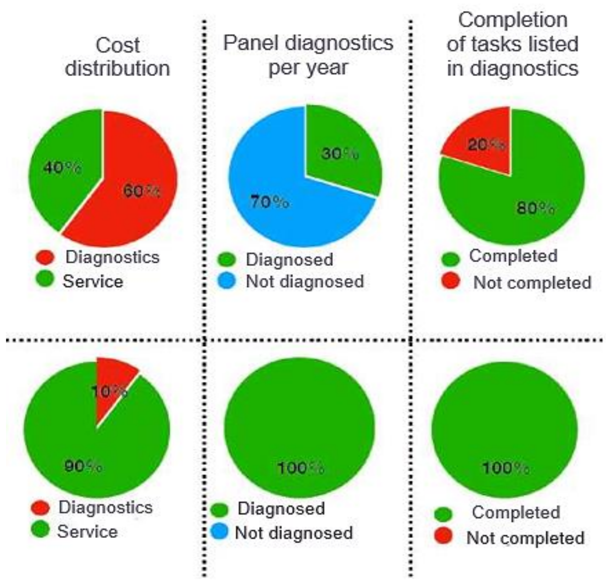

Figure 3. Comparison of the current service model based on manual diagnostics and the proposed model based on online diagnostics.

Source: Own elaboration.

Research in recent years has focused on the use of UAV-based thermal monitoring (Akai et al., 2024). This is significant progress, but it does not solve all problems and limitations and does not allow for the introduction of online monitoring.

The problem can be solved only by introducing to the market a service based on new technologies, enabling to detect failures and defects online with an accuracy of a single solar panel, automatically define and prioritize the service tasks and assign tasks to service teams, as well as introduce automatic verification of their implementation. However, this requires introducing a change in monitoring systems and the use of new – but also increasingly refined – IT technologies, the basis of which will be high-definition monitoring working online.

5. Fog computing as an alternative to cloud-based solutions in the diagnostics of solar farms

Moving to the next, lower level, i.e. to the level of a single panel, exponentially increases the number of measurement points. The use of instantaneous measurements of voltage, current and power obtained from sensors at all or most of the grid points, and collected by the system operating in real time will result in an exponential increase in the demand for IT systems and will not be possible without the use of emerging technologies. Currently, existing control and measurement, as well as automation solutions perform a specific task in a precisely defined location and only for the largest photovoltaic power stations. In most cases, they consist of a control and measurement or sensory layer, and a local data aggregation system. A natural development step is to transfer data aggregation to cloud-based solutions. With the current state of infrastructure and security systems, using measurement data from two or more farms of an operator is very difficult, even only for security reasons (Ferrag et al., 2020). In this situation, the existing model of IT architecture has been preserved and the current state of information technology has not yielded any good solution.

Taking into account the already available technologies, if we know that there will be a change in monitoring architecture trends, we should answer the following question: what should an IT system based on the IoT and AI look like and what challenges does it face? Universal access to the Internet, widespread technology and growing automation tend to have a significant impact on the development of the new generation. Thanks to this, the operation of IT systems becomes the basis of education, while the number of specialists in fields other than power engineering is decreasing. This trend will inevitably force the digitization of all industrial sectors on a scale, that we have not witnessed so far. Not out of a desire for progress, but out of the need to improve the quality of services provided, improve efficiency and with shrinking expert resources. This means that aforementioned IT systems will become the basic working tool for the next generation. So, now is the right time to make directional decisions and prepare to enter the next level. The fourth industrial revolution and the introduction of 5G technology translates into millions of connected devices, PCs and smartphones and, above all, machines and sensory devices, that emit the data sets, based on which decisions are made. The same will also apply to the monitoring and servicing of solar farms. The main problem of IT systems will be not so much the collection of information, as its transmission and processing. This is also visible in the case of introducing HD monitoring in large solar farms. The role of the next generation of employees will be reduced to that of the system operator and decision maker, approving the scenarios created by the IT systems. It will allow us to maintain the increase in service levels, at least in the renewable energy industry. The support of artificial intelligence (AI) will also play an increasingly important role in developing optimum scenarios, especially service scenarios. For this purpose, it is necessary to consider collecting historical data now, which will serve as the basis for developing optimum decision-making models in the future. This approach will provide an advantage, due to the possessed database, that serves as a base for artificial intelligence. Even if the data will not be fully used immediately, it should already be collected now.

By observing market trends and cycles, we can expect a rapid growth and an increase in the sensory layer (Alba et al., 2020), followed by the amount of stored data and the need for computing power capable of processing these resources. The current decentralized architecture is highly inadequate, considering the impending large scale of the problem, and keeping this direction will exponentially increase the challenges associated with maintaining data integrity and security. Introducing superior units in the form of central operators for both information and maintenance will be sufficient, at least temporarily, but in the long run it will involve a significant risk of inhibiting the development of the O&M market. Scenarios for introducing a centralized system based on building and maintaining own infrastructure in the form of large server rooms or implementing computing clouds are also being considered. There is a strong temptation to introduce centralized solutions, but this may create a vendor lock-in in a newly emerging market. We should, therefore, ask ourselves whether these systems meet the basic goals set by the energy industry, including renewable energy sector, for the coming years, if we treat renewable energy industry as a sector subject to special supervision? It can be assumed, that large computing centers can, at least to some point in time, be sufficient for operation, considering the digital wave. However, with the current performance level of the communication infrastructure, they will not be able to perform an efficient and quick analysis, due to the inability to deliver data from a large number of sensors within the time required for analysis. Therefore, they will not meet the above-mentioned requirement, that a modern smart grid system should support the operating process, and not only the analytical process performed afterwards. Another important aspect is data security, which raises considerable doubts, especially when stored on servers outside the country. The introduction of the central system will result in failure to meet the condition of local autonomy. Thus, the centralized architecture does not meet the basic goals of security, scalability and interoperability a modern infrastructure should feature in the era of the fourth industrial revolution. Currently, we are witnessing a stormy process of adopting distributed blockchain-based systems, rapidly conquering the financial market, posing a real threat to the long-standing status quo. The year 2017 saw the birth of the blockchain-based distributed data storage market, whose aim was to completely abolish the monopoly of large data centers in favor of small local infrastructure providers. Currently, large financial institutions, including the largest Polish banks, have already introduced this technology into their transaction systems, which additionally confirms their usefulness and guarantees further development. Such decentralization, thanks to post-cloud technologies, also opens the market of local services, enabling local providers to compete openly for local customers, while being part of a global system. Their major advantages will be flexibility and quick access to data for local users. The concept of the so-called fog computing goes exactly in the same direction. It aims at eliminating the need to build wide-area networks (WANs) and large computing centers for local infrastructure providers. Fog computing is a horizontal, physical or virtual layer, located between intelligent devices and traditional data centers (Figure 4). Its task The conceptual model of the fog computing was already described by the National Institute of Standards and Technology (NIST) (Iorga et al., 2020). It defines a new architectural model, an important part of which is the distributed infrastructure layer, operating on local computing power, distributed data storage and network connections edge computers. Its task is to aggregate and process data swiftly, using data centers and available, dynamically-allocated resources.

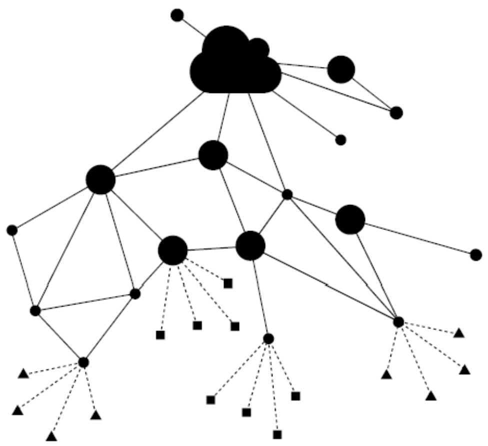

Figure 4. Fog computing model.

Source: Own elaboration.

The concept of fog computing fits perfectly into the requirements and directions for the development of intelligent monitoring systems. It introduces a unified infrastructure management mechanism and eliminates operational problems typical for the centralized system. It does not have a central unit, thus meeting the goals of local autonomy. The concept of fog computing described by NIST precisely defines the direction, in which the market will go, and what expectations should be met by IT systems in the era of total digitization. Smart grid is a technological challenge, which goal is to combine coherently operating IT systems and the entire infrastructure of both the modern automated, as well as the older one, in order to optimize electricity generation. That is why distributed systems are a breakthrough for Industry 4.0. Their most important features include location awareness and real-time or near-real-time data delivery. Computing nodes belong to an extensive p2p-class network, that can locate the nearest computing resources and data warehouses. The fog computing systems will process data much faster, more efficiently and ultimately cheaper than current cloud systems.

The local allocation of resources results in a drastic reduction of costs related to data storage and an equally drastic reduction of the load on telecommunication links. Fog computing uses distributed networks (p2p) making up primarily a different model of communication based on connections, where nodes can connect with many other nodes in the network and establish communication with one another, even using other nodes as intermediaries. If they cannot establish a direct connection, it is also possible to connect distributed networks operating even without Internet access.

Another significant feature is the dynamic allocation of resources (Foukalas, 2020). The main challenge of fog computing is quick adaptation to current computing requirements and releasing resources when they are no longer needed. The distributed processing system contains a mechanism that allocates resources in the nearest server room, and just in time when they are needed. Thanks to a specific data addressing system, fog computing provides the data set with a unique identifier, with which we query the whole network and the knowledge of the network node, to which the set belongs, is not required.

If we generate a redundancy mechanism by deploying selected sets not in one, but in several nodes, we will be able to automatically receive them when reading from several sources. This approach allows us to introduce the previously described local autonomy, with which the system works properly, even without Internet access, and provides the data on a continuous basis.

The implementation of the private blockchain concept is considered exceptionally useful. The blockchain is used as a control and management mechanism for distributed fog computing. Thanks to this, one can fully safely control all resources, without the need to install a central control unit.

The listed functionalities are only some of those, that a well-designed fog computing solution should have (Moura, Hutchison, 2020). Introducing this consistent environment into the renewable energy industry, especially for large solar farms, will make it possible to build a scalable IT system and a structure independent of external providers. The solutions already available on the market should be used as a basis for building new monitoring systems in large grids, including the solar farms.

6. Summary and Conclusions

Large photovoltaic farms are complicated organizationally and financially. The technologies used so far did not allow for effective monitoring and servicing of these facilities. Numerous sources indicate that it is necessary to introduce online HD monitoring. There are more and more new solutions, but none of them allows for full online monitoring down to the level of a single element of the installation. The author focuses on the latest and revolutionary methods of collecting and processing large data sets and their possible application in monitoring large photovoltaic farms. The analysis of the possibilities of these technologies allows us to draw the conclusion that using post-cloud solutions it is possible to meet all expectations regarding modern HD monitoring of photovoltaic farms and indicates the direction of their development without current technical limitations.

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