

Centralized Controlling of Distributed PV Systems using Cloud and IoT Technologies

Ivan Vujović, Mladen Koprivica, and Željko Đurišić

Abstract — Usage of electrical energy obtained from renewable sources is rapidly increasing. Distributed solar systems will be widely used. The photovoltaic (PV) systems can be used to produce active and reactive power or to compensate reactive power. This paper proposes a solution for monitoring and management of distributed PV systems from the integrated center. The main parts of the system are a cloud infrastructure at the Data Center and Internet of Things (IoT) devices at distributed sites. Also, networks that are used for communication between main parts are an important piece of the proposed solution. While IoT devices continuously send information about electrical parameters of the system and environmental conditions, the inverter, as a part of the PV system, can be controlled by influencing the Maximum Power Point Tracking (MPPT) algorithm operation and inverter functionality.

Keywords — distributed PV system, MPPT algorithm, cloud, Internet of Things, network.

I. INTRODUCTION

BASICALLY, two main types of the PV systems are used, and the main difference between them is in installed power. Large PV plants, from the aspect of monitoring and management, are treated the same as other large power plants in the Power System (PS). Smaller PV systems, mainly very heterogeneously distributed across some area, should have the possibility to be controlled. Possibility to monitoring and management of the PV systems is important in aspect to PS stability or when overload and malfunctions on PS parts occur. When a large number of PV systems with large total installed power are distributed in a certain, relatively small, area which is under one management domain, and, in the case when suddenly sky turns clear from cloudy, a large amount of active power will be injected in the PS within a short period of time. That may produce frequency instability and, in the worst case, collapse of the part of the PS or whole PS. Overloads and malfunctions occur during PS exploitation. That happens on

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the parts of the PS. If these parts are close to the distributed PV systems, from the aspect of position in the PS, the relief and conditions improvement may occur by taking certain actions on PV systems. A solution for named situations is in reduction of the generated active power from each individual PV system for the value that will enable preserving stability of the system, reduce overload and power transmitted through alternative paths during fail conditions. Also, PV systems, that is, inverters can produce or compensate reactive power thus contributing to the stabilization of voltage conditions in the grid.

The second section of the paper refers to a general approach of the PV systems design and implementation. The basic way to connect designed PV system on the grid at Low Voltage (LV) level is described in section three. The fourth section contains guidelines for integrated monitoring and management center design based on Cloud technology. Communication infrastructure between this center and infrastructure of the remote terminals as well as remote terminals infrastructure itself is described in sections five and six. In section seven it is explained how to control inverter functioning and effectively affect this device output. Finally, section eight gives us a conclusion and future work guidelines.

II. PHOTOVOLTAIC SYSTEMS DESIGN

Distributed PV systems are composed of the devices like those shown in Fig. 1 [1]. Solar panels generate electrical energy from the sunlight. The amount of generated electricity depends on irradiation, ambient temperature, panel efficiency and sun position relative to the solar panels.

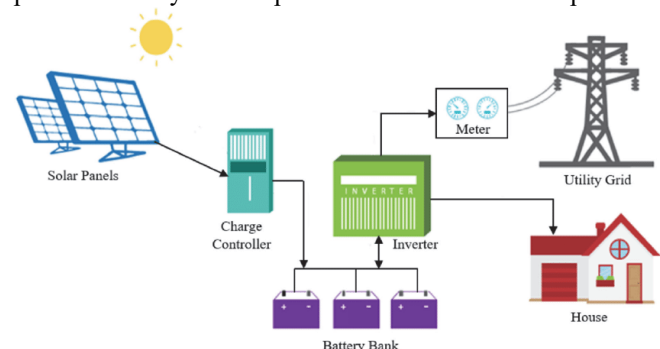


Fig. 1. Typical on-grid PV system [1].

For each panel, output Direct Current (DC) voltage is defined. Combining multiple solar panels in serial and parallel arrays, the input voltage for the charge controller is obtained. Charge controller regulates its own input and output DC voltage. This device uses MPPT algorithm to extract maximum power from the solar panel arrays under

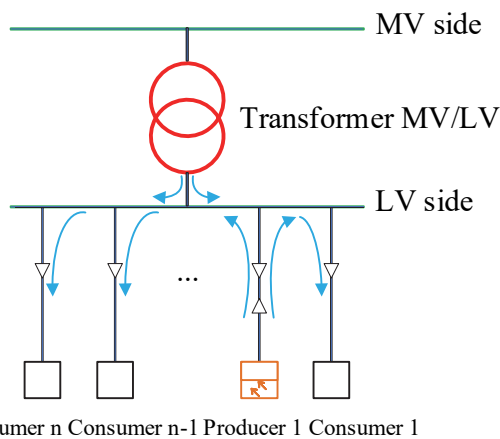
current conditions and defined efficiency [2]. When PV system does not contain a battery bank, a charge controller is not required. Then, inverter applies MPPT algorithm. By controlling the MPPT algorithm, it is possible to change (decrease under the maximum) the input power of the controller/inverter, and therefore, decrease the output power of the PV system.

Inverter converts input DC to output Alternating Current (AC). Electrical energy goes to the grid and can be used for supply of local consumers (house) where the PV system is installed. When PV panels do not generate electrical energy at all (during night) or generate a small amount of electrical energy (cloudy days), a consumer is supplied from grid or, for a limited time period, from a battery bank. Depending on the economic part of the contract between PV system owner i.e. solar electric energy supplier and PS provider, generated electrical energy can be directly distributed to the grid, and local consumers can be directly supplied from grid. Both directions of the energy flow (from supplier to the grid, and from grid to the local consumers) are measured by a two-way meter. Generated electrical energy from all distributed PV systems can be significant. Total output electrical power, in some periods of time, can be very high. Therefore, PV systems' impact on the PS can be also significant. Constantly monitoring and controlling all of the distributed PV systems in the same, real time, enables positive influence on the PS.

Monitored parameters enable information about working conditions of the PV system itself but information obtained from many systems can be used to predict possible problems related to the PS stability and functionality. If those problems occur, centralized control will send a command set to the PV systems after the execution of which will be prevented the occurrence of undesirable working conditions in the PS.

III. PHOTOVOLTAIC SYSTEMS CONNECTION ON GRID

Distributed PV systems are usually connected to the grid on LV level, that is on 0.4 kV, because they are small installed power. On the same busbars of the transformer, in the substation, there are connected other consumers or producers of electrical energy. Basic scheme of distributed PV system connection to the grid is presented in Fig. 2.



Consumer n Consumer n-1 Producer 1 Consumer 1

Fig. 2. Scheme of distributed PV system on a grid.

Blue arrows mark current flow direction. Consumers can

be powered from Middle Voltage (MV)/LV transformer or directly from the producer. More producers on the busbar means more energy for consumers and less energy needs from the grid (transformer). Theoretically, when energy from the producers becomes larger than consumers need, transformer will work in the opposite direction (current will flow from LV to the MV side). When the inverter of the PV system is in use for reactive energy compensation, current will flow in direction from the grid to the inverter. In that case, all consumers and producers will be powered from the grid (transformer).

At this point it is necessary to mention that this scheme is valid in situation of a small power PV system. For a higher power PV system, a new substation must be built, and connection with the grid is realized on MV or even High Voltage (HV).

IV. MONITORING AND MANAGEMENT CENTER

Measurements data from all PV systems are collected at Data Center. Data processing is done within cloud system. Cloud computing service model can be: Infrastructure as a Service (IaaS), Platform as a Service (PaaS) or Software as a Service (SaaS). From the ownership point of view, cloud can be: private, public or hybrid [3]. Communication between PV systems and cloud system can be enabled through different: types of networks, telecommunication service providers and PS communication network to enable ubiquitous for the monitoring and management of the distributed PV systems. Cloud system should ensure that received and processed data are displayed in the real time, but also stored for future computing. System must support vendor independent hardware and software. Also, testing of a new software and upgrade of an existing function should be included. It is necessary to enable security in data transmission and processing. Therefore, the best choice is to implement IaaS model, private cloud system. This system can be part of the bigger PS Data Center system. The proposed cloud solution can be realized as described in [4]. All virtual resources are mapped on the physical system. Basic IaaS cloud system scheme is shown in Fig. 3.

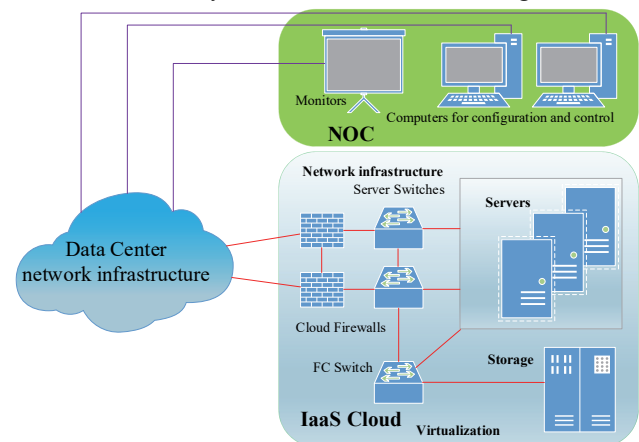


Fig. 3. Scheme of the IaaS Cloud system.

All received information from distributed PV systems at cloud are collected through Data Center network infrastructure. Inspected packets at firewalls are processed on the servers. Results will be displayed, in the real time, on

the Network Operating Center (NOC) monitors and, at the same time, saved on the storage system for future usage.

Basic software solution for PS monitoring and management is: Supervisory Control And Data Acquisition (SCADA). Newest SCADA systems are implemented on the cloud environment. As explained in [5], the most important thing in SCADA design is to ensure real-time monitoring and control. Availability, reliability and security should be considered as important also. Basically, SCADA system is not time critical but the shorter time period from alarm signalization to command execution is better. According to [6], Round Trip Time (RTT) in communication between distributed PV systems and cloud or remote terminals and SCADA system can be reduced through: Service Level Agreement (SLA), region selection and traffic policing. Monitoring and Management Center (MMC) has to be available for remote terminals all time. As it is not possible to achieve 100% availability. Guarantee percentage is defined in SLA. Remote terminals as individual systems are not critical for PS functioning, except in the case where PV system generates significant power (that is not the topic of this paper) and therefore there is no need for them to be available in high percentage as MMC. Key concept to enable high MMC reliability is to replicate SCADA virtual machine, install it on redundant system or on Disaster Recovery Site (DRS) and synchronize with original. When primary machine becomes malfunction, replicated one continues to work. Reliability for the remote terminals is achieved on communication level. Data can be sent through two physically independent paths and using different transmission technology redundantly. Security on MMC is enabled through private cloud IaaS concept. Encrypting data that are sent between remote terminals and SCADA enables communication security.

V. COMMUNICATION NETWORK INFRASTRUCTURE

Distributed PV systems can be placed on different locations with different communication availability. Some of them are setup in urban areas, some in industrial and some in rural. In urban areas there is usually lack of space and therefore PV systems are with just a few panels which have relatively small installed power. At the same time, number of these systems can be significant. Also, high speed optical communication links from different service providers are available for them. There is a lot of space for PV systems on the roofs of the industrial plants and factories. Because of that, a significant number of panels can be placed which have larger installed power. Optical links are available, usually not from different providers but only one. Therefore, redundant links can be wireless. Rural areas are characterized by a large space for PV systems but, in most cases, poor communication resources. Wireless links are usually used for data transmission. When installed power of the PV system is significant, it is justified to use even satellite links. Fig. 4 represents basic network infrastructure for communication between distributed PV systems and cloud.

Utilization of the Power Line Communication (PLC) means modems usage at both ends of the communication

channel. These modems convert modulated signal into the Ethernet and vice versa [7]. The most reliable system for the communication is based on Gigabit Passive Optical Network (GPON) technology. By implementing 10 Gbit/s Ethernet Passive Optical Network (10G EPON) symmetric high data rates in both directions are enabled [8]. Wireless communication can be effectively realized using 2G to 6G cellular networks [9]. Information transfer in CORE network can be achieved through directional radio links or using optical infrastructure. Satellite links are solution to enable IP packets transfer in both directions when other communication technologies are not possible to implement. This type of communication is usually implemented via Low Earth Orbit (LEO) satellites [10].

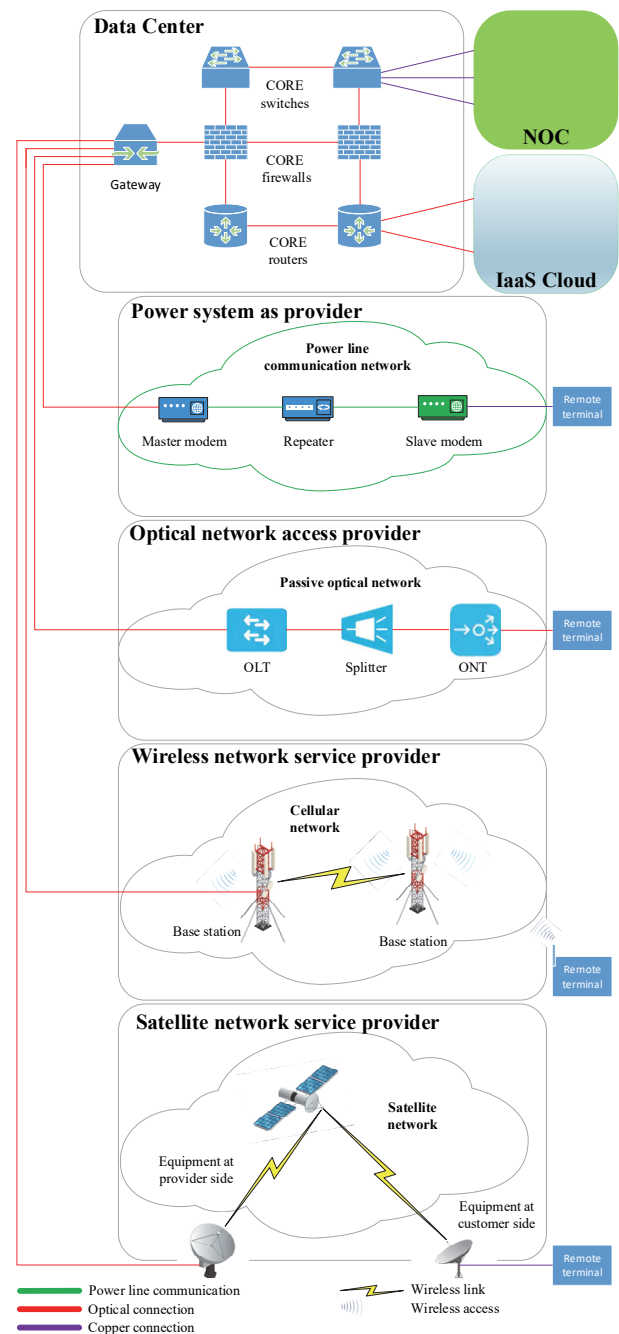


Fig. 4. Network infrastructure.

In reality, connections between Data Center (Gateway) and service providers access networks are not direct, as well

as connections between access network devices and remote terminals, but they are shown as such for simplicity of the figure. Service providers CORE networks that are between Data Center and access networks are not in the scope of this paper. Also, Customer Premises Equipment (CPE) is out of the paper scope. Remote terminals on distributed PV system locations use two types of connection to achieve redundant communication.

Remote terminals send unicast IP traffic (measured values of the parameters, logs of events etc.) to the SCADA system, while SCADA sends unicast or multicast traffic to a group of distributed PV systems because commands sent from the SCADA should affect many individual PV systems at the same time. When a multicast is used as a way of communication, PV system grouping should be realized by region, from smaller to larger, because changes in insolation are usually of local character. Every multicast group must be in the separate Virtual Local Area Network (VLAN) [11].

As any potential malicious attack on the control process of the PS could cause devastating consequences, it is necessary to ensure security of the data. Protection of the integrity of sender and data itself, as well as the encryption of the transmission, are mechanisms that ensure the fulfillment of protection requirements. Also, subjects in communication should use Virtual Private Network (VPN) technologies [12].

VI. REMOTE TERMINALS INFRASTRUCTURE

Devices that play major role in monitoring and management of the distributed PV systems are remote terminals, or, in SCADA terminology, Remote Terminal Units (RTUs). Basic PV system monitoring and management architecture is described in [13]. In this paper, IoT devices are presented as remote terminals. Connections between IoT devices, peripheral devices and PV system are shown in Fig. 5.

Monitoring and management system at PV location is divided into three parts: data acquisition level, processing level and command level. Sensors are the main part of the data acquisition level. They send measured values of parameters with defined resolution (number of measurements in selected period of time) directly to the processing level devices, through wired or wireless connections. There are only analog sensors on Fig. 5, but that doesn't mean digital sensors like relays, contactors and others can't be deployed. Environmental conditions sensors give information about parameters values that directly affect PV panel utilization. Generated DC current and voltage are measured by the sensors that are connected on the output of the PV panel arrays.

All data collected from the acquisition level are processed and converted in suitable format for transportation to the cloud (SCADA) at processing level. As described in [14], it is good to use different IoT components together at this level to achieve better performance of the whole system because every device is responsible for different tasks. Accordingly, "Arduino" micro-controller works with sensors (values measurement), actuators (execute commands) and other hardware components,

while "Raspberry pi" single board computer is used for data software processing and network communication.

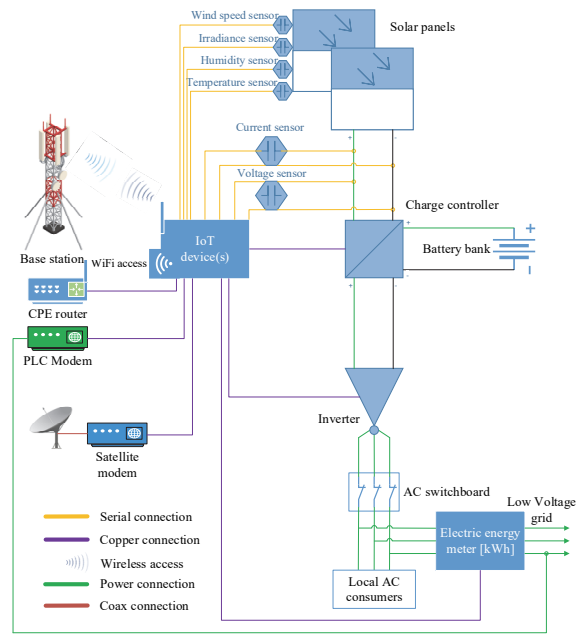


Fig. 5. Remote terminal IoT devices connections.

VII. INVERTER OPERATION CONTROL

Data received from current and voltage sensors at the input of the charge controller are important to MPPT algorithm function. Working principle and basic types of this algorithm are presented in [15]. Regardless of MPPT type, the goal is to achieve maximum power on the output of the charge controller or inverter (when system does not contain battery bank), for all changes in irradiance and temperature because these parameters affect the most on the generated power from the solar panels. Based on [16] and generated power curve show in Fig. 6 [17], following conclusion can be drawn: MPPT algorithm adjusts input voltage of the charge controller on value for which PV system produces maximum power.

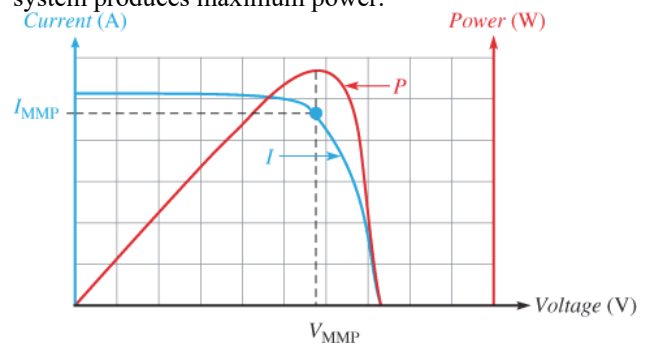


Fig. 6 PV system generated power curve [17].

When voltage goes to the left side on Fig. 6 that is it decreases, power also goes to the left side and decreases. Therefore, by decreasing value of the input voltage, charge controller decreases output power of the PV system. In this process, at approximately constant irradiation and temperature, current remains almost unchanged.

By programming IoT device to manage charge controller or, rather, MPPT algorithm, MMC (SCADA) can

manipulate with generated power of the PV system. For example, when SCADA sends command to the remote terminal (IoT device) to decrease PV system generated power by 20 percent, MPPT algorithm will decrease output voltage of the PV system (input voltage of the charge controller) on the value for which output power is 20 percent less. Information and commands between IoT device and: charge controller, inverter, electric energy meter are exchanged through direct Ethernet connections. Information about electrical energy distributed to LV grid is important when PV system doesn't deliver all generated electrical energy to the grid. Then, IoT device, based on the power values on inverter output and electrical energy meter output, calculates power used by local consumers, and sends command to charge controller that decrease generated power of the PV system for 20 percent of value which is delivered to the grid. When it is no longer necessary for the PV system to produce electrical energy with lower power than optimal, SCADA sends command to IoT device to exit MPPT algorithm. After that, generated power is determined by the MPPT algorithm. Sometimes it is necessary to completely stop injecting generated solar energy into a grid. It can be done by sending command from SCADA to IoT device and then to electrical energy meter to switch-off connection between PV system and grid. Generated electrical energy from PV system continues to supply local AC consumers and, through charge controller, charges battery bank.

When PV system works with power factor smaller than 1, besides active, inverter can produce or compensate reactive power also [18]. In that case, IoT device can control inverter functionality and based on commands from SCADA, sets inverter into the appropriate working mode. Based on PS conditions, inverter can be under-excited (absorbs, that is, compensates reactive energy) or over-excited (produce reactive energy) [19]. Reactive power compensation prevails during night or cloudy weather when PV system doesn't generate active power. When inverter compensates reactive power, device components are under increased temperature. That causes inverter lifetime reduction [20]. Usually, time duration when inverter works in this mode is short related to the device time of use, so this effect is small.

Basic contribution of this paper is a suggested solution to affect MPPT algorithm functioning, when it is necessary, from monitoring and management center, using IoT devices. Advantage of this solution relative to existing MPPT algorithms operation is possibility of remotely controlling many PV systems output power and type of power (active and reactive) at the same time, in contrast to current systems where the operation of the algorithm is only for the purpose of production of as much as possible active power.

VIII. CONCLUSION

Distributed PV systems of a wide range of installed power are more and more present as a renewable source. This increases their influence on the PS. Therefore, it is very important to have possibility of monitoring and management for these systems. Three main components of

the PV systems monitoring and management are: MMC cloud with SCADA, network infrastructure and remote terminals with peripheral devices. Impact on MPPT algorithm by executing external commands that SCADA sends to the remote terminals, that is IoT devices, allows modification on PV system generated power (active and reactive). By controlling inverter functionality through IoT device, reactive power can be compensated.

Information about parameters values on PV system location that remote terminals continuously send to the SCADA enables calculations and predictions of the PV systems behavior.

In the future work should be proposed a solution that implies higher resolution of measurements on all sensors at remote terminals, faster data transfer networks and faster processing and display of data in real time. Full control of the MPPT algorithm operation for each individual PV system from the integrated monitoring and management system should be considered. Although neural networks are already used in some types of MPPT algorithm, use of artificial intelligence on all parts of the management and monitoring system, automatization of data preparing, transfer, processing and display will contribute to more reliable and accurate functioning at the level of the whole system.

REFERENCES

- [1] R. Syaputra, I. Sosanti, "Renewable energy systems based on micro-hydro and solar photovoltaic for rural areas: A case study in Yogyakarta, Indonesia," *Energy reports*, vol. 7(3), pp. 472–490, January 2021.
- [2] P. Jain, S. N. Joshi, N. Gupta, K. G. Sharma, "Analysis of MPPT techniques in grid connected PV system," *3rd International Conference and Workshops on Recent Advances and Innovations in Engineering – ICRAIE*, pp. 1–4, Jaipur, India, November 2018.
- [3] X. Luo, S. Zhang, E. Litvinov, "Practical design and implementation of cloud computing for power system planning studies," *IEEE Transactions on Smart Grid*, vol. 10(2), pp. 2301–2311, August 2018.
- [4] M. E. Suliman, "A brief analysis of cloud computing Infrastructure as a Service (IaaS)," *International Journal of Innovative Science and Research Technology – IJISRT*, vol. 6(1), pp. 1409–1412, January 2021.
- [5] M. Yi, H. Mueller, L. Yu, J. Chuan, "Benchmarking Cloud-based SCADA System," *IEEE 9th International Conference on Cloud Computing Technology and Science*, pp. 122–129, Hong Kong, China, December 2017.
- [6] P. Church, H. Mueller, C. Ryan, S. V. Gogouvis, A. Goscinski, H. Haitof, Z. Tari, "Moving SCADA systems to IaaS clouds," *2015 IEEE International Conference on Smart City/SocialCom/SustainCom*, pp. 908–914, Chengdu, China, December 2015.
- [7] N. Pavlidou, A. J. Han Vinck, J. Yazdani, B. Honary, "Power line communications: state of the art and future trends," *IEEE Communications magazine*, Vol. 41, Issue 4, April 2003.
- [8] B. Batagelj, V. Eržen, J. Tratnik, L. Naglič, V. Bagan, Yu. G. Ignatov, M. Antonenko, "Optical Access Network Migration from GPON to XG-PON," *The Third International Conference of Access Networks (ACCESS 2012)*, Venice, Italy, June 2012.
- [9] A. A. Segun, F. D. Chizea, A. G. Benjamin, "A Review of Cellular Networks: Applications, Benefits and Limitations," *Network and Complex Systems*, Vol. 11, pp. 21–33, December 2020.
- [10] P. Techavijit, P. Sukchalerm, N. Wongphuangfuthaworn, A. Plodpai, S. Manuthasna, S. Chivapreec, "Internet Network in Space for Small Satellites: Concept and Experiment," *Sensors and Materials*, Vol. 30, No. 10, pp. 2295–231, 2018.
- [11] IEEE Computer society, "802.1Q - IEEE Standards for Local and Metropolitan Area Networks: Virtual Bridged Local Area

- Networks”, The Institute of Electrical and Electronics Engineers, 2003.
- [12] P. Knight, C. Lewis, “Layer 2 and 3 virtual private networks: taxonomy, technology, and standardization efforts,” *IEEE Communications Magazine*, Vol. 42, Issue 6, pp. 124–131, June 2004.
- [13] S. Ansari, A. Ayob, M. S. H. Lipu, M. H. M. Saad, A. Hussain, “A review of monitoring technologies for solar PV systems using data processing modules and transmission protocols progress, challenges and prospects,” *Sustainability* 2021, vol. 13(15), pp. 1–34, July 2021.
- [14] L. O. Aghenta, M. T. Iqbal, “Development of an IoT based open source SCADA system for PV system monitoring,” *2019 IEEE Canadian Conference of Electrical and Computer Engineering – CCECE*, pp. 1–4, Edmonton, AB, Canada, May 2019.
- [15] O. F. Tozlu, F. Callk, “A review and classification of most used MPPT algorithms for photovoltaic systems,” *Hittite Journal of Science and Engineering* 2021, vol. 8(3), pp. 207–220, September 2021.
- [16] J. Mikulović, Ž. Đurišić, *Solarna energetika*, Akademska misao, Beograd, 2019, pp. 221–232.
- [17] <https://electricalacademia.com/renewable-energy/maximum-power-point-tracking-mppt-charge-controller-working-principle/> available on (12.07.2023).
- [18] F. L. Albuquerque, A. J. Moraes, G. C. Guimaraes, S. M. R. Sanhueza, A. R. Vaz, “Photovoltaic solar system connected to the electric power grid operating as active power generator and reactive power compensator,” *8th Latin-American congress on electricity generation and transmission – CLAGTEE*, pp. 1–6, Ubatuba, Brazil, December 2009.
- [19] D. Stanelyt’e, V. Radziukynas, “Analysis of Voltage and Reactive Power Algorithms in Low Voltage Networks,” *Energies* 2022, 15, 1843, March 2022.
- [20] E. M. da Silveira Brito “Lifetime Evaluation of Photovoltaic Inverterswith Capability of Reactive Power Support,” PhD dissertation, Universidade Federal de Minas Gerais, Belo Horizonte, Brasil, August 2021.
- [21] I. Vujović, M. Koprivica, Ž. Đurišić, “Monitoring and management solution for distributed PV systems based on cloud and IoT technologies,” In *Proceedings of the 30th Telecommunications Forum (TELFOR)*, Belgrade, Serbia, 15-16 November 2022.