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Monitoring of photovoltaic micro installations

***Abstract**. The paper presents a comparative analysis of currently used monitoring systems of photovoltaic installations, focusing on systems applicable in PV micro installations. The characteristic features and the most important advantages and disadvantages of each monitoring systems were presented. The papers also indicates typical electrical parameters of the PV system and discusses the impact of environmental conditions on PV system operation.*

***Streszczenie.** W artykule przedstawiono analizę porównawczą wykorzystywanych obecnie systemów monitoringu instalacji fotowoltaicznych, szczególny nacisk kładąc na systemy znajdujące zastosowanie w mikroinstalacjach. Zaprezentowano charakterystyczne cechy oraz najważniejsze zalety i wady poszczególnych systemów monitoringu. W pracy wskazano również typowe parametry elektryczne instalacji fotowoltaicznej oraz omówiono wpływ warunków środowiskowych na funkcjonowanie systemu. (**Systemy monitoringu mikroinstalacji fotowoltaicznych**).*

Keywords: photovoltaics, micro installations, PV monitoring systems.
Słowa kluczowe: fotowoltaika, mikroinstalacje fotowoltaiczne, systemy monitoringu.

Introduction

Recently introduced legal regulations, which the most important part is the Act on Renewable Energy Sources [1], resulted in significant increase in renewable energy investments. This increase is especially visible among the smallest generating installations, operating under the name of micro installations. Under this term were defined renewable energy sources with total installed electrical capacity of not more than 40 kW, connected to the grid of nominal voltage less than 110 kV or sources with total installed thermal capacity of not more than 120 kW. According to the registers carried out by the Polish Energy Regulatory Office, at the end of 2014 total installed capacity of electrical micro installations in Poland was only approx. 2.8 MW. However, current data show the dynamic growth in the installed capacity – at the end of September 2015, it was already more than 22 MW. Among all micro installations, the vast majority (approx. 78% of installed capacity) are currently photovoltaic micro installations [2,3]. Further and even more intensive growth of PV micro installations development assume current forecasts. According to them at the end of 2017 in Poland will be approx. 200 000 PV micro installations (at a current level of approx. 5 000) [4].

The growing number of photovoltaic installations causes that it is particularly important to ensure their appropriate operating conditions. There can be many abnormalities in a PV system operating – starting from the incorrect selection and installation of PV modules and inverters, by the unfavorable modules working conditions (connected with their shading or too high operating temperature), up to wrong programming of a inverter. All these abnormalities adversely affect on the plant functioning by reducing the energy yield as well as causing improper cooperation with the grid. Most of the problems in the PV installation can be detected by the use of an appropriate monitoring system, which should enable control and analysis of the installation operation parameters [5]. It is especially important in the smallest generating installations, where the lack of sufficient investor knowledge and supervision can result in numerous errors during the PV installation implementation and operation. A complete monitoring system, in addition to the abnormalities detection, usually also allows [5]:

- control of generated energy quality,
- measurements of energy produced and delivered to the grid,
- monitoring of PV system efficiency,
- conformity check of installation real parameters with project assumptions and simulations,
- notification the installation owner and the system operator of the most important operating parameters and failures,
- remote management of the installation .

All presented monitoring system functions have as their purpose two basic tasks – to maximize the photovoltaic system energy yield and to ensure its proper grid cooperation. The use of monitoring systems and appropriate analysis of obtained data are currently considered crucial in the development and optimization of photovoltaic systems [5].

Electrical parameters of the PV installation

The electrical parameters of the photovoltaic installation can be divided into parameters associated with a single photovoltaic module, with a group of connected modules and parameters associated with the inverter. The electrical parameters of a single photovoltaic module, which can be determined during normal operation conditions, are the module voltage and current. On the basis of these values it is also possible to determine the module actual power and energy produced in a given period of time. Identical measurement data can also be obtained for any connection of the modules.

In determining the parameters of connected modules, there are differences depending on the connection method. These differences do not affect power and energy, which independently of the connection are always the sum of respectively power and energy of all connected modules. However, the differences appear in determining the collective voltage and current. In the case of serial connection, the output voltage is equal to the sum of voltages of all connected modules and the output current is equal to the single module current. The opposite situation occurs in the case of parallel connection. In this case the output current is equal to the sum of currents of all connected modules and the output voltage is equal to the voltage of a single module. Similar correlations occur in the most frequently used mixed connection, wherein modules at first are connected in series to strings, which are then connected in parallel.

The rules presented above are true only on the assumption of identical parameters and operating conditions of all connected modules, what is often not possible. Differences in modules operating parameters are mainly caused by:

- different solar irradiance, due to the different tilt angle or orientation,
- irregular shading,
- differences in the modules parameters, due to their specific manufacturing tolerance,
- different operating temperatures, due to differences in irradiance or ventilation.

The effects of presented parameters inequality are current (in series connection) or voltage (in parallel connection) mismatches. Each of these mismatches results in impairing collective installation parameters. In the serial connection case, the output current is limited by the current of module with the lowest current value. In the parallel connection case, the output voltage is approximately equal to the arithmetic average voltage of individual modules (or strings). Every kind of mismatch in a PV system results in its power and energy yield reductions.

The electrical parameters of a inverter can be divided into two groups – these associated with the inverter DC side and these associated with its AC side. DC side parameters are actually collective parameters of all modules connected to the inverter. The possible measurements range as well as the impact of mismatches are the same as for the measurements conducted before the inverter. AC side parameters determine operation conditions after the DC/AC processing and they consist of AC voltage and current as well as output voltage frequency. On the basis of these values measurements it is possible to determine the real output power and generated energy yield, after taking into account losses of processing.

Environmental parameters of the PV installation

Environmental parameters have a significant impact on most of the previously presented electrical parameters. Because of operation principles of photovoltaic cells, thus also photovoltaic modules, environmental conditions determine the operating parameters of the entire installation. The most important meteorological parameter, which determines achievable energy yields, is solar irradiance. It specifies the value of solar energy reaching specific area in relation to its surface. Irradiance affects proportionally to the module current and does not affect significantly to the module voltage. This relation results in module power decreasing with the decrease of irradiation. The real impact of solar irradiation on a specific type of photovoltaic module is determined by its current-voltage characteristics at different values of irradiance (Fig. 1).

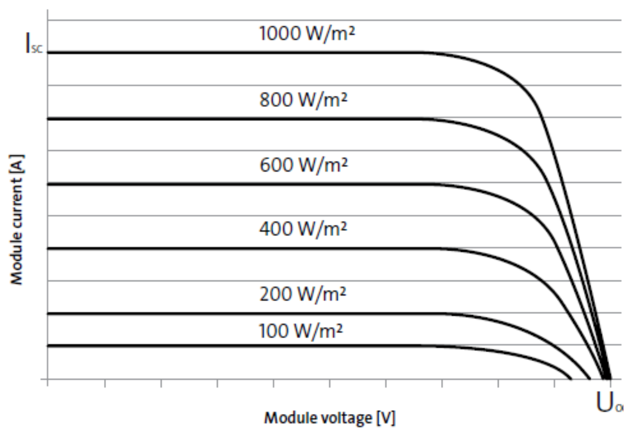

Fig. 1. Current-voltage characteristics of PV module at different values of irradiance [6]

Another very important non-electrical parameter of the photovoltaic system is the photovoltaic cells temperature. This quantity has a significant impact on the PV module output voltage – the higher the cell temperature is, the lower is the module voltage and, consequently, the module power. In contrast to the solar irradiation, temperature has no significant impact on the module current. The real impact of cell temperature on a specific type of module is determined by its temperature coefficients of power, voltage and current. The cell operating temperature is the result of the module construction and installation as well as environmental parameters – already mentioned solar irradiation (proportionally), ambient temperature (proportionally) and wind speed (inversely).

Monitoring of photovoltaic micro installations

Commonly used photovoltaic monitoring systems based on expanding the functionality of devices used in installations for other purposes, such as electricity meters, inverters or power optimizers. In each of these cases, the possibility of monitoring is only an additional functionality of mentioned devices. The capabilities of the entire monitoring system and the range of possible measurement data depend mainly on applied devices types and functionality.

Electricity meters

The simplest way of photovoltaic system monitoring is to use electricity meter, which is required for each grid-connected installation. In a PV micro installation are typically two types of meters – bidirectional meter for measurement of energy taken from and delivered to the grid and unidirectional meter to measurement of energy generated in the photovoltaic installation. However, the use of bidirectional meter for PV system monitoring purposes is not possible, because its measurements do not include the energy used in a consumer internal installation. For this reason, the measurement data does not coincide with the actual energy production and thus cannot be reliable. Unidirectional meter, which is placed between inverter and internal installation, does not have this defect. Due to its location, this meter measures and registers total electricity generated in photovoltaic system, so it can be used for monitoring purposes. The functionality of this kind of a monitoring system is highly dependent on the applied device type. The simplest induction meters usually have only the possibility of total energy measurement, without the ability to divide production into time periods, which making their functionality strictly limited. The elimination of these defects is possible through the use of electronic smart meters (Fig. 2) characterized by enhanced capabilities.

The use of a more advanced meter combined with dedicated software enables the measurement and registration of electricity generated in any user-defined period of time (default 1-hour). Similar possibilities exist also in measuring of instantaneous and maximum power. Depending on the device, it is possible to access the measurement data either locally or remotely, using a wired or wireless communication [7,8,9]. In meter-based monitoring system, all measurements are conducted only for the entire installation and only on its AC side. The DC side of a PV installation is not monitored in any way. Therefore, it is possible to receive only aggregated information about the installation, specifying only its total power, generated energy and inverter output parameters: voltage, current and frequency. These data are sufficient to determine the level of installation power and energy, however, in case of failure or other operating problems does not allow for their precise identification.

Fig. 2. Apator EQUS smart electricity meter [7]

Inverters-based monitoring

This kind of monitoring system is based on the use of standard solar inverters (Fig. 3), which are part of almost any photovoltaic installation. The capabilities of the system depends on the specific device and dedicated software functionality. An inverter as a device connected to DC and AC sides of installation allows monitoring of both parts of the system, strongly extending functionality relative to the meter-based solution. On the AC side, as in the meter case, it is possible to control values of voltage, current, frequency, power and generated energy. On the DC side it is usually possible to control connected modules voltage and current, resulting in direct access to the DC installation. Depending on the number of inverter inputs, it is possible to separate the operating parameters to individual groups of modules connected to the each input. Integrating monitoring system with an inverter also allows precise observation and analysis of the inverter condition. By using solutions dedicated directly to photovoltaics, the process of communication and presentation of the results is much facilitated. Depending on the device manufacturer, access to measurement data is possible via a wired, wireless or Internet communication [10,11,12]. Although this monitoring system allows to control the DC side, in the case of standard inverters the control is limited only to collective parameters of the connected module groups – it is not possible to gain access to individual modules. Therefore, although it is possible to identify a failure or disturbance due to the installation side, it is not possible to directly identify the source of problems appearing on the DC side – they may be caused by any of the connected modules.

Fig. 3. SMA Sunny Boy 3000TL inverter [10]

Microinverters-based monitoring

Microinverters (Fig. 4) are a subgroup of inverters, whose characteristic feature is the use of a single inverter to cooperate with a single photovoltaic module. The range of realized measurements is the same as for standard inverters, the most important difference is the level of monitoring precision. The microinverters-based monitoring system eliminates the drawback of system using standard inverters, which allow only a collective control of the connected modules. The use of microinverters connected to individual modules allows their individual monitoring, thereby detecting failures or disturbances is definitely easier. Microinverters allow monitoring of both sides of installation: the DC parameters of a connected module and the AC output parameters of inverter. Inseparable part of this type of installation is a gate (Fig. 4) which connects multiple microinverters to the grid. The gate provides monitoring functions of collective parameters of all connected microinverters – voltage, current, frequency, power and energy generated in PV system. This device is also an access point to measurement data, because the direct connection with a single microinverter is not possible. The connection to the gate is realized via a wired, wireless or Internet communication [13,14,15]. The microinverters-based monitoring system significantly increases the accuracy of failures and disturbances detection by precise identifying their type and place of occurrence. The biggest disadvantage of the system based on microinverters is its price – much higher than the use of standard serial inverter. The advantage unrelated to the possibilities of monitoring as well as the main advantage of microinverters is higher energy yield, resulting from equipment of each microinverter in a separate maximum power point tracker.

Fig. 4. SMA Sunny Boy 240 microinverter with SMA Sunny Multigate [13]

Module-level monitoring

This kind of monitoring systems do not use standard parts of a photovoltaic system, but are based on additional equipment called power optimizers (Fig. 5). The power optimizer is a device directly connected to a single photovoltaic module and its primary task is to provide the best module operating conditions. This possibility is related with embedding a maximum power point tracker into each power optimizer, as is the case of microinverters. The most important difference between optimizers and microinverters is the lack of built-in inverter in power optimizers – on the both sides of the device appears constant current. For this reason, an installation based on power optimizers must be equipped with an additional standard solar inverter. The use of single module dedicated power optimizers enables, as is the microinverter case, individual monitoring of each module. However, optimizers monitoring functions apply only to the DC side of an installation – the lack of inverter function causes the impossibility of access to the installation AC side. To complement the monitoring system also on the

AC side, it is necessary to use an inverter with its own monitoring [16,17]. The main advantage of optimizer-based monitoring system is to provide individual access to each module parameters while achieving lower single device prices. As in the microinverters case, it is possible to achieve higher energy yield through the use of individual maximum power point trackers.

Fig. 5. SolarEdge OP400-MV power optimizer with dedicated SolarEdge SE3000 inverter and monitoring software [16,17]

Conclusions

The choice of monitoring system significantly affects the photovoltaic installation control scope. The use of electricity meters allows to obtain information about the generated energy, but they do not have the ability to control the DC side of an installation, which parameters are most important to assess the installation operating condition. These possibilities are given by the use of monitoring systems integrated with standard solar inverters, which monitoring functions are, however, limited to a collective control of groups of connected modules, without analyzing the operating status of individual devices. The most detailed data about each module can be achieved by using microinverters or power optimizers which, in addition to monitoring functions, provide increased PV installation energy yield. Unfortunately, the most precise solutions are also the most expensive to buy, so it is expected that their use will be limited to installations where the benefits associated with the individual MPP tracking will exceed the increased investment costs. It should be noted that the scope of all of the analyzed system was limited only to the electrical parameters of the installation and does not allow monitoring of environmental parameters, such as solar irradiation and cells temperature. The lack of environmental conditions data may hinder proper analysis of the installation operating conditions. During the reduced values of electrical parameters may be impossible to determine whether this fact is related with occurring failures or disturbances, or it is a natural reaction for reduced irradiation or high cells operation temperature.

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