Application of a bidirectional electricity meter in the 5kW grid-connected photovoltaic power plant

Zoran Petrušić and Andrija Petrušić

Abstract - In this paper the application of a bidirectional electricity meter in the 5 kW grid-connected photovoltaic (PV) plant is presented. The PV plant is operating since August 2013, as the research laboratory at the Faculty of Electronic Engineering in Niš. The realised PV plant enables performance evaluation of different PV system components under environmental conditions. The realised PV system for evaluation of characteristics of a PV system is consisted of a rotating and fixed part. The solar tracker can carry up to 10 PV modules with different technologies, power and dimensions, while the fixed construction can support up to 12 PV modules. The PV plant is connected to the grid within the industrial hall through the concept of net metering. The complex contemporary system for measurement of generated and consumed electric energy is also presented in the paper. This system is realized using the bidirectional electricity meter.

Keywords – bidirectional meter, on-grid PV plant, net metering, monitoring system.

I. Introduction

The Renewable energy sources (RES) represent a healthy alternative to conventional energy sources, taking into consideration all the negative impacts that fossil fuels have on environment. For most Countries achieving significant levels of RES exploration will lead to certain degree of import independency of primary sources, thus making the RES part of Country's strategic development.

A. *The strategic importance of PV*

The photovoltaic (PV) solar energy is one of the most distinctive RES, which main characteristic is the unlimited availability, possibility to have the installations in close proximity of consumer and without the need for significant investments in existing infrastructures. Over the years, the technological maturity and increase in energy efficiency of PV modules made this kind of investments cost-effective even on the level of household consumers. In combination with adequate policy instruments the significant increase in installation of small-scale PV plants in Europe was notices, with Germany as the best example even with moderate solar energy potential [1].

B. *Overview of successful projects*

Good example of German success is the project [2] conducted in 1994 and funded by the German Federal Ministry for Research and Technology and Governments of involved German Federal States, under which 2000 of on-grid PV plants was installed with variable power output form 1 kW to 5 kW, with total installation of 5 MW. Being that in urban areas the lack of available space is always the issue, the biggest potential for PV plant installations are to rooftops. Therefore, all the PV systems within the project were installed or integrated on south side of households' rooftops.

The key aspect of the project was the development of special program for long-term tracking and analyzing of installed PV plants (L-MAP) that involved all national eminent institutes.

Under the global monitoring program, each PV plant contained three meters for measurement of total generated electric energy, the excess produced energy that was fed into the grid and the locally consumed energy. The detailed measurements carried out on the field were initiated for performing a comparative analysis between efficient and less efficient PV installations, as well as to gain experience for larger integration and further optimization of on-grid PV systems.

Larger presence of PV installations in overall energy production led to increase in number of PV laboratories around the globe.

For instance, in South Korea the Field Demonstration Test Center with four 3 kW on-grid PV systems was developed [3]. The designed system for monitoring enables measurement and analysis of PV system performance in relation to the meteorological conditions. Furthermore, the conditions were made for long-term assessment of installed components, as well as of entire PV systems, through various indicators, such as efficiency, capacity and generated electric energy.

Another example of PV laboratory is the 10 kW PV system, part of the energy farm within the School of Renewable Energy Technology of Naresuan University in Thailand [4] [5] [6], which was designed to enable detail efficiency and performance assessment of PV systems and individual components. Beside the comparison of different module technologies and outputs, short-term and long-term

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dynamics of energy efficiency and other parameters can be observed as well. In addition, system was designed modularly allowing full development to the level of micro-grid system, which included integration of other alternative technologies for primary source, e.g. biomass and fuel cells.

C. *The PV laboratory*

The PV laboratory within the Faculty of Electronic Engineering, University of Nis represents the combined PV system of 5kW installed power integrated within the facilities of small-scale industrial consumer with volatile load curve. It is designed for conducting multifunctional and multidisciplinary assessments and analysis (stationary vs. rotating systems, measurement of performance and UI characteristics of PV modules under outdoor, working conditions, the impact of wind on system supporting construction, the impact of temperature and other external condition of performance of PV plant, etc.). The implemented PV laboratory is an open system able to integrate other RES such are wind turbines, fuel cells, biomass generators, accumulating banks for energy storage, which will allow further comparative analysis.

With connection of the PV system to the distribution grid, the conditions have been met for the development of modern system for the monitoring of various parameters for performance measurement. The current system for supervision of PV laboratory enables data acquisition from inverters, installed meteorological unit and installed bidirectional meter. The monitoring information system is based on not standardized data acquisition and storage methods, which represent combined hardware and software solutions, which are distributed as a technical support by manufactures of aforementioned components.

The data that can be collected from inverters produced by DIEHL (Germany), under the Platinum production series, derives from parameters such are: DC input power, AC output power, the inverter status, operating time, network signal, inverter alarms, etc.

For collecting meteorological data, a professional meteorological unit WXT510 produced by Vaisala (Finland) is used. This device allows measurements of six meteorological parameters: direction and power of wind, intensity of rainfall, atmospheric pressure, and relative humidity.

Bidirectional meter constructed by ATLAS-AMR (Serbia) is used for collecting overall system performance data through various parameters: active and reactive electric power for different tariffs, in both direction and for all four quadrants [7], furthermore maximum min power, real time value of current, voltage, power, frequency and power factor in three phase system with four or three conductors.

In the construction phase the focus was on bidirectional meter, because of the potential that PV systems with net metering will have in the future.

In cooperation with domestic producers (ATLAS-AMR) of programmable electronic meters a modification of an existing meter was performed for measuring performances in all four quadrants (in both directions of current flow). Suitable modifications were made to supporting software application for collecting all measured data for further data storage in centralized database.

In this paper are presented two independent energy source installations in on-grid PV system. The configuration for generation, transmission and consumption of electric energy is given as well. Furthermore, the basic functionalities of software framework are presented. The use of bidirectional meter for net metering is a novelty in this region and, therefore a special attention will be given to this concept of metering.

II. SYSTEM DESIGN AND COMPONENTS

PV power plant converts sunlight into electric energy. In the realized grid –connected PV system (figure 1) there are few sources of electric energy which include:

1) 3kW PV power plants with fixed mechanical construction placed on the ground with PV modules in single crystal and polycrystalline technology. Fixed system on which PV modules are installed is oriented to the south with the possibility of changing the inclination from 30° to 45°, in order to experiment with the optimal tilt angle for our geographical latitude. Change of the inclination makes it possible to determine the dependence of the reduction of annually generated electric energy in the function of deviation from the optimal orientation.

2) 2kW PV power plant with installed two-axis rotating solar tracker also with PV modules in single crystal and polycrystalline technology. The realized rotating system belongs to the group of small positioners and enables experimental determination and confirmation of theoretical advantages of electric energy generation, which are associated with single-axis and two-axis systems in large PV power plants.

Fig. 1. Sources of electric energy in the realized grid connected PV system

Grid-connected PV systems are consisted of a PV string, one or more grid-connected solar inverters, safety device for automatic shutdown when the grid is disconnected and electricity meter. Grid inverter converts direct current (DC) from the PV modules into alternating current (AC), which is simultaneously synchronized with the grid.

Currently there is no global stance on size and number of grid-connected PV systems and economic factors, which limit the optimal size of a grid-connected PV system, depend mainly on various financial incentives and legal regulations of individual countries.

Today, there are two dominant concepts in the world. The concept of "Net metering", which is widely used in the U.S. and Canada and rely on grid-connected PV systems which are dimensioned in the way to generate electricity at the level of consumer spending, so that the power distribution network appears only as a local energy storage. There are no incentives and legal regulations to build a sustainable system that would generate more electricity, instead there are limitations and levels in terms of the maximal power [8]. Since local energy storage facilities are not needed, limiting factors for determining the size of grid-connected PV system in this concept are the available space (often the roof), investment costs and regulatory frameworks including subsidies and promotional programs.

Another concept, known as a "feed-in" which is present in Germany and other EU countries, relies on financial incentives for the construction of large PV systems and allows the excess of net profit. Despite all the economic benefits, generated photovoltaic energy has not yet reached parity with the grid energy network, that is the point at which the costs of producing and buying from the grid are the same.

In Serbia, there are only PV systems with feed-in tariff, but the quota is limited and dedicated every three years. The quota is limited up to 5 MW for the ground and up to 4 MW for roofs. Net metering in Serbia isn't legally regulated, but it is likely in the near future and it should be adopted, because almost all countries have adopted it. Net metering is used in cases where the prices of purchased and delivered energy are the same. Since the realized PV plant does not belong to the group of privileged energy producers a bidirectional smart metering group is installed with the aim of implementing various research because it will be inevitable component of future smart grid.

The structure of the realized grid-connected PV plant with the basic components for generation and transmission of energy is shown in figure 2.

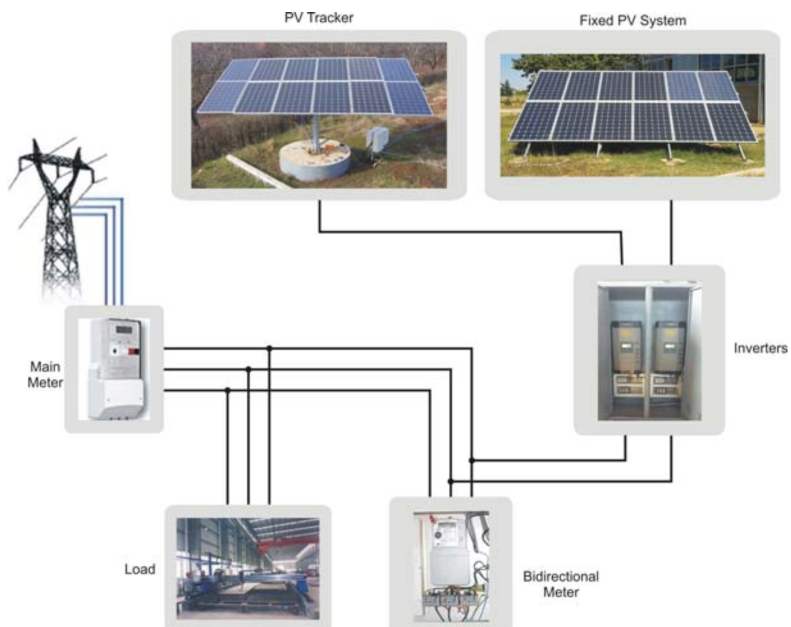

Fig. 2. Block diagram of the realized 5kW grid-connected PV plant

III. MONITORING SYSTEM

This part of paper presents a system for monitoring of generated and consumed energy with the realized 5kW, modular PV system (figure 3). Concept of this modern monitoring system is such that it fits perfectly with the modern so-called smart grids. Smart grids can efficiently (cost-effective) integrate behavior and actions of all connected users (generators, consumers and those that perform both activities), in order to provide sustainable power system with low losses and high levels of safety, quality and security of supply. The main objective of this system is real time acquisition of the operating parameters of PV power plant.

Some of the benefits obtained by realization of such a system are:

- Monitoring of profitability with advanced tools for data analysis,
- Automatic access to the reports,
- Easy way to generate appropriate graphs, tables and reports,
- Web based monitoring and control with application access from multiple levels.

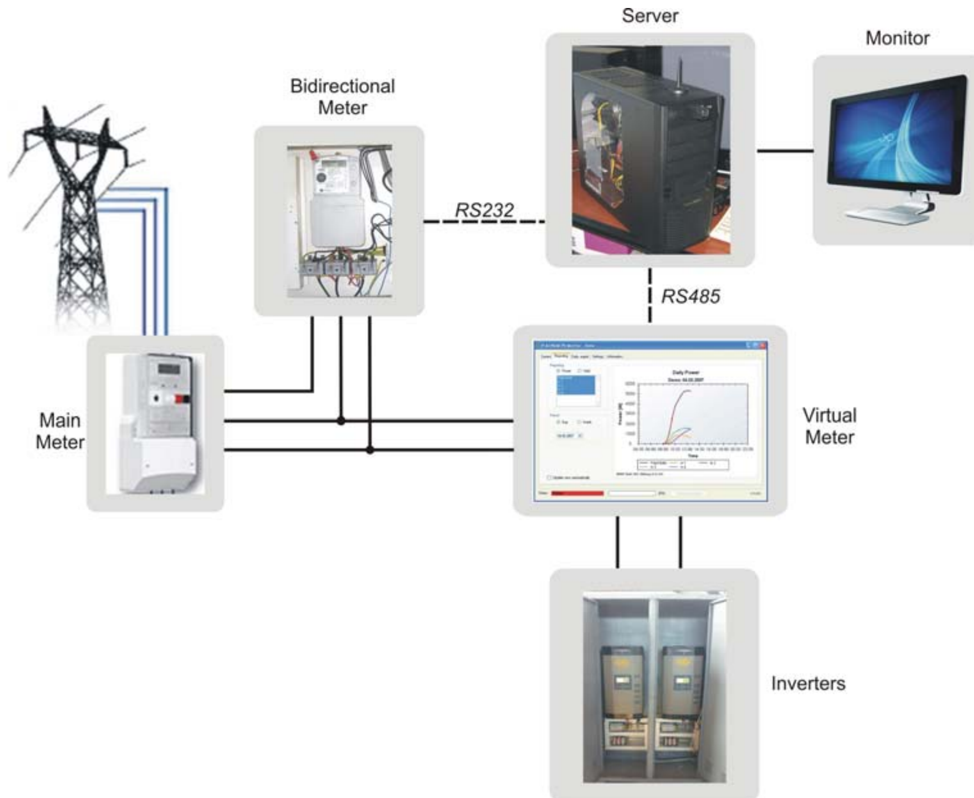

Fig. 3. Realized modern system for monitoring of the 5kW grid-connected modular PV system

During the grid connection of the PV system, it was decided to install the modern programmable electricity meter as a control meter. This enables that all of the requirements set by the advanced metering infrastructure are fulfilled, and on the other hand this meter is actively involved in new systems for monitoring and management of energy consumption.

Installed meter is modified four quadrant three-phase electricity meter for four-wire connection with three measuring systems. Tariff management is performed with the meter's real time clock with calendar implemented in the meter. The meter has different types of communication modules, in order to fully support the active management. The available communication modules are: GPRS/GSM, PLC, RS232/RS485, MBUS, wireless MBUS, ZigBee, RF. The realized system is based on RS232 communication due to the proximity of PC server.

Installed electronic programmable meter monitors 13 parameters of the distribution network, active energy, reactive L and C energy, as well as the maximal output power. Screenshot of the realized communication software for data transfer into the database is shown in figure 4. Also, the meter automatically generates data of mean power for the previous hour on every 15 minutes, which are essential for optimization of electricity consumption by a user.

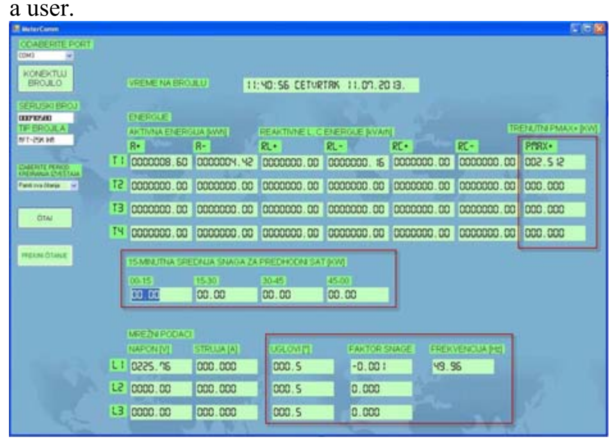

Fig. 4. The screenshot of the application for manipulation the data from the bidirectional meter

IV. Software framework

The software framework is based on three functional segments:

1. Data acquisition –collecting data from various installations within PV system, such are invertors, bidirectional meter, meteorological unit, etc.
2. Data storage –in predefined time interval collected measurements are stored in the database (SQL Server 2012), creating a base for further analysis and report generation.
3. Data overview –allows the presentation of all data via web application that support the complete management of PV plant (reporting, alarms, geo-referencing, etc.).

A. *Data input from bidirectional meter*

The software provided by the manufacturer is designed in a manner to generate daily XML files containing data from the bidirectional meter which are collected from parameter measuring sensors within scalable time interval. The software solution is implemented as a "Windows service" [9] that is constantly looping as the background activity. The application that was custom made is set to start up every hour and check for new records in the XML file and afterwards make a new entry in the database (Fig. 5).

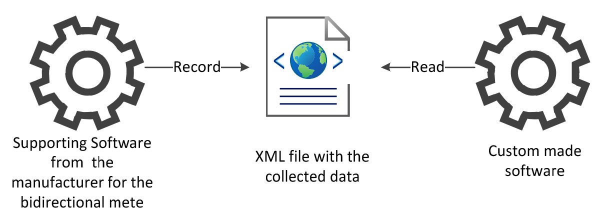

Fig. 5. Reading and storing measured data from bidirectional meter

B. *Data overview*

For using the collected data in most effective way, a subsystem has been developed for data representation. This reporting system was developed to satisfy the following needs:

- To represent the total amount of generated electric power;
- To make a correlation between meteorological conditions and generated electric power;
- To facilitate the analysis of electricity consumption and yield up to annual level;
- To allow the use of data for further system development

The system for data overview relies on SQL Server Reporting Services. The advantages for using this technology are easy and fast generation of new reports and the online accessibility.

Based on aforementioned needs different categories of reports can be generated. First, the reports concerning the consumption allow tracking of consumption and defining patterns based on the data collected from bidirectional meter. This kind of reports provides the useful information on consumer behavior in using the electric energy from the grid, as well as when the needs are satisfied locally. Second, the reports on generated electricity give the information on generated electric energy from PV modules. The correlation reports are also possible where certain dependency can be determined between meteorological factors and produced electric energy, which allows further analysis and predictions.

However, the core of the monitoring system is the alarm management system which is defined through following steps:

1. Acquisition –the alarms are automatically collected from all devices or are generated by software on the server side, after certain conditions are met.
2. Analysis procedure –before sending, alarms are automatically filtered based on the category, priority level, and time, therefore allowing efficient system maintenance.
3. Distribution –the information can be sent to multiple users, each with competence in specific field (technical, economical, etc.)
4. History –used for the analysis or representation of potential failures of PV plant components.

V. Conclusion

This paper presents the structure of the implemented PV system for production, transmission and consumption of electric energy in small-scale industrial facilities. Currently, the PV system is with the output power of 5 kW, but the production scaling in a function of consumption needs will be the subject of further research. The orientation toward the concept of net metering resulted with the integration of bidirectional meter and the development of software solution for data acquisition and storage.

By introducing the system for bidirectional metering and its further development, conditions have been met for the development of system hybrid management that allows optimization and adjustment of consumption in relation to optimal electric energy production from the PV modules within the small-scale industrial on-grid systems.

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REFERENCES

[1] Marcel Šúri, et al., *"Potential of solar electricity generation in the European Union member states and candidate countries"*, Solar Energy Vol. 81, 2007, pp. 1925.

[2] Decker, B., Jahn, U., *"Performance of 170 Grid connected PV Plants in Northern Germany-Analysis of Yields and Optimization Potentials"*, Solar Energy Vol. 59, Nos. 4-6, 1997, pp. 127-133.

[3] Jung, H. S., Young, S. J., Gwon J.Y., Ju, Y. C., Jae H. C. *"Performance results and analysis of 3 kW grid-connected PV systems"*, Renewable Energy, 32, 2007, pp. 1858–1872.

[4] Sasitharanuwat, A., Rakwichian, W., Ketjoy N., Suponthana, W., *"10 kW Multi Photovoltaic Cell Stand-alone/Grid Connected System for Office Building"*, 15th PVSEC, October 2005, Shanghai, China, Volume 1, pp. 638-639.

[5] Sasitharanuwat, A., Rakwichian, W., Ketjoy N., Suponthana, W., *"Designs and Testing of a 10 kWp Standalone PV Prototype for Future Community Grid Adapted for Remote Area in Thailand"*, International Journal of Renewable Energy, Vol. 1, No. 2, July 2006, pp. 31-43.

[6] Sasitharanuwat, A., Rakwichian, W., Ketjoy N., Ketjoy, N., *"Performance evaluation of a 10 kWp PV power system prototype for isolated building in Thailand"*, Renewable Energy 07/2007; 32(8), pp.1288-1300.

[7] A. Marcoci. A., S. Raffaelli. S., Sanjuan J. M. G., E. Cagno. E., Micheli G. J. L., G.Mauri. G., R.Urban. R., „*The Meter-ON project: how to support the deployment of Advanced Metering Infrastructures in Europe*?", C I R E D, 22nd International Conference on Electricity Distribution, Stockholm, 10-13 June 2013, CIRED2013 Session 6, Paper No. 1261.

[8] Massachusetts Net Metering First Bill Walkthrough, National Grid Net Metering Webpage MA, **http://www.nationalgridus.com/masselectric/home/energyeff/4_net-mtr.asp, http://www.nationalgridus.com/masselectric/business/energyeff/4 net-mtr.asp,**

[9] Introduction to Windows Service Applications, **http://msdn.microsoft.com/en-us/library/d56de412%28v=vs.110%29.aspx**