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PHOTOVOLTAIC POWER PLANT AT THE INSTITUTE OF POWER AND APPLIED ELECTRICAL ENGINEERING

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The contribution deals with the current state of the photovoltaic power plant installed at Slovak University of Technology in Bratislava. The power plant with an installed power of 20 kW peak has been operated since August 2012. The purpose of this experimental power plant is to enable in-operation state modelling for researchers and students, which cannot be conducted in profit-oriented commercial power plants.

K e y w o r d s: renewable energy sources, photovoltaic power, unpredictable power source

1 INTRODUCTION

The contribution refers on the progress in the Renewable Energy Sources Laboratory established at the Faculty of Electrical Engineering and Information Technology of Slovak University of Technology in Bratislava. Construction of this multi-disciplinary electrical, chemical and mechanical engineering laboratory, consisting of cogeneration units, biogas station, photovoltaic power plant and photothermal concentrator with a Stirling type engine evolves from the primary needs of the Institute of Power and Applied Electrical Engineering. The laboratory was developed with the help of European Unions structural funds.

The contribution focuses on the current state, actual results and the future of the photovoltaic power plant situated at the roof of the laboratory building on Technická Street 5 in Bratislava. The facility is used for educational and scientific purposes but it serves also as a green energy source.

2 SOLAR CELLS THEORETICAL PART

The total production of solar modules was dominated by crystalline silicon (c-Si) solar cells, which accounted for 87% of the total production [1], but serious attention is paid to prospective materials [2-4].

In a real solar cell there exist at least two extrinsic effects which have to been taken into account: the series resistance R_{S} and current leaks proportional to the voltage. The latter are usually characterized by a parallel resistance R_{SH}, see Fig. 1(a). These effects are distributed throughout the device and cannot always be represented by a resistance of a constant value. Once R_{S} and R_{SH} are included, the equation for the illuminated solar cell can be written as

$$I = I_{\mathrm{L}} - I_0 \left[\exp\frac{q(U + IR_{\mathrm{S}})}{nkT} - 1\right] - \frac{U + IR_{\mathrm{S}}}{R_{\mathrm{SH}}}. \qquad (1)$$

Here, I_0 is the reverse saturation current of the diode, q is the elementary charge, n is the ideality factor of the diode and U is the output voltage.

From a practical and functional point of view, the use of lumped resistances, as shown in the equivalent circuit in Fig. 1(a), turns out to be an acceptable and extremely useful solution.

For a more detailed study, an equivalent circuit with two different diodes is more convenient as shown in Fig. 1(b). In this model, an extra diode is attached in parallel to the circuit of single-diode model. This diode is included to provide a more accurate $I\!-\!U$ curve that considers for the difference at low current values due to charge recombination in the depleted semiconductor.

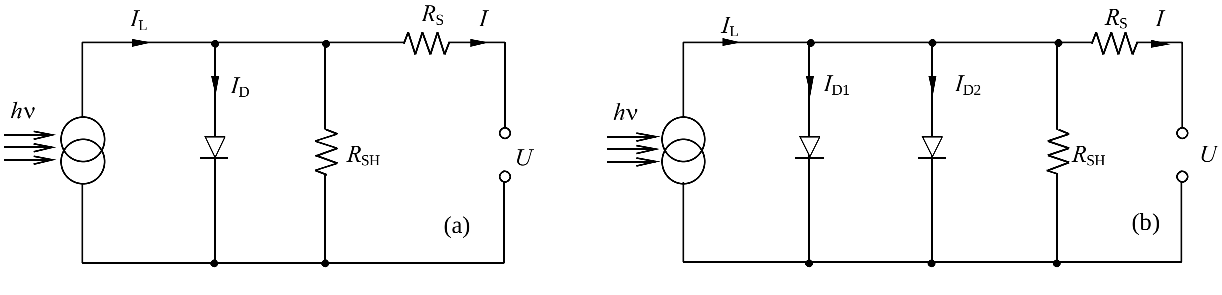

Fig. 1. Equivalent circuits of solar cells

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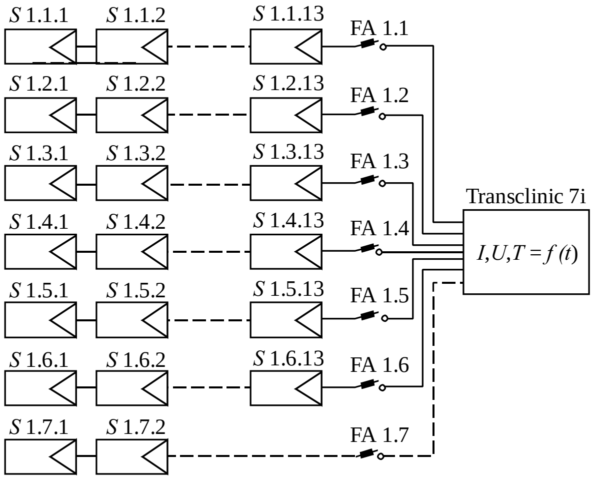

Fig. 2. Strings interconnection diagram

The accuracy of this model is better than that of the single diode model but there are some difficulties to solve the equation. The basic equation of the two-diode model of the photovoltaic cell reads as

$$I = I_{\mathrm{L}} - I_{01}\left[\exp\frac{U}{n_1 kT} - 1\right] - I_{02}\left[\exp\frac{U}{n_2 kT} - 1\right] - \frac{U + IR_{\mathrm{S}}}{R_{\mathrm{SH}}} \tag{2}$$

where I_{01} is the reverse saturation current due to diffusion, I_{02} is the reverse saturation current due to recombination in the space-charge layer, $n_1 = 1$ is the diode D1 ideality factor and $n_2 \geq 1.2$ is the diode D2 ideality factor.

The light-generated current of the module depends linearly on solar irradiation and is also influenced by temperature. Two different diodes represent two different transport processes within the solar cell structure. The electronic equivalent circuit is useful for both the solar cell and the solar module [5].

3 CURRENT STATE OF POWER PLANT

The power plant with an installed power of 20 kW-peak consists of 80 pieces of monocrystalline solar modules FE250M with installed powers of 250 Wpeak each. The highest output voltage of a module is 50.6 V at the nominal power, and 60.5 V in the case of no load. The effectiveness of photovoltaic energy conversion is stated by the manufacturer as 14.9%.

The modules are interconnected to 6 strings to obtain higher power [6], and two panels are extra to extend the possibilities of educational and researcher activity. The module interconnection is shown in Fig. 2.

Each string is monitored by a Transclinic 7i string monitoring system allowing precise measurement of the string current, voltage and temperature in real time. Then a DC filter follows connected to a Vacon NXI-series inverter with a nominal power of 20 kW at 400 V AC and maximal power of 22 kW. The inverter is equipped with advanced MPPT tracking capabilities as well [7].

After the inverter, an RF filter, a choke coil and an LC filter are connected. The main contactor with voltage, frequency, temperature, power-flow protection and electrometer of production ends the power output. The wiring schematic is shown in Fig. 3.

Thanks to the visualization made, the operation of the photovoltaic power plant can be real-time observed and controlled by a computer through a visual web-based user interface from all over the world.

All measured data, such as string current, voltage, temperature, total current of strings, total energy produced or the state of inverter and main contactor are collected in the data central of the High-voltage Laboratory and the National Centre for Research and Applications of Renewable Energy Sources for the purpose of later evaluation. The whole photovoltaic power plant is tailored to be easily understandable in education. The key objective was to design an experimental device in which various operational conditions can be modelled, which is not allowed in similar commercial power plants. The electricity produced by the experimental power plant is mostly consumed at the place of production, so the production will not be analysed from the economic point of view. The installation of photovoltaic power plant was finished on

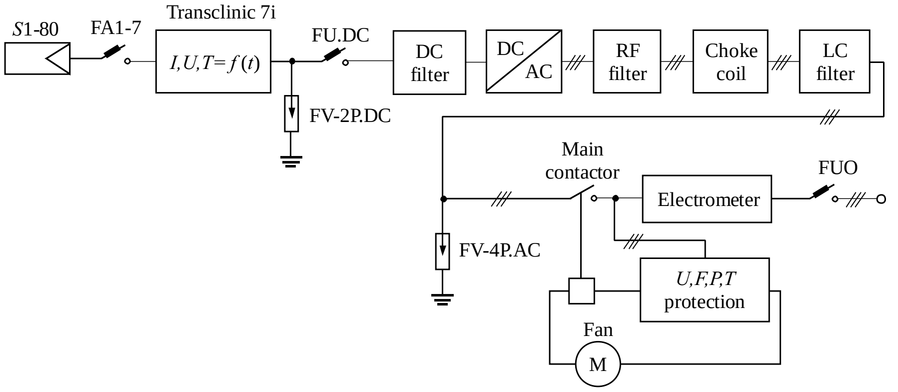

Fig. 3. Wiring schematic of the photovoltaic power plant

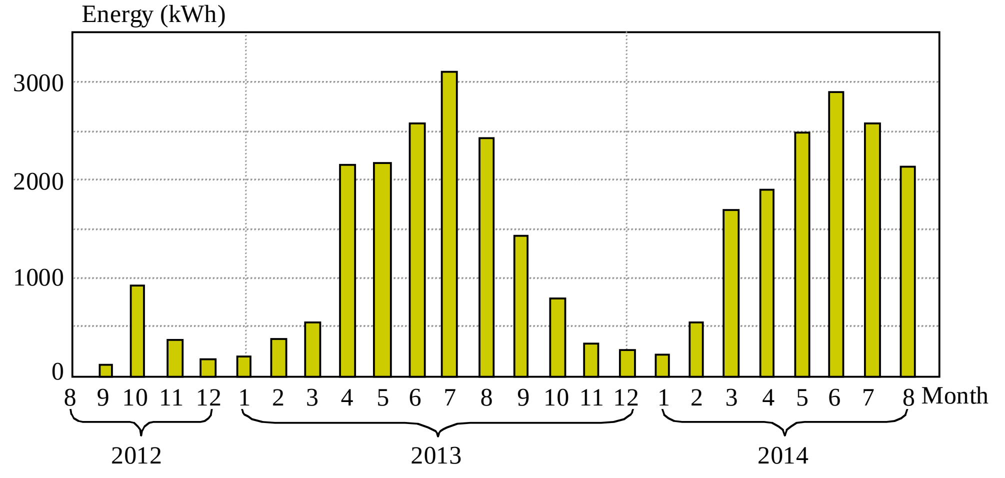

Fig. 4. Production analysis of the experimental power plant

Table 1. Power plant monthly energy production

Month	Transclinic 7i (kWh) - DC	Electrometer (kWh) - AC
2012		
August	2334.9	-
September	1744.5	90.0
October	972.0	927.0
November	382.0	353.7
December	194.0	169.7
2013		
January	215.0	187.9
February	405.0	365.4
March	563.0	521.6
April	2277.0	2168.9
May	2398.3	2196.0
June	3042.0	2592.5
July	3257.0	3123.1
August	2540.0	2423.1
September	1511.0	1420.6
October	878.0	804.1
November	371.0	330.5
December	280.0	246.3
2014		
January	272.0	239.0
February	598.0	546.5
March	1787.0	1688.3
April	1998.0	1895.5
May	2613.0	2494.9
June	3024.0	2897.8
July	2717.0	2593.8
August	2256.0	2145,8
Total	38629.7	32422.0

1st August 2012, and the electrometer was interconnected with the web-based user interface on 28th September 2012 at 10:30.

4 PRODUCTION ANALYSIS DISCUSSION

The production analysis on a monthly basis together with all produced electrical energy is shown in Tab. 1, and graphically in Fig. 4.

The highest electricity production took place on 2nd of July 2013, when 124 kWh of energy could be utilized at the place of installation. The amount of 124 kWh of energy was produced between 5:00 AM and 7:00 PM. The highest hour rate, 13.8 kWh was observed that day at 12 oclock as well. Since on that day the consumption at the laboratory was only 53 kWh, the rest of energy could be exported to the power grid. The hour-based production chart on 2nd of July 2013 is shown in Fig. 5.

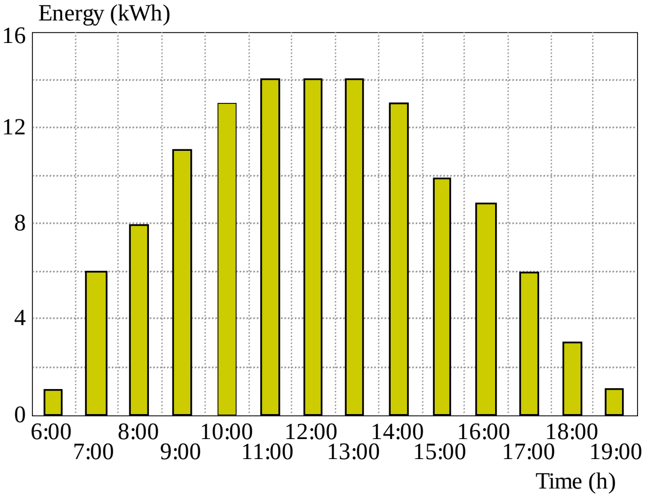

Fig. 5. Highest production of Power plant on 2nd of July 2013

5 CONCLUSION

The described photovoltaic power plant improves the research and educational potential of the National Centre and of the Institute of Power and Applied Electrical

Engineering. The concept and implementation of this experimental device allows easily to understand and control its operation through a web-based user interface via the local area network of the laboratory. Nowadays five students work on the power plant. They complete the measured data by real-time weather data from a locally installed weather station, heliometer and pyrometer. In the future, the databases of the two systems, the photovoltaic power plant and weather station, should be interconnected, which is necessary for further exact analysis of the influence of weather conditions upon electricity production.

Acknowledgement

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