Optimization of a Photovoltaic $LiFePO_4$ Battery Charger

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Abstract *– The paper describes the analysis and construction of an autonomous photovoltaic system for charging a $LiFePO_4$ battery. The system is optimized for available components and their pricing to achieve a minimum battery charging time. The efficiency of the power transmission from the photovoltaic generator to the terminals of the charging battery, when they are directly inter-connected, is compared to the efficiency of conventional chargers with a DC/DC converter controlled by the "Maximum Power Point Tracking" algorithm. The simulation showed that the efficiency in the range of 94-99% can be achieved by matching the battery to the photovoltaic generator. The experimental photovoltaic system was tested at the end of summer 2019. During the sunny days, the intensity of the solar flux reached a maximum value of only 880 Wm^{-2} at a module temperature 52°C. An average efficiency achieved by an experimental system, when the battery was charged throughout the day, was in the range of 95–97%, which corresponds to the values set by the simulation with a deviation less than 2%.*

Key words: $LiFePO_4$ battery, PV power accumulator charging, MPP tracking effectivity

Introduction

The paper presents a functionally verified design of the island photovoltaic (PV) power plant system charged by a $LiFePO_4$ battery that is significantly simpler, cheaper and more reliable than conventional commercial systems.

The design of a conventional charging system of the PV power plant has resulted from the economic optimization based on the analysis carried out 20 years ago. Since the most expensive part of the system was the PV generator, the only way of the optimization was to maximize its output power by applying the Maximum Power Point Tracking (MPPT) controller (Hohm & Ropp, 2003).

The price of photovoltaic modules has dropped approximately 20 times over 20 years (Benda, 2019). The purchase price of the MPPT controller remains numerically constant: in obsolete systems the price of the MPPT controllers was practically negligible; nevertheless, in present systems it is comparable with the price of a PV generator, which complements, see Fig. 1.

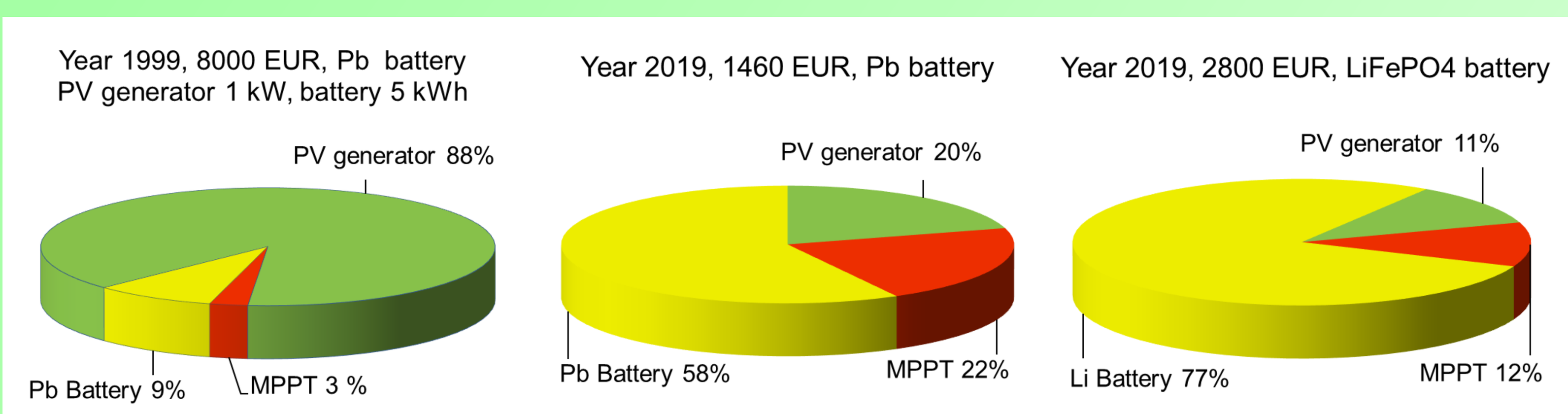

Fig. 1. *Comparison of the purchase prices of the source and accumulator basic components of the PV power plant.*

Considering the above mentioned purchase prices, on condition that the PV generator and MPPT controller are of the same price, the MPPT controllers are profitable only if an average efficiency of a PV charger without a controller is less than 50%.

Materials and Methods

The experimental charging system was, in terms of achievable charging power, analysed by simulating the circuit connecting the PV generator and battery, by determining the time course of the battery charging process and its dependence on the working conditions of the PV generator, see Fig. 2.

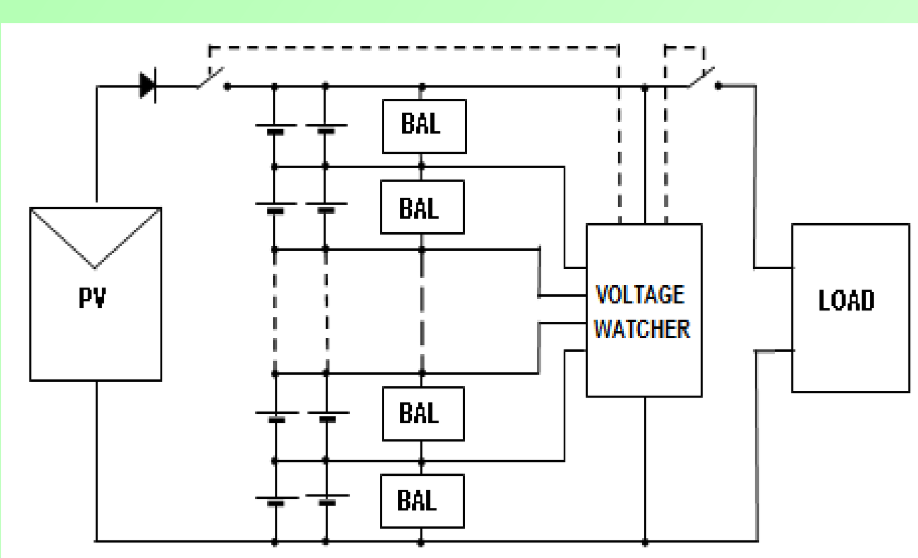

Fig. 2. *Block diagram of the experimental charging system.*

To describe the PV generator, its I-V characteristic curve was used. It was described by a mathematical approximation and further parameterized by a working temperature T and irradiance G (1). The approximation of the I-V characteristic curve is based on the model function with the Shockley description of the PN junction (Wolf, 2013).

$$I_g = f(V_g, T, G) \qquad (1)$$

The waveforms of the I-V characteristic curve for the irradiances of 100 - 1000 W m^{-2} and selected temperatures in the range of 10–75°C are shown in Fig. 3 and Fig. 4.

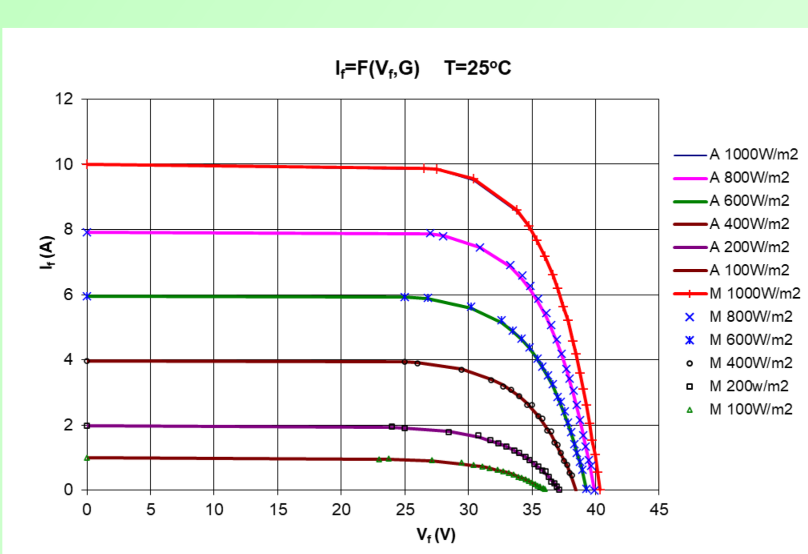

Fig. 3. *Typical waveforms of PV module characteristic curves for the irradiance of 1000 Wm^{-2} and temperature 10–75°C, M-measured, A–approximated.*

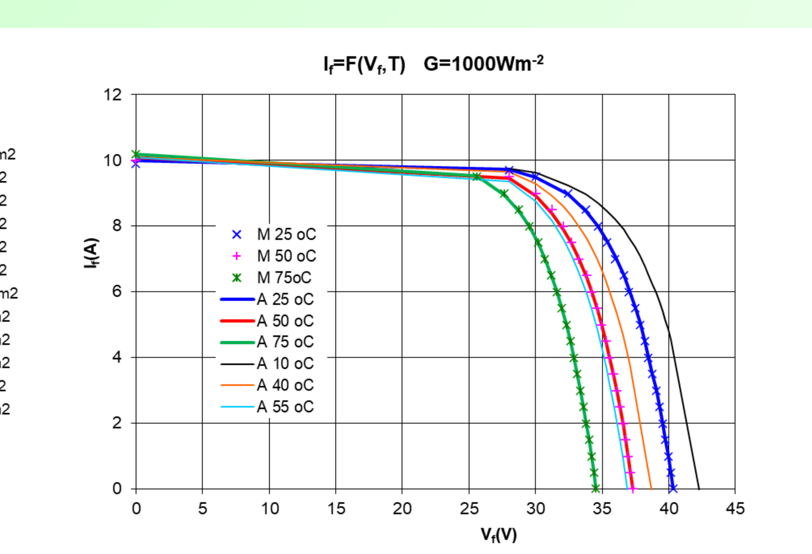

Fig. 4. *Typical waveforms of the PV module characteristic curve for the temperature 25°C and irradiances of 100-1000Wm^{-2}, M-measured, A–approximated.*

The battery was described by a sequence of voltage values V_Q valid for the defined charge values Q during the charging process. For each value Q_n and voltage V_{Qn} valid at time t_n, the value of the photovoltaic current $I_{ph,n}$ was determined the energy E_n (2) delivered to the battery during the n^{th} interval.

$$E_n = (t_{n+1} - t_n)V_{Q_n}I_{ph,n} \quad (2) \qquad E = \sum_{1}^{N} E_n \quad (3) \qquad E_{MPP} = P_{MPP}\, t_n \quad (4)$$

The charging process efficiency is further determined by comparing E (3) with the maximum energy that a PV generator operating in the MPP under the expected operating conditions (4) could reach.

The dependencies of achievable charging process efficiency on the PV module temperature and irradiance set by the simulation of the experimental circuit (see Fig. 2) is shown in the graphs in Fig. 5.

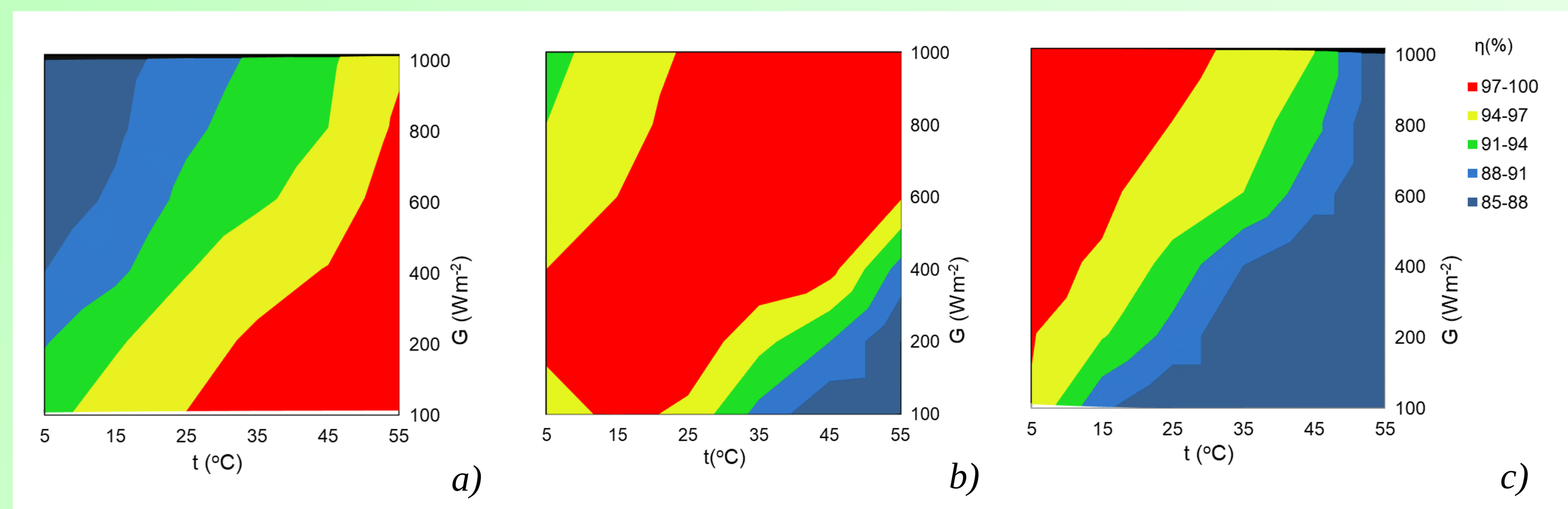

Fig. 5. *Achievable battery charging efficiency depending on temperature and irradiation for a) 8 cells, b) 9 cells, c) 10 cells*

Results and Discussion

A PV battery charger $LiFePO_4$ operated by the described control system was implemented and tested during the summer of 2019. A schematic diagram of the charging system is shown in Fig. 2. The PV generator was realized by a PV module of the type Eco Delta ECO-310M-60, which was firmly fixed in a south orientation, having a 45° slope. The battery was built from 8 in-series connected parallel pairs of recorded during the day not appreciably affected by the clouds are show Winston LYP 100 AHA cells.

The waveforms of the PV module irradiance and temperature, its output current and the instantaneous charging process efficiency varying with a day time are shown in Fig. 6.

The maximum recorded irradiance was 880 Wm^{-2} at a module temperature 52°C, which corresponds to the maximum power output of 240 W in the module and maximum power of 225 W, which is 94% efficiency of the charging process in the battery.

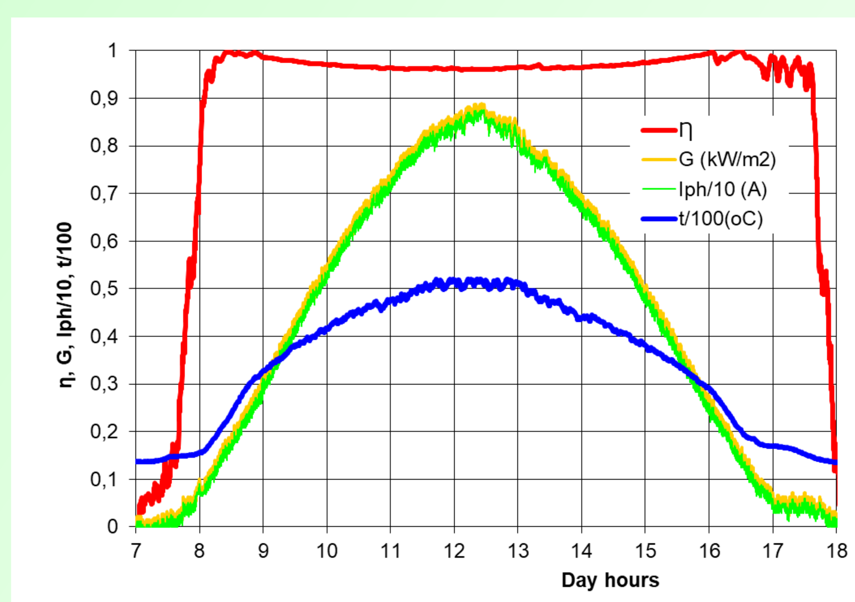

Fig. 6. *Courses of efficiency, irradiance, temperature and charging current during the day.*

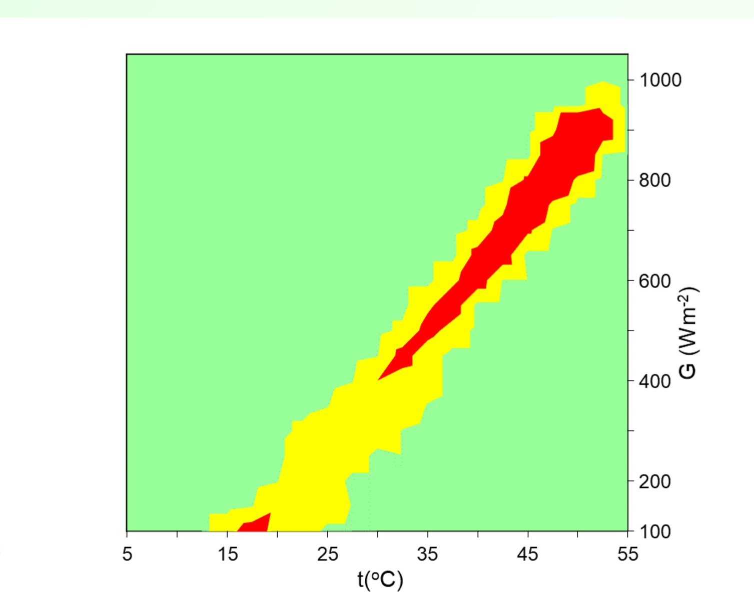

Fig. 7. *Rate of PVG operating states at the end of summer 2019.*

The statistical evaluation of the rate of the occurrence of PVG operating states with irradiance exposure levels greater than 100 Wm^{-2} and different temperatures during August and September 2019 is shown in Fig. 7. The yelow area shown in the graph represents 95% of the PV generator operating time. The red area represents 80% of the PV generator operating time.

The comparison with Fig. 5 shows that in the case the PV generator is loaded by 9 in-series connected $LiFePO_4$ cells, it will operate at least 95% of the operating time with the efficiency higher than 97% and during the whole operating time the efficiency will be better than 96%.

Conclusion

The power delivered by the PV generator to the battery, which is practically identical to the maximum power of the PV implemented generator, can be achieved by matching the battery to the PV generator.

The implementation of the MPPT controller is not cost-effective for any of the configurations and operating modes of the charger described in the paper. The MPPT controller can be used only if the matching is not possible, e.g., in case the PV generator and the battery have different operating voltages.

References

Benda V. 2019. Main Development Trends in Photovoltaic. In: *Smart energy forum*, Praha, Czech Republic (in Czech).

Hohm, D. P. & Ropp, M. E. 2003. Comparative Study of Maximum Power Point TrackAlgorithms. Progress in Photovoltaics. *Research and Applications* **11**, 47–62.

Wolf, P. 2013. Modeling of PV cells and panels in conditions of non-uniform radiation and temperature. Doctoral Thesis. České vysoké učení technické v Praze, Praha, 151 pp. (in Czech).