Sensor Design and Data Transfer in a Smart Grid

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Abstract— This paper discusses the sensing of physical variables used in smart grid power modeling. In the applied distant power sources, we measured the interdependence between physical variables such as lighting (in the photovoltaic power plant) and water level (in the hydroelectric power plant). The data were transferred via a DA4 datalogger, which used the GPRS; the data represented physical variables stored in an SQL database. In our 24 V smart grid, the power obtained from a power source was measured. In the hydroelectric power plants was problem with non-harmonic voltage and current generated turbine. The module designed for accurate power measurement included an analog multiplier, and it was powered — together with the datalogger — by a small photovoltaic panel. Functionally, the module was directly connected with a cable to a PC hosting the Compact Rio program. The last of the renewable energy sources utilized was a battery-powered, self-charging wind power plant.

1. INTRODUCTION

The distant power source experiments were performed using an experimental energy network (E.E.N.) formed within the Centre for Research and Utilization of Renewable Energy (CRURE). The obtained energy was measured on the spot, directly or indirectly, and transmitted via a DA4 datalogger and the GPRS to an SQL database. The values accumulated in the database were subsequently processed by CompactRIO and employed during the laboratory simulation. For correct modeling of the performance, we placed sensors in the given locations and measured the power transfer characteristics of the applied renewable sources [1].

2. CONFIGURATION

Small power plants utilizing renewable energy sources are connected to a grid. Some of these plants are shown at the Laboratory of Automation, Brno University of Technology, where the E.E.N. is located. A PV panel and a small wind power plant are situated on the roof of the building; the hydropower plant, however, is located elsewhere for practical reasons. A hydrogen fuel cell will be connected to the smart grid in the nearest future. The electric energy produced by these remote sources is materialized and connected into the E.E.N. by means of RES (Remote Energy Sources) boxes, see the Appendix. Each RES box is controlled by the CompactRIO and LabView control systems according to the information provided by the GPRS wireless data logger situated near the remote source to measure its power Pi.

The resources supplying the E.E.N. are a wind and a water turbines, a fuel cell, solar panels, and possibly other renewable elements (such as a gas turbine). Each of these items supplies approximately 200–500 W peak to the E.E.N. Given the simplicity of the physical realization, the safety experiments, and the low cost, the E.E.N. works with 24 V DC.

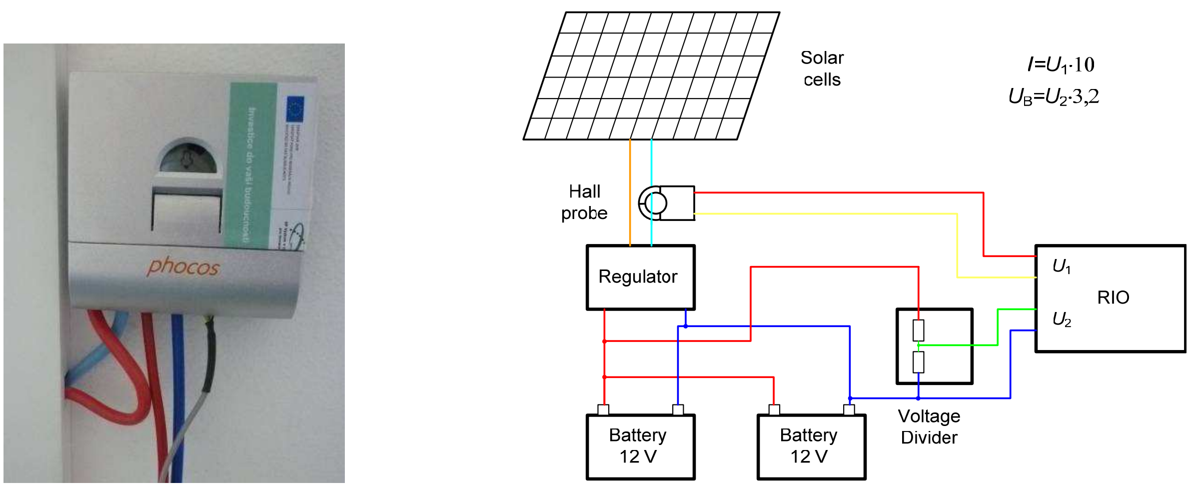
The authors are convinced that this simplification is acceptable for most variants of the control algorithm in the smart grid design methodology. In this context, one of the objectives is to develop a strategy for switching and controlling the amount of energy supplied by the varied energy sources. Within the development of such a strategy, it will be necessary to consider consumption fluctuations and stochastic changes in the wind, sunshine, and partly also the water flow. The designed E.E.N. is equipped with a number of batteries for each individual power source; however, the introduction of centralized battery storage is proposed. Although the storage of electric energy in the form of hydrogen does not seem to be a promising approach, a hydrogen fuel cell (FC) (one metal-hydride container as a form of hydrogen storage) will be integrated into the E.E.N. in order to materialize a source of peak energy.

Personal computers physically connected via simple DC/AC converters without the need for strict adherence to the phasing and frequency constituted an important portion (appliance) of the E.E.N. Other appliances so connected to the E.E.N. included heaters, car battery charges, and also electrolysers (EL) as a backup to store the energy produced by overgeneration. The energy consumption is controlled by the CompactRIO/LabView control systems and the Control Block (CB2), see the Appendix. At this point, the researchers simplified their situation: to switch and control the sources into a common energy grid, the CB2 controls the current (and power) only because the E.E.N. is a DC grid. The authors assume that the optimal control strategy, developed for the DC E.E.N., will be adequate to that commonly developed for a three-phase AC grid, where the resources are connected and synchronized at the same frequency and phasing. The reason for such assumption consists in the fact that the control of each energy source frequency and its proper phasing is a standard question and a standard technical solution of each AC energy source. These features do not correspond with the higher strategic algorithms of distribution, production, consumption, and optimality (the time optimum, and the energy and fuel optimal real time control) of the grids in general. Hence, such strategic algorithms to be developed, simulated, and evaluated in experiments with the E.E.N. will be appropriate for any other smart grid.

3. MONITORING

Two solar panels with the total power of 360 Wp were installed on the roof of the central laboratory building; these devices supply the experimental Smart Grid. The solar panels are manufactured by Solartec, which also delivers the battery charging regulator.

The applied four lead-acid batteries exhibit the total capacity of 120 Ah. They are connected in parallel and provide the total voltage of 12 V when charged. If the solar panel voltage is higher than that of the batteries, the regulator will initiate the charging cycle. The regulator includes overvoltage protection; if the batteries are fully charged, the cycle is terminated. The device is shown in Fig. 1.



(a) (b)

Figure 1: (a) The battery charging regulator of the solar power plant, (b) the solar cell system: power measurement.

Generally, the regulator facilitates the recording of the charging current and battery voltage from the USB interface. However, the value of the current did not correspond to reality, and we had to create a module to measure the current at the input and the voltage at the output of the regulator. The related block diagram is indicated in Fig. 1(b).

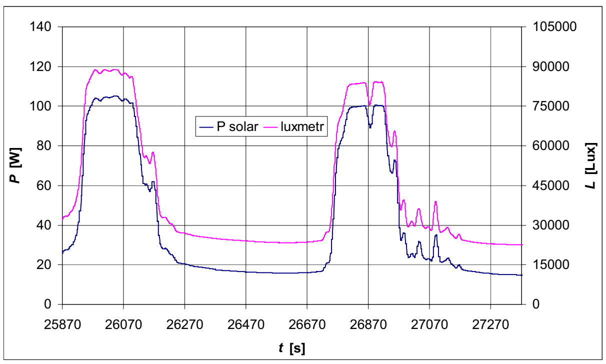
In the previous phases of solar cell modeling [2], the solar power plant source and the supplied power values were measured in remote laboratories; in the current system, the power station is connected directly to the grid, and this arrangement enabled us to find the transfer function between the power and the lighting. The solar cells with the applied photometer are shown in Fig. 2.

Figure 3(a) indicates the dependence of both values (LUX Solar) in winter, on the morning of 15 March 2014. The main problem we had to face was the cloudy weather and low angle of the solar rays illuminating the cells. The transfer function is linear, and it is shown in Fig. 3(b).

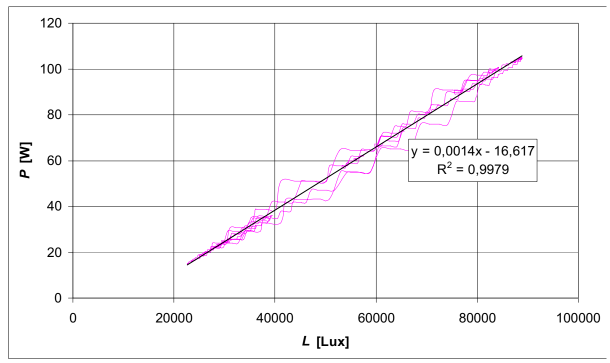
(a)

(b)

Figure 2: The solar cells and the (a) photometer and (b) detailed.



(a)



(b)

Figure 3: The relationship between (a) the lighting and the power provided by the solar cells lant, (b) the transfer function between solar power and lighting.

4. HYDROPOWER MONITORING

To enable on-line monitoring of the voltage in the battery positioned in the research laboratory, we used a DA4 datalogger placed in a telephone pillar. This datalogger included a SIM card, which sent the data to a CRURE server via the T-Mobile GSM network operator [3]. From this server, the data were resent to the central system server of the provider. This CRURE-based system allowed us to observe the electrical variables in a solar panel. The acquired information was used to simulate the solar panels in the experimental smart grid. We utilized the power supply of 80 V/50 A controlled through Labview. In the measuring intervals, we established the water level and the voltage of the datalogger supplied from a small solar panel. Thus, it was possible to model the behavior of a solar panel in the smart grid. The selected time interval was chosen as a compromise between the real (simulated) hydropower plant and the cost of the data transfer. The sensing of this variable was realized by means of an auxiliary CIO unit with 10 V analog voltage inputs.

Figure 4 shows the general structure of the hydropower plant. The main part of the station is a hydroelectric turbine, which generates energy in the form of an electric field. The energy produced by the turbine is fed to a regulator, which should keep the harmonic network voltage at 230 V and maintain the frequency of 50 Hz. It is possible to connect a load (and also a charger) to the

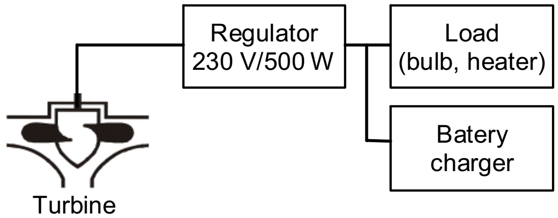
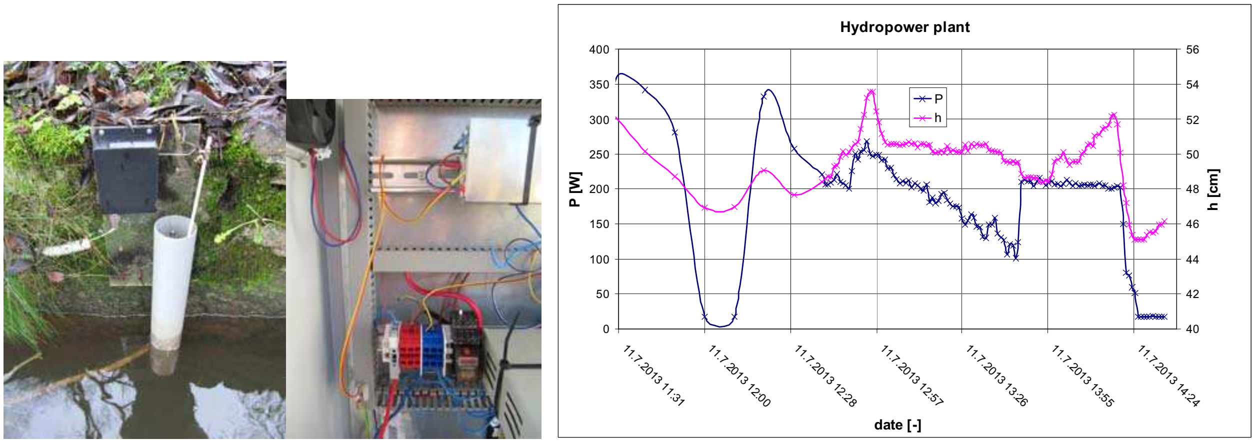


Figure 4: A block diagram of the hydroelectric unit.



(a) (b)

Figure 5: (a) The water level sensors and the measurement module and (b) the three-hour record turbine output power.

output of the regulator. The function of the charger is to charge the 12 V battery of the datalogger transmitting to an SQL server the data related to the water level and the current output power value.

The measurement was performed at the small hydroelectric station. Our aim was to determine the conversion characteristics between the water level in the weir and the corresponding actual output power. The switchboard cabinet comprising the hydropower plant regulator and a load was completed with a water level measuring module, a power meter, and a voltmeter for the non-harmonic waveform. Fig. 6 right shows the three-hour record of the turbine output power; the decrease power is depend leaves and water turbulence.

5. CONCLUSIONS

The paper presents the output power characteristics of a photovoltaic and a hydroelectric power plants; these characteristics can be suitably utilized in the modeling of an E.E.N.. The power units can be connected directly to the grid loads via a regulator; alternatively, the energy can be stored in batteries. Data loggers are located in the stations to transmit the measured output power data to an SQL server. In the future, the data could be used to support the entire process of modeling the E.E.N. functions.

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