# EXPERIENCING RENEWABLE ENERGY: DESIGN AND IMPLEMENTATION OF A MOBILE EDUCATIONAL LABORATORY

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*As renewable energy solutions tend to become important players in the energy market, while attracting large support from governments and other important interested factors, introducing renewable energy topics in bachelor and master studies curricula becomes a must. Driven by this, we propose a cost effective solution that can be adopted by other university, similar to the popular adoption of Arduino.*

*In this paper, we present an optimal suite for studying the basic principles of renewable energy by offering reduced scale models of three of the most common methods of harnessing energy: wind farms, hydroelectric stations and solar panels.*

**Keywords**: renewable energy education, wind farm model, hydroelectric model, solar panel model

## 1. Introduction

Renewable energy has been the focus of many public debates and government regulations in the past decades, transitioning from solutions reserved for environmental enthusiasts or remote location applications, towards an important component in the public energy production scheme of many countries around the world. For example, the European Union (EU) commission had passed a directive that raises the percentage of renewable energy to be used by EU to 20% [1].

Renewable energy technologies, though available for a long time, have been ignored because of: (1) their low efficiency compared to classic fuels, (2) high costs of execution and maintenance, (3) difficult control and (4) low reliability. All these concerns became obsolete as large companies or states started

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investing into the development of such technologies. Their interest was stirred both by general advancements in technology and by the increase in global tensions over natural resources [2].

Funding universities and creating programs enables continuous innovation in this field, surpassing challenges regarding implementation and integration in the current grid, and, overall, public acceptance.

There is a general agreement that education plays an important role in our management of resources [3], [4]. Teaching concepts such as the dependence of human life on the environment, or the importance of reducing our carbon footprint, is already becoming a reality in most educational systems starting from a young age.

Learning through examples has always been perceived as having the best results for teens or adults [5]. Renewable energy education has adopted this approach with reduced scale models being used to illustrate the methods of power conversion. As many education providers turn their attention towards implementing renewable energy curriculum [6], there is a high demand for educational kit-like solutions that can be used inside university laboratories.

Our proposed system focuses on three important and widely-used types of technology inside the renewable energy industry: wind-powered turbines, solar panels and hydroelectric power.

The educational kit can be used either in high-schools, for demonstrations, or by university students for experiments, and has been designed to facilitate effortless integration in the curricula of students from faculties of energy systems or affiliated domains. Nevertheless, close attention has been given to obtaining a working study-suite by using widely available materials, assuring cost effective and user-friendly blueprints.

## 2. State of the Art

There are a few compact, renewable energy educational kits currently available on the market covering all student levels. Amongst most notable we find Heliocentris's “Clean Energy Trainer” [7] and Horizon's “Renewable Energy educational lab” [8]. The first is most focused on the importance of dimensioning and designing of components by studying their efficiency; while the second lacks any possibility of acquiring data from a personal computer. Additionally, neither has true customizable capabilities, especially considering the wind turbines (each is delivered only with one turbine). By visualizing entire wind farm, allowing positioning of the turbines and changing generators, students can get a broader view of the subject while considering more factors that influence the energy output.

The US based National Renewable Energy Laboratory as well as many energy or automation companies offer enhanced modules and support for university students. However, they consist of heavy industrial-like equipment hard to be moved for presentations, while the cost exceeds our proposed kit by orders of magnitude.

## 3. Objectives of Education through the Mobile Laboratory

Solutions for educating the future generation of engineers in the field of renewable energy should empower students to better understand the processes of scientific investigation, and to design, conduct, communicate about and evaluate such investigations. Such a system must enable custom scenarios, multiple variations and optimizations, and a detailed data collection that can be used in analyzing efficiency and costs of available technologies.

In order to maximize the impact of such a system, mobility and space economy should also be emphasized, to allow easy relocation and deployment in various laboratory or presentation locations.

To facilitate an increased interest in the field, the system also has to be presentable and attractive for usage in promotional stands that can attract both current and future engineering students.

Furthermore, such a system should be easily replicable using technology familiar and accessible to university stuff and students, as it should be possible for them to duplicate it with reasonable costs and effort. This introduces certain design constrains, accounting for material availability, general PCB implementation possibilities, and total cost of construction and operation.

## 4. Data Acquisition System

Each of the three modules was fitted with a data acquisition and display system. Its purpose is to read the power output and to communicate with a PC for data storage.

For this task an ATmega32u4 microcontroller was selected, specifically for its integrated full-speed USB peripheral and 12-channel, 10-bit ADC. A virtual serial port was implemented over USB and tested with a terminal. Its performance proved satisfactory, with no noticeable delay for 5 parameter sets. The serial port implementation is based on the LUFA (Lightweight USB Framework for AVRs) open-source project.

Voltage readings, over a load of 1kΩ, are made directly using the ADC channels. The 10 bit resolution of these channels corresponds to a quantization error of 5mV.

Currents are measured through shunt resistors. An INA214 current-sense amplifier is used to raise the small voltage drop generated up to the ADC input range. It has a gain of 100, a common mode voltage range of -0.3 to 26V, and very low offset voltage. Unlike similar amplifiers designed for shunt measurements, it is also linear around zero, allowing precise measurement of small currents. Tests have shown very good performance with a maximum error of 0.05mA.

A standard HD44780-based LCD screen (2 rows of 16 characters), as well as 4 buttons were connected to the microcontroller to enable using the board even when a PC workstation is not available.

An intuitive menu system was implemented in software, offering the following functionality:

- Display of voltage, current and power readings
- Selection of measurement channels
- Load control
- Timed data-logging configuration, allowing later download of recorded data to a PC.

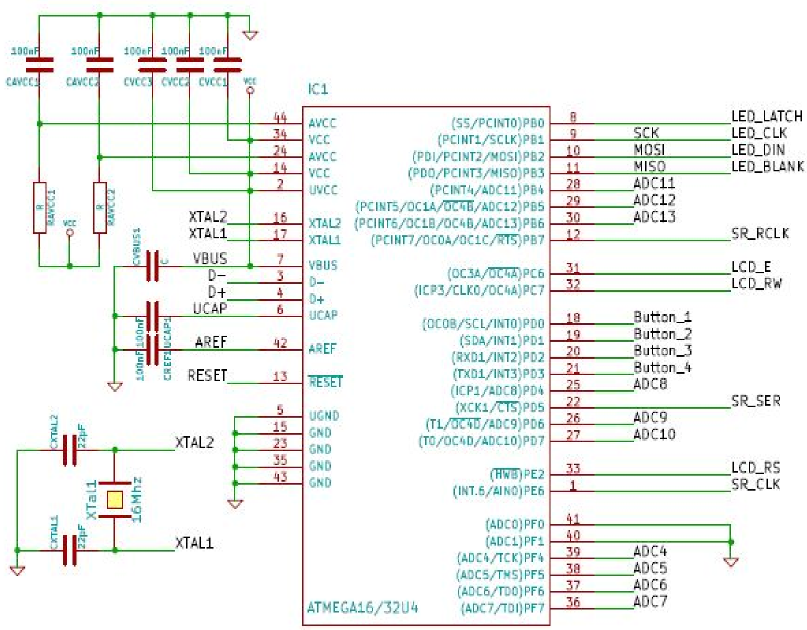


Fig. 1: Main control unit of the acquisition board

The data acquisition board also includes the necessary DC/DC regulators, as well as a LED bar graph with two rows that show the voltage and current output in real time. These offer an intuitive, highly visible representation of the measured parameters. The full-scale range of these displays can be adjusted from the menu system, allowing them to be matched to the system under study.

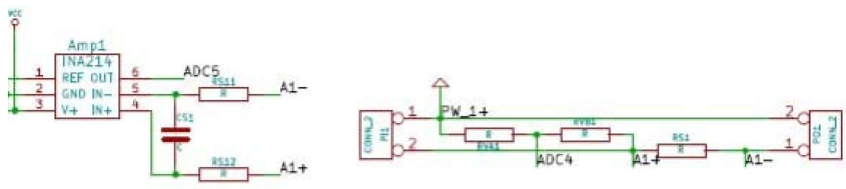


Fig. 2: One of the five input channels of the acquisition board

## 5. Wind Farm Kit

The wind farm kit allows the study of a scaled-down wind farm consisting of up to 5 wind turbines and their associated generators. Its design is focused on modularity and configurability.

A matrix of 3 x 5 slots was patterned on a plastic platform, allowing the placement of 5 turbines in any of the 15 available slots. Each slot is provided with two pins that can be connected to the data acquisition board via jacks placed on the board edge. The distances between slots are mapped on the platform. This design facilitates the study of a wide variety of wind farm configurations, minimizing the time and effort needed to implement a desired configuration.

Parts were built to facilitate easy remodeling. Both the propeller blades and the small generators are easily switchable, allowing comparison between different designs. Only the size of the axis has to match the trough of the rotor hub.

3D printing was employed to fabricate a scaled-down physical replica of a real wind turbine, ensuring its exact calibration and behavior. The used model was that of a three-bladed turbine, a common and highly efficient design, proven even for small scale applications [9]. Recommendations like [10] were also taken into account.

The tower was also set up considering its diameter must be proportional to the rotor blade size. The small generators have reduced friction; therefore a medium-sized fan can be used to generate air flow.

Students can change the pattern in which the turbines are deployed, the angle of the air flow and the fan power; they can analyze the resulting power outputs, in real-time or by using the data-logging feature, calculate the efficiency and determine an optimal setting.

Fig. 3: Wind Farm Kit operational, on display

## 6. Hydroelectric Power

The hydroelectric assembly allows the study of a simplified model of a hydroelectric plant.

It is comprised of a 250L holding tank fitted with a top section which holds a turbine-generator assembly and a 1m tube that emulates the penstock. An electric pump supplies water from the holding tank for driving the turbine.

The experimenter is given two choices regarding the turbine drive mode.

The first option is to employ a 1L buffer tank that is fed by the pump. The tank then drives the turbine from an adjustable height. This mode illustrates the direct relationship between the height difference and the generated power.

The second option is to drive the turbine directly from the pump via a plastic duct. An end nozzle is used to direct the flow of water at a configurable angle onto the turbine. The pump power is adjustable, allowing the system to simulate various height differentials.

## 7. Solar Panel

Upon reviewing available options for sun tracking methods for solar panel systems [11] it was decide that a single axis system that offers enough performance [12] is appropriate for learning applications [13]. Dual-axis solar tracker systems were also considered [14] but analysis of implementation complexity deemed this as too complex for the purpose of this kit.

This kit allows the study of photovoltaic systems. While the other kits are open-loop systems, the design approach for the solar panel kit employs an automatic control algorithm that rotates the panel in order to maximize the electrical power output. Two solutions were designed and implemented.

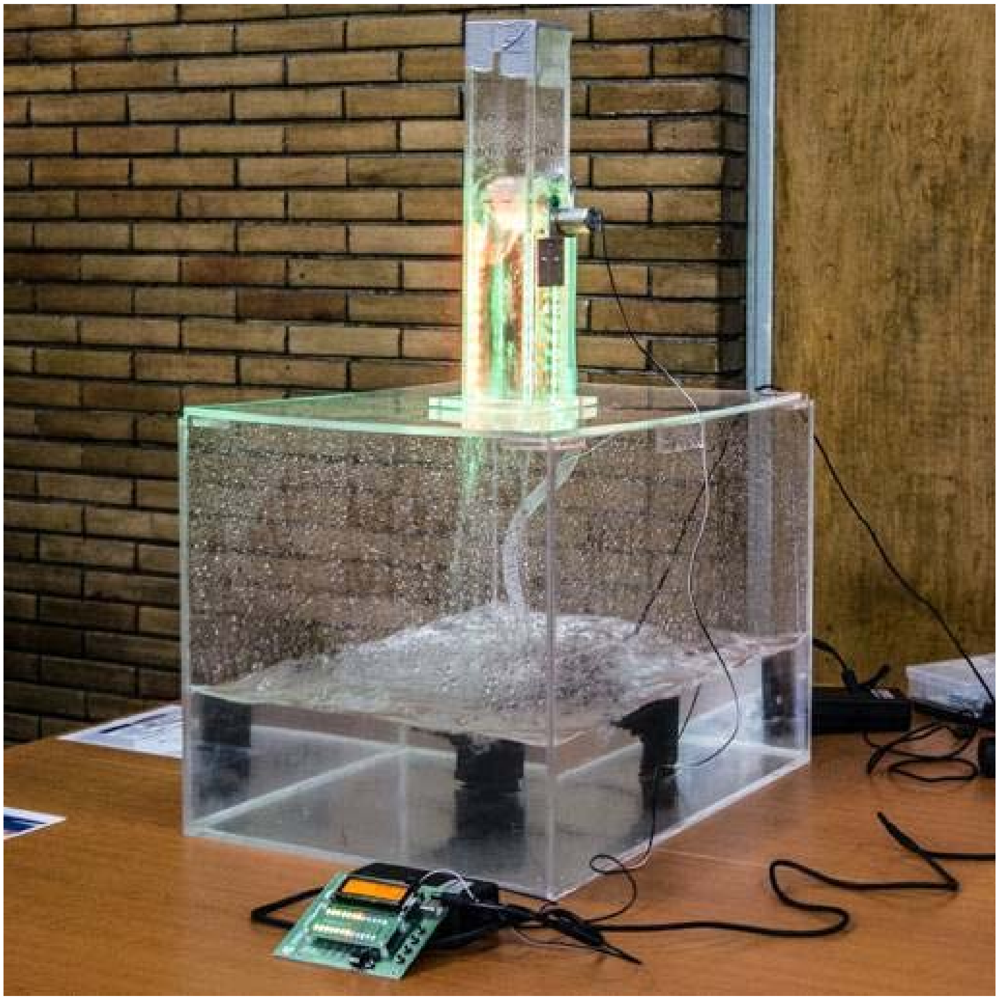

Fig. 4: Hydroelectric kit on display, with measurement system center down

The first solution uses two light sensors and compares their outputs. Once the difference is under 5%, it is considered that an optimal placement of the panel has been reached. Tests have shown that this simple approach works in many situations but lacks proper feedback and is susceptible to interference from ambient light.

The second solution is more precise but slower. The control system scans the available field in 1-degree increments and measures the output power. The scan progresses in the direction of increasing power; it is stopped when a maximum is reached and the direction is reversed, ideally resulting in a ±1 degree oscillation around the maximum power point.

A servo motor (MCN-SRV-03) ensures satisfactory speed and precision; its 3 kgf·cm torque is sufficient to rotate the solar panel.

The solar panel itself is composed of 16 individual photovoltaic crystalline silicon cells, which were selected from available samples for maximum efficiency. The cells are connected in series and are illuminated from an adjustable light source; at maximum output they can drive a small DC motor.

The data acquisition board for this kit is similar with the other ones, but has additional control functionality and can also report the panel angle. The experimenter can select one of the two control algorithms described above, each with tunable parameters, or can use the manual control mode to study the relationship between the panel angle and the output power.

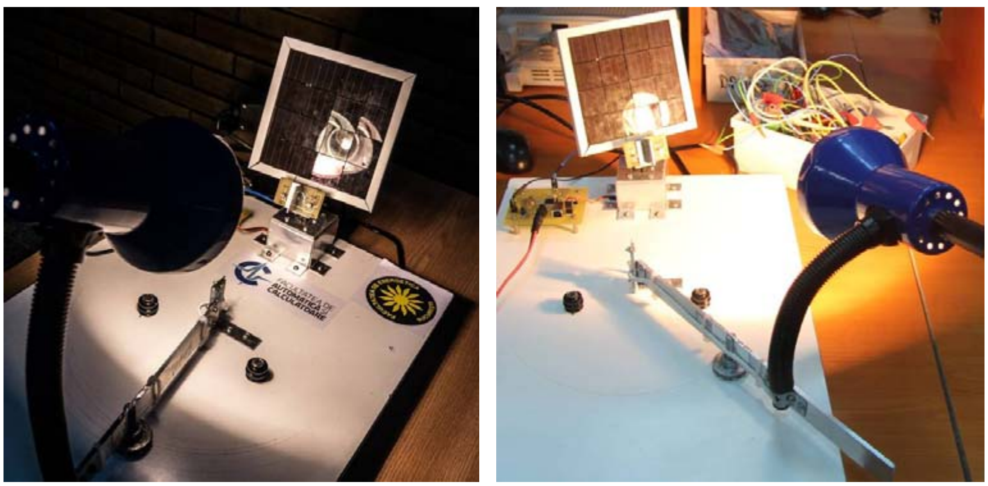

Fig. 5: Solar panel kit

## 8. Using the Kits

The kits can be used in a standalone fashion through the displays mounted on the data acquisition boards. However, interfacing them with a PC-type workstation or mobile computer provides additional value. The acquisition boards provide numeric data in human-readable ASCII format rather than binary data. This facilitates interfacing and debugging while providing a sufficiently high data rate for this application. Therefore, any terminal software can be used to view the numeric data in real-time or a more user-friendly application can be developed using the experimenter's preferred software framework.

As an example, a simple data visualization application written in Matlab is described below. After connecting the data acquisition board and installing the necessary virtual serial port driver, the specific COM port has to be opened:

```
s = serial('COMx');
fopen(s); %% where x is the number of the COM port;
```

The command for converting an input line into the desired data type is:

```
A = fscanf(obj,'format',size);
```

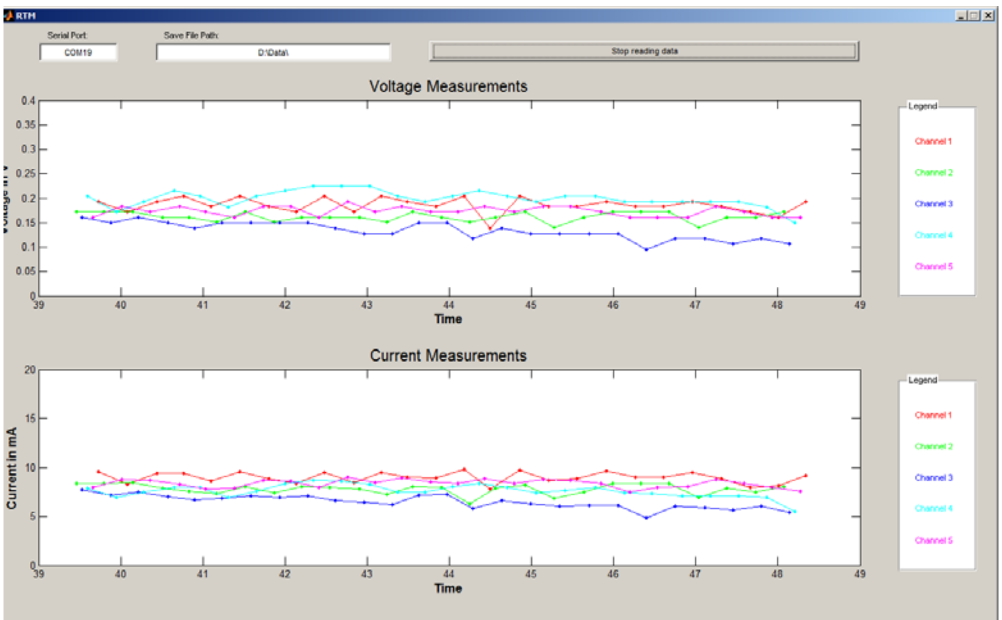


Fig. 6: An example of a simple chart body made using the MATLAB GUI

## 9. Conclusion

The modular approach has been chosen as this study tries to emphasize on the simplicity of the solution and the fact that it can be assembled from a multitude of parts, each offering a different outputs of the system. These differences can then be analyzed and their importance in the mathematical model be quantized in a specific number of parameters that define the system. This process helps students weigh the strengths and weaknesses of a given design and allows choosing the best one.

As future improvements, from a didactical approach point of view, we are thinking of integrating the experiments into a serious game type of learning system [15]. Regarding the hardware, we are now working on two tracks: wireless data acquisition technology and a virtual Smart Grid that can be included in order to allow students to manage the output of all three modules so that the necessary power output to a given virtual consumer can be obtained.

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