Learning with smart grids: an implementation proposal for Uruguay

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***Abstract*--The Uruguayan electric system will reach 1.160 MW of total power installed from wind farm and solar photo voltaic plants resulting in a penetration factor of 28% in solar and wind energy. Demand-response technology gives significant benefits in systems with high levels of penetration of renewable resources.**

We have developed a smart-grid concept adapted to the technology available in Uruguay —using the national deploy of One Laptop Per Child program—, in order to teach and implement demand-response system. We have developed a device that focuses on a smart-grid teaching concept that gives students the opportunity to choose when to consume power, suggesting that they do it when a renewable source is able to generate the energy in the grid. For a demand-response system to have significant impact on the electric grid system, citizens must behave responsibly, so teaching children (and their families) how the system works provides an opportunity to enhance the introduce of a national demand-response system. The didactic tool, named *aty arandu*, was developed as a plug-in for Turtle Bots software, allowing students to explore and learn about energy sources and the responsible use of them. We postulate that students who are in control of their learning are more effective learners [11].

Index Terms--demand response, learning tool, renewable resource.

I. Introduction

By 2016 Uruguay will have a wind and solar-energy penetration of 28 %. The wind and solar forecast that is used in this work is based on a model output statistic (MOS) that uses as an input a weather research and forecasting (WRF) model.

In order to implement an effective demand response program, it is necessary to create customer understanding through the use of educational materials. In [1], the authors identify as crucial to realize benefit from a demand-response program success the need to help end-user customers understand how to change their consumption patterns to achieve bill savings. While industrial customers often developed their own tools and materials to assist in evaluating and participating in demand-response programs, smaller customers generally need help understanding their electricity usage profile. At present, the only demand-response tariff signal in Uruguay is the triple-hour price of the electric energy. The successful roll out of a more complex demand-response tariff mechanism will need a clear understanding by the consumer.

We present the idea of using an energy forecast to connect or disconnect electric devices in houses; we propose teaching these concepts in the public schools. We use publicly available forecast data [2] to implement a demand-response device. These data are used in algorithms programmed by children on an intelligent device connected to the national ***O**ne **L**aptop **P**er **C**hild* program [3]. We hypothesize that this project will achieve two main objectives: (1) the increase of the logical and technological understanding of children; and (2) the need for a citizen-comprehension program about smart grids for the later introduction of a demand response program related with renewable energy resources. In the future, there will be more wind and solar energy production in the country and more electric devices will be connected to the electric system (computers, washing machines, water heaters, among others) increasing the potential for the batch connectivity of devices with the electric grid.

II. Uruguay electric system

In the Uruguayan electric system the frequency is 50 Hz having a physical interconnection with Argentina that allows a maximum power exchange of 2.000 MW. There is an interconnection with Brazil that is under construction with a capacity of 500 MW summing to the actual 70 MW of interconnection with Brazil. By the end of 2016, the total installed wind-energy power in the electric Uruguayan system will be 931 MW; photo voltaic solar energy will be 229 MW. Hence there will be a penetration factor of 28% of wind and solar energy.

The Uruguayan system is small in comparison with neighboring countries such as Argentina with 31.072 MW total installed power and Brazil with 120.973 MW. Nonetheless, there is an opportunity to exchange energy by interconnection with these two countries. It will be possible to export marginal energy and import energy when required to meet the total demand. Demand response can filtrate fluctuation associated with the energy production of renewable energy resource.

978-1-4673-6605-2/15/$31.00 ©2015 IEEE

III. A DIDACTIC TOOL

In the Uruguayan context previously described, it is very important to generate educational materials that allow young students to learn about different energy sources: their characteristics as well as the impact that the individual actions of consumers has on the energy system. We propose and present a prototype of a technological tool named *aty arandu* that enables students to explore these concepts and to make decisions with social awareness. When using *aty arandu*, students are in control of their learning and in control of which type of energy they will use to power their electronic devices. Our prototype lets the user to determine through programming when an electronic device is to be switched on or charged, taking into consideration the source and amount of the energy available in the electric grid.

aty arandu also provides an opportunity to generate a dialog between academia and the society by teaching social awareness to its users. Also, as a research tool, this prototype and its educational use will be used to develop a set of requirements for a demand-response system.

A. Energy Forecast.

The operational forecast model we have developed is based on numerical simulations from the mesoscale numerical WRF model from the National Centers for Environmental Prediction (NCEP) [4]. The simulations use initial and boundary conditions in the larger domain of the Global Forecast System (GFS) from the National Oceanic and Atmospheric Administration (NOAA) National Weather Service NCEP.

Data are periodically download from NOAA. The initial and boundary conditions are provided by the NOAA GFS at 00:00, 06:00, 12:00 and 18:00 GMT [5]. The WRF simulates fluxes of momentum, heat, and mass in the boundary layer. The model makes it possible to generate a wind profile at levels of interest to wind-energy applications. Model output statistics (MOS) were developed using WRF model simulations as input information [6].

Figure 1 shows daily steps of the forecast from the operational model related to the various initialization hours, UY refers to local time in Uruguay, when each step is programed in a Linux crontab file at the Unversity cluster computer.

Every six hour a new forecast is computed, related to the initial conditions, later the real power that is produced by each wind farm is introduced in the statistical model, this approach have shown a significant increase in the model skill

http://www.fing.edu.uy/cluster/eolica/				
Global observational data	00:00 GMT	06:00 GMT	12:00 GMT	18:00 GMT
	21:00 UY	03:00 UY	09:00 UY	15:00 UY
NOAA-GFS Initial condition available public on line	03:15 UY	09:15 UY	15:15 UY	21:15 UY
Download in Cluster FING start WRF running	03:30 UY	09:30 UY	15:30 UY	21:30UY
MOS (Model Output Stadisctic)	09:00 UY	15:00 UY	21:00 UY	03:00 UY
Time Horizon of Numerical Wind Power Forecast	09:00-14:00 UY	15:00-20:00 UY	21:00-02:00 UY	03:00-08:00 UY

Figure 1. Daily steps of the operational forecast system.

The statistical models were based on a time-series approach [7]. These models are based on past production data; they take as input only past values of forecast variables (e.g., wind speed and wind power generation). A simple model with excellent predictive power over a very short forecast horizon (1 to 4 hours) is the persistence model.

Persistence models assume that power production at a future time will be the same as that at a previous time: $\hat{P}(t+k/t)=P(t)$, with $\hat{P}(t+k/t)$ the power forecast for time $t+k$ made at time t, and P(t) the measured power at t.

Reference [8] describes some statistical methods considered for short-term forecasting of wind power. We present here a short-term operational wind energy forecast with a horizon of six hours and the combined model which links the numerical atmosphere circulation and persistence models, a more detailed description of the model is presented in [9]. There are four daily outputs of the numerical model, related to the initial conditions of the general circulation model at 00:00, 06:00, 12:00 and 18:00 GMT.

$P_{Numerical}$ is the wind energy forecast, based on the MOS from WRF simulation. A combined model is defined for each initial condition; for the combined model the X_k coefficient (which varies from 0 to 1) is calibrated. This is done to combine the real-time wind power $P(t)$ at t with $P_{Numerical}$, as it shows in the equation 1.

$$\hat{P}(t+k/t)=X_k P(t)+(1-X_k)\hat{P}_{Numerical}(t+k/t)$$

Equation 1.

X_k can be interpreted as a weight of the best approach depending on the forecast horizon k. Figure 1 reveals that the persistence model had superior predictive power for the very short horizon of one hour, with X_k close to 0.9. At the six-hour forecast horizon, the numerical model had greater predictive power, with X_k approaching 0.2.

B. TurtleBots

Turtle Art [10] is a programming environment with a Logo-inspired graphical “turtle” that draws colorful art based on snap-together visual programming elements. Its “low floor” provides an easy entry point for beginners to programming [11]. Turtle Art aims to engage learners in personal expression helping children to become fluent users of technology and be in control of their learning, we postulate that students that are in control of their learning are more effective learners [12].

Turtle Blocks [13] is a fork of Turtle Art that has "high ceiling" programming features that challenge the more adventurous students. Turtle Blocks extends Turtle Art from a compact turtle graphics environment to a full-fledged programming environment.

Butiá Project [14] has developed and maintain extensions using Turtle Blocks plug-in extension system to control various educational robots and enables the user to explore available sensors in the computer in a easy way (e.g., pattern detection or color tracking with the web cam) enforcing the creative use of the technology. Turtle Bot [15] is a Turtle Blocks distribution with robotics plug-ins maintained by Butiá Project.

For this work a new plug-in has been developed and added to TurtleBots distribution extending the tool with special blocks which allows the student to interact with the forecast model presented.

C. USB4Butiá

USB4Butiá[16] is a open and free hardware Input/Output(IO) board with USB interface developed in the context of the Butiá Project to extend the sensory and actuation capabilities of a computer. It was design with the objective that the reproduction of the board would be simple enough that anyone could do it without the need of expensive manufacturing and assembly equipment, using components available in the local electronic market of Uruguay. (In many developing countries is very hard to access state of the art electronics.)

The printed circuit of the USB4butia board has only one layer which makes it easy to print and transfer using simple elements that are available, such as an ordinary clothes iron. Our goal was to make a design of an IO board that can be built by hand, enabling the experience of building it for those who are interested in hardware; enforcing the idea of being not only users but full developers of the platform.

Despite its simplicity USB4Butiá has sophisticated features, like Hot-Plug sensors and Plug-and-Play capabilities that free children from worrying about many of the details that makes programming more difficult.

In the context of *aty arandu*, a electrically operated switch has been developed as a new actuator for the USB4Butiá IO board using a relay. This module allows the connection of an electronic device to it in order to decide when electric current can pass, using the relay block developed in the *aty arandu* TurtleBots plug-in.

D. aty arandu plug-in

The name *aty arandu* comes from the *Guarani* language; it means “smart network” [17]. The *aty arandu* plug-in to TurtleBots allows the user to consume the service of the forecast model using simple programming blocks. The a*ty arandu* plug-in palette and its programming blocks are shown in the Figure 2.

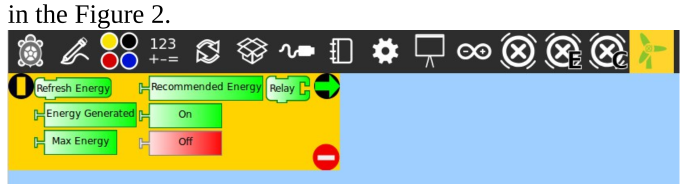

Figure 2. Aty arandu plug-in palette

Using blocks included in the palette of the plug-in, the user is able to program the behavior of the energy consumption, deciding when a device that is connected and controlled by the plug-in will be switched on or off. This activity not only has the role of introducing the user to programming, but also in the understanding of responsible energy consumption. A brief description of the semantic for each block is given below.

- **Refresh Energy**: Force a check of the relay module (the autonomous-demand device) connected to the USB4Butiá board and the renewable energy values.
- **Energy Generated**: Returns the renewable-energy forecast for Uruguay for the next hour.
- **Max Energy**: Returns the maximum amount of renewable energy that could be generated in Uruguay at that time.
- **Recommended Energy**: Returns the predefined recommended value by the authors. It value means that if the generated energy is higher than this value then it is recommended to use renewable energy at that moment.
- **Relay:** This block governs an external device, the autonomous-demand device, a relay. A relay is an electrical component that can open or close an electrical circuit acting like a switch.

As syntactic “sugar”, when the value of the block “Energy Generated” is less than “Recommended Energy”, the block “Energy Generated” turns from green to red, suggesting that is not a good idea to consume energy at that moment, because the there is a high possibility that the energy consumed is not from a renewable source.

Two examples of behaviours programmed using TurtleBots are described to show how the plug-in works. In both examples, the program waits for one hour (3.600 seconds) before re-checking the forecast value, because this is the period of time used by the forecast to update its predicted values. The first example (Figure 3) demonstrates a simple employment, where the user makes use of the recommended value of "Recommended Energy" trusting in the default value configured by the plug-in, as in the case when the user has no knowledge of what the measurements mean. In this case, the connected device will be switched on only when "Energy Generated" is higher than "Recommended Energy".

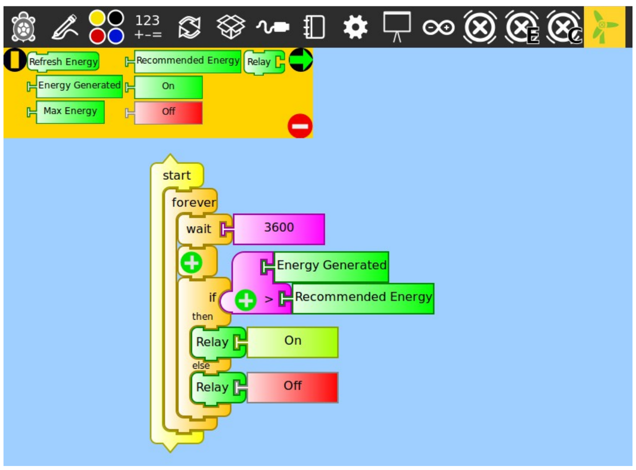

Figure 3. First simple example.

The second example (Figure 4) shows how an advanced user could use percentage values. A user could choose this methodology of programming in order to make programs that will remain valid over time. This program will work even when the value of "Energy Generated" and "Max Energy" change, because it uses a ratio instead of a fixed value to set the threshold.

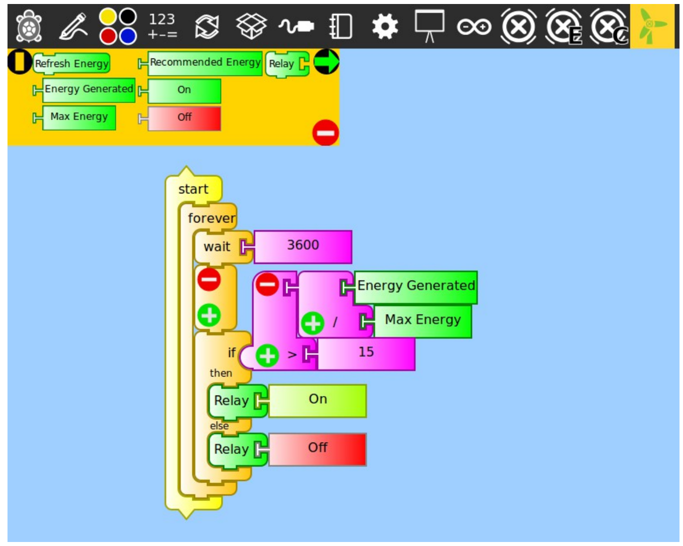

Figure 4. Advanced example.

E. Conclusions and future work

The *aty arandu* demand-response device has been developed using existing technology previously developed by this group as prototyping platform like the forecast model, TurtleBots and USB4Butiá. *Aty arandu* empowers students by giving them tools to create technology, exploring energy and programming concepts. Students can create solutions for problems that are meaningful to them. In this type of learning children will not simply know the name of some device and how it might be used in a narrowly defined context, but they will understand its utility and its limitations. Put more succinctly, *"You learn things through doing, so if you want more learning, you want more doing."* [12]

Future work includes developing a more evolved version of this first demand-response device. A relevant aspect of autonomous demand device to improve is the design in order to build a portable autonomous demand device. To achieve this goal many aspects must be under consideration, such as how to get the forecast model data from Internet (A web-based version of Turtle Bots in under development that may facilitate access to on-line weather data), which communication technology it uses (e.g., WiFi, 2G/3G/4G Mobile), what kind of battery it uses in order to have adequate autonomy, the design of a programming model that allows the download of programs to the device or collect utilization information from it.

The use of wireless technology on the device opens up a wide range of topics to study. One topic is efficiency: in the case of a 3G mobile connection, the use of the network has an economic cost associated with it, so optimizing network access is necessary. The use of WiFi technology permits to share information between peers (between demand response devices) so it could be possible to share information obtained by a single device from the forecast web-service to the others, reducing total costs of Internet access. The problem of sharing information between nodes of a no dense wireless network is the topic of study of the opportunistic networks.

Finally, is important to study the system behaviour in a larger deployment. Opportunistic networks may help in the task of collecting usage information in a cost-effective manner because the information could be transmitted via a no-cost WiFi mesh network build between peers. Usage data enables the generate of usage profiles based on real data or statistical data, and these data could be used as an input for a control system to change parameters on the grid in order to adjust the forecast model itself or to know if consumers are using the energy in a responsible way.

IV. Acknowledgments

The present results were from the development of the project ANII FSE-2011-6562 and the recent advances of an agreement for implementation of a forecast system of wind energy power input to the national grid between the state owned electric company (UTE, *Administración Nacional de Usinas y Trasmisiones Eléctricas* and UdelaR).

We would like to thanks to Patricia Añon, Adriana Gómez, Orlando Hernández and Mercedes Marzoa for their work on the development of the *aty arandu* software plug-in, Gustavo Evovlockas and Agustín Cabral for the development of the relé module, Walter Bender, Federico Andrade and Pablo Margenat for his help during the development of *aty arandu* and Diana Magano for the revision of this document.

This work was partially founded by the *Acortando Distancias* Program of the *Agencia Nacional de Investigación e Innovación (ANII)* of Uruguay ANEP and PEDECIBA.

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