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A Virtual Power Plant with the use of the Energy Box in a Smart Grid concept

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Abstract. Recent years have witnessed considerable advances in designing and operating of energy grids, while the concepts related to the operation of Smart Grids, Vehicle-to-Grid, responsive demand, among others, are gaining research interest worldwide. From an educational viewpoint, the use of a complementary laboratory approach is expected to contribute to the effective communication of these concepts to the students of engineering courses at university level. To this end, this work presents the development of a virtual lab for educational purposes, simulating the operation of a Virtual Power Plant in a Smart Grid context. The system under study involves renewable energy generation, controllable loads and local electricity storage options from electric vehicles, while allowing the students to experiment with the system parameters and perform real-time monitoring and control of the system operation.

Key words

Smart House, Smart grid, Virtual Power Plant, Vehicle-to-Grid

1. Introduction

The increasing share of distributed energy resources (DER) combined with the need for electrical services of high reliability, quality and availability, gave rise to the Virtual Power Plant (VPP) concept, which aggregates many small capacity generation, storage and demand units into one larger system that operates as a single entity [1]. The aggregated units are collectively run by a central control system [2], while their total capacity can be comparable to a conventional power plant [3]. A VPP is primarily based on advanced ICT infrastructure, providing two-way communication with the DER units in order to effectively control their operation and thus optimize their use [4]-[5].

On the other hand, the idea of a consumer, and potentially micro producer, having the so-called energy box (EB) running as a 24/7 computer process and managing the electrical energy usage at his home or small business under a real time tariff was first proposed by Livengood and Larson [6]. In this direction, the case of deploying a number of EBs managed by an aggregator in a Smart Grid context is considered in [7].

For the purposes of the present work, the EB concept is employed to deal with the energy management decisions at a group of modern Smart Houses. To this end, we consider that an individual EB is responsible for controlling the electricity generation from micro-renewable energy sources (mRES), as well as the electricity storage and consumption at each Smart House. Given the increasing interest on electric vehicles (EV) as an alternative means of road transport, we further consider that there is the possibility to connect a plug-in electric vehicle (PEV) to the electric system of the Smart House, using vehicle-to-grid (V2G) technology. The main concept in V2G is that a vehicle having electricity storage capacity could deliver power back to the grid, i.e. the electricity flows from the EV to the grid [8].

In this context, the use of a VPP in the form of a simulation tool for educational purposes is considered to have a beneficial effect on the student's understanding of the concepts related to the Smart Grid operation. The frame of the work presented here, which began initially in Portugal and is further continued in Spain, involves the development of a virtual lab that simulates the operation of a VPP, while the proposed approach could complement the coursework taught in the corresponding programmes of postgraduate studies at universities.

2. System characteristics

The system under study includes a small scale DC (instead of AC) model of a Smart Grid having the following characteristics:

1) Electricity generation from renewable energy sources (RES), namely wind and solar energies.
2) Several variable loads representative of those installed at typical houses.
3) Two identical Smart Houses with mRES and V2G capacity (simulated with electronics) managed by EBs.

Fig. 1 illustrates the infrastructure under the control of the EB in each Smart House.

Fig. 1. The Residential Smart House Energy Box Paradigm (retrieved from [7]).

The software application developed within the frame of this work is capable of simulating the conditions of the Smart Grid and/or the Smart Houses with the EBs and provides user interaction, e.g. allows for monitoring the impact of a particular action, such as connection of the EVs to the electric system of the two houses in order to supply electricity to the smart grid. Among the options available to the user, we choose to highlight the following:

1) Control the power of the air conditioning system for heating/cooling.
2) Set the EVs to charging/discharging mode.
3) Set the Smart Grid to operate either connected to the grid or in islanded mode.
4) Load an electricity generation profile for the mRES.

A. Electricity generation, storage and consumption in Smart Houses

The model of the house chosen for the purposes of this work includes 5 distinct areas, namely 2 rooms (A), 1 WC (B), 1 dining room (C) and 1 standard kitchen (D), according to the layout shown in Fig. 2, while it is considered that each space is equipped with a number of electricity loads, as listed below:

A) *Rooms*: Heating and cooling loads between 3 and 720 W and lighting and general loads from 5 to 225 W.
B) *WC*: Lighting and general loads from 0 to 75 W.
C) *Dining room*: Heating and cooling loads between 3 and 2000 W, and as well as lighting and general loads from 5 to 625 W.
D) *Kitchen*: Lighting and general loads from 5 to 200 W, as well as a washing machine with rated power of 3300 W.

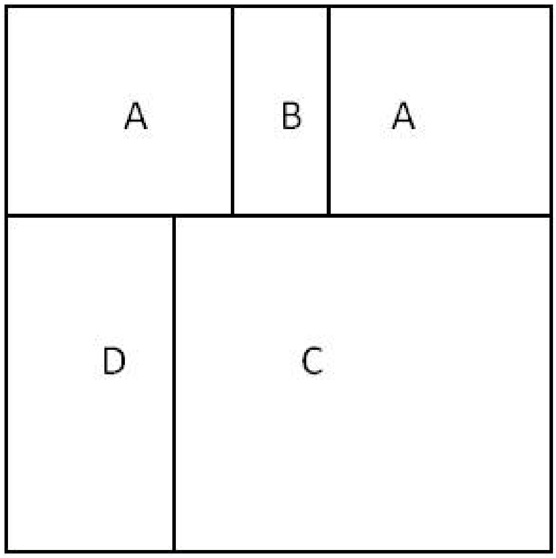

Fig. 2. Layout of the house model.

Overall, the categories of electricity consumption in each house are as follows:

1) Heating and cooling (synchronized): 6 to 2720 W.
2) Lighting and general loads: between 15 and 1125 W.
3) Remote controlled appliances (washing machine): 3300 W.

The electricity generation options include:

1) A photovoltaic (PV) array with a power output between 0 and 3680 W, mounted on the roof of the house.
2) A small scale wind turbine with a power output between 0 and 3680 W, installed on a tower annex to the house.

We further assume that an EV equipped with an onboard battery pack that can be connected to an external power source (e.g. a plug-in hybrid electric vehicle or a battery electric vehicle) plays the role of a local electricity storage option at the house. Moreover, the charging power of the EV battery is considered equal to 1800 W.

The components of the system under study are simulated as DC circuits with a scale factor of 1:680. To this end, the electricity resources are scaled respectively, as stated below:

1) *Heating and cooling loads*: 4 W.
2) *Lighting and general loads*: from 0 to 1.65 W.
3) *Remote controlled appliances*: 4.85 W.
4) *PV panel output*: from 0 to 5.41 W.
5) *Wind turbine output*: from 0 to 5.41 W.
6) *EV charging power*: 2.64 W.

B. Printed Circuit Board of Smart Houses

Fig. 3 presents the design of the electric circuit for simulating the electric system of each Smart House. Accordingly, the software component of the system uses a set of two electric circuits to control the two identical houses.

C. General Components

A total of 6 electric circuits are designed to control each one of the standard loads considered at a house. Each circuit receives a logic signal from the PC (running the software application) in order to connect or disconnect the corresponding load. Indicatively, Fig. 4 shows the case for the washing machine.

D. Special Components

Fig. 5 depicts the common equivalent circuit for simulating the operation of each one of the two types of renewable energy generators, namely a mini wind turbine and a PV panel, which are present in each house. The basic components of the circuit include 2 operational amplifiers, 1 transistor, 1 diode and 8 resistors. This circuit receives an analog signal [0,5 V] from the PC and acts as a voltage proportional current source.

The equivalent circuit for the battery charger is shown in Fig. 6. The basic components of the circuit are 1 relay, 1 transistor, 1 capacitor, 5 resistors and 2 diodes, of which the one is of LED type. This circuit receives a logic signal from the PC and charges the battery present at the terminals (+) and (-). When the voltage at the battery terminals reaches 5 V, the charging process is terminated to avoid any damage from overcharging. The voltage supply to the circuit must be 9 V in order to charge the battery with certain safety.

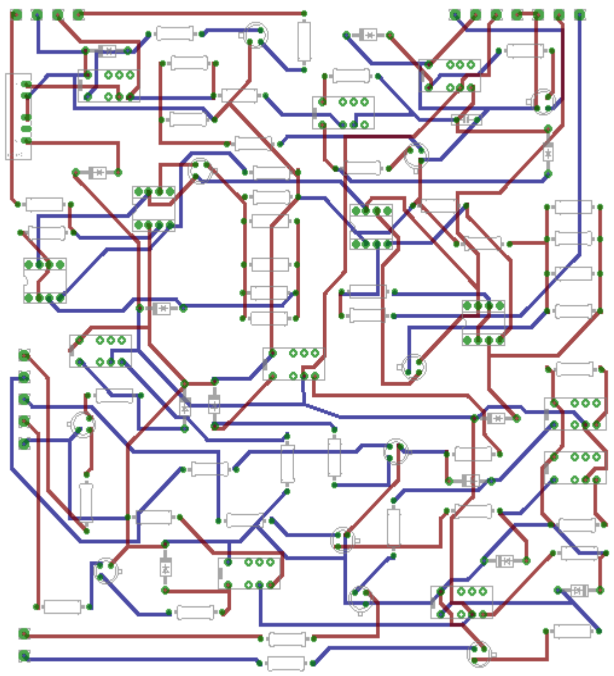

Fig. 3. Printed circuit board design for the Smart Houses.

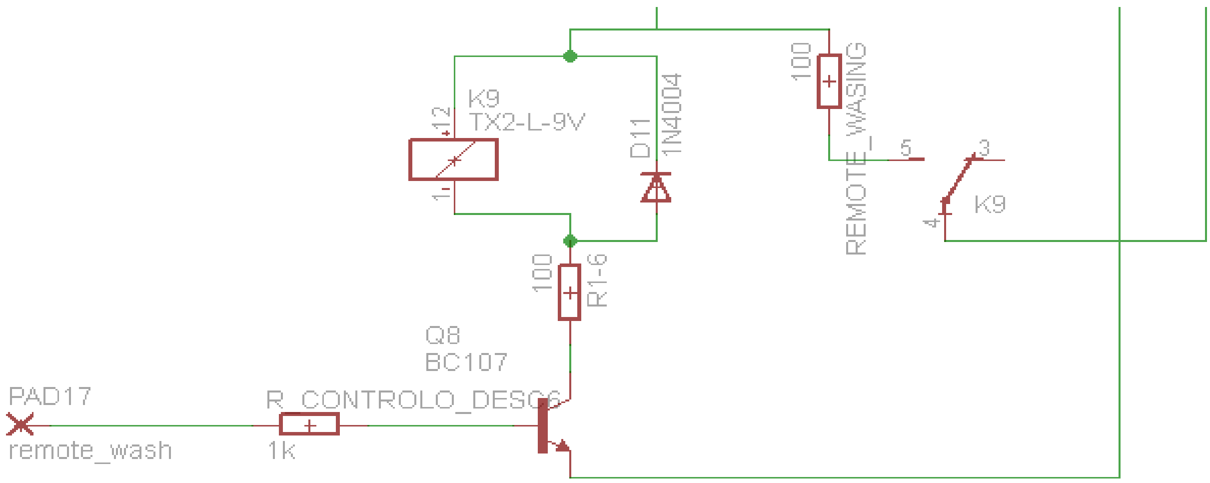

Fig. 4. Standard load and signal of the washing machine.

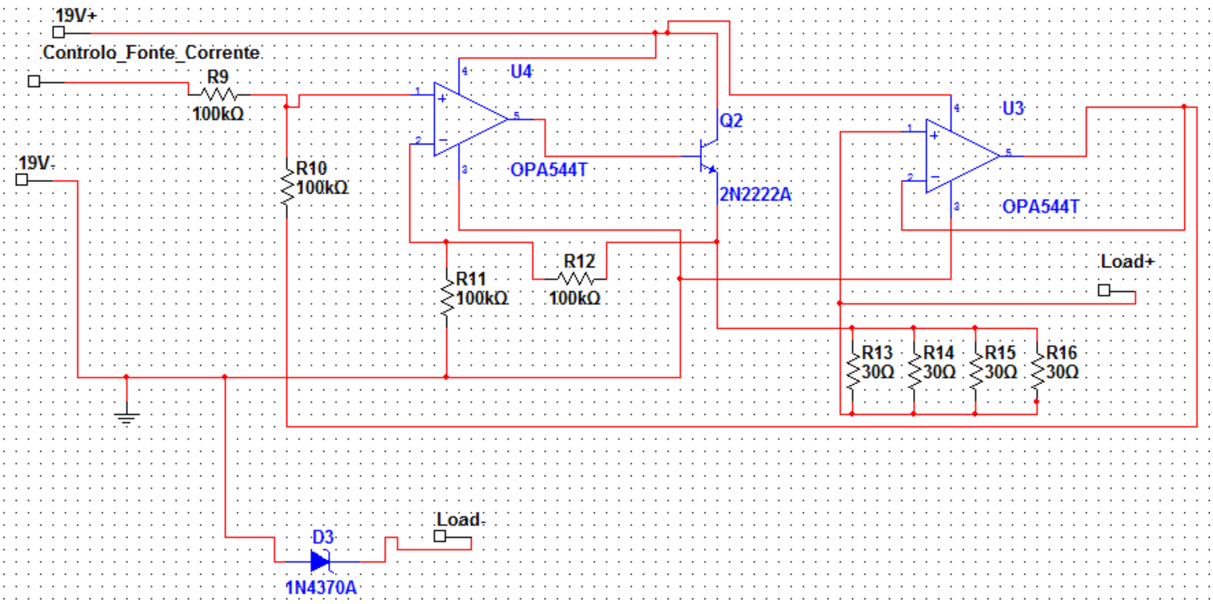

Fig. 5. Wind turbine/solar PV panel equivalent circuit.

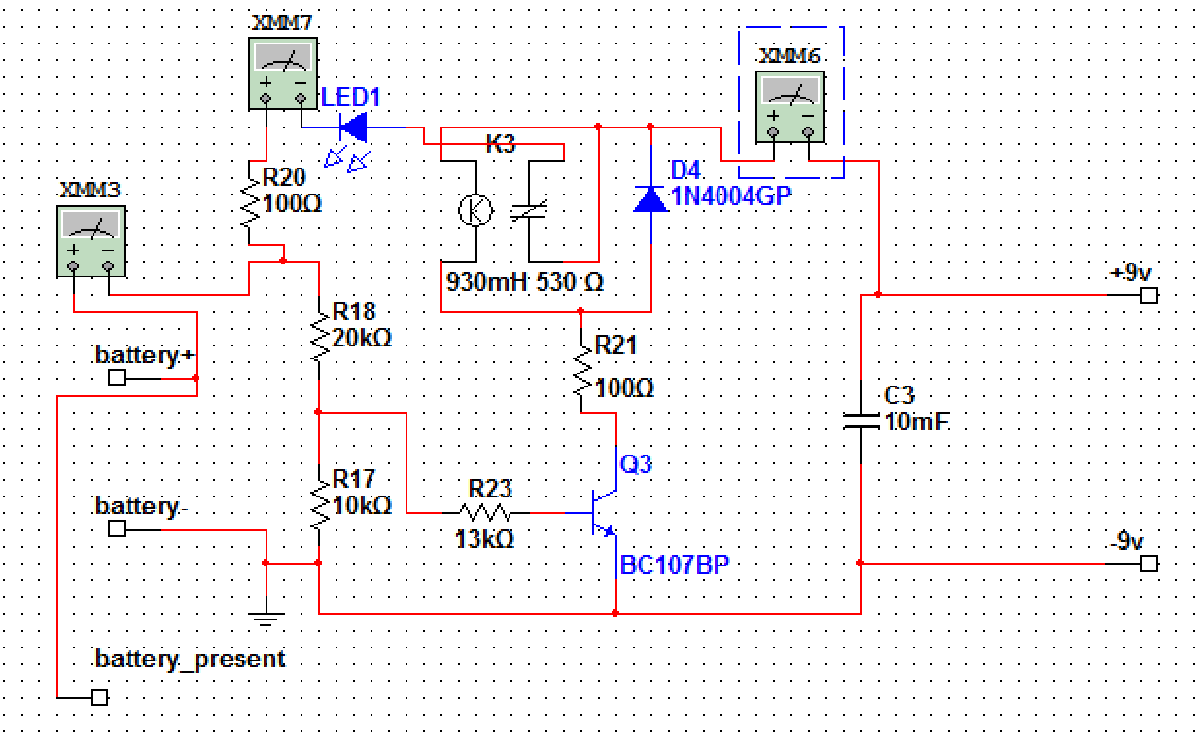

Fig. 6. Battery charger equivalent circuit.

E. Design of the software application

The software module developed for the purposes of this work is responsible for the real-time monitoring and control of the various system components representing the aggregated resources, such as distributed generators and controllable loads. Fig. 7 presents a screenshot of the main application that exemplifies the capabilities of the software part. Indicatively:

- The section entitled “House 1 - Energy Box 1” on the upper left part of the figure allows the user to parameterize the electricity generation from mRES, connect/disconnect the air conditioner, the washing machine or the various general electricity loads, as well as set the EV to charging/discharging mode.
- The bottom left part of the figure depicts the details for monitoring the electrical parameters of the aggregator, e.g. voltage of the grid (9 V in state of equilibrium). The real time status update of the aggregator parameters is activated when the “Update All” button is pressed.
- The bottom center part of the figure shows the detailed data of a virtual tool developed for simulating the economical parameters of the microgrid for educational purposes, while the general controls of the system are shown on the bottom right part.

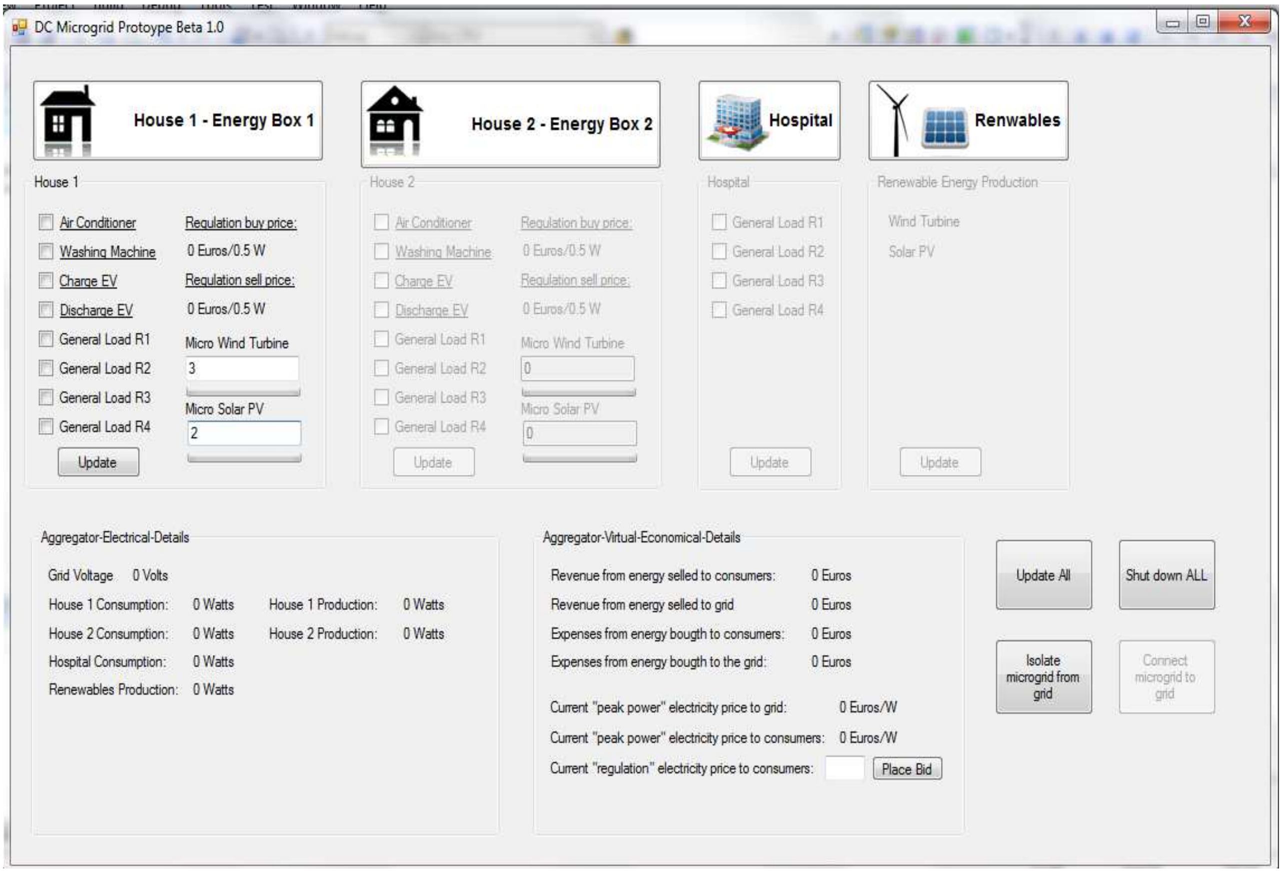

Fig. 7. Main window of the software application.

3. Conclusions

The present work details the design of the software and hardware components for the development of a VPP tool for educational purposes. To this end, it is considered that a group of Smart Houses with mRES and V2G capacity are managed by individual EBs, while an aggregator, in the form of a small scale VPP, is responsible for the coordination of the available DER units. The proposed tool offers a range of energy management options and allows real-time monitoring of the system and control of the distributed generators, loads and devices for local electricity storage. Consequently, the VPP tool can play the role of a laboratory platform for simulating the operation of a Smart Grid and thus complement the theoretical part of the corresponding engineering courses at university level.

Future work includes the further development of the software part in order to include an additional block for the case of a complex building, such as a hospital as indicated in Fig. 7.

References

[1] M. Peik-Herfeh, H. Seifi and M. K. Sheikh-El-Eslami, “Decision making of a virtual power plant under uncertainties for bidding in a day-ahead market using point estimate method”, International Journal of Electrical Power and Energy Systems, Vol. 44, 2013, pp. 88-98.

[2] “Smart Grid Projects in Europe - Lessons Learned and Current Developments”, available at http://publications.jrc.ec.europa.eu/repository/handle/111111111/22212

[3] A. Molderink, V. Bakker, M. G. C. Bosman, J. L. Hurink and G. J. M. Smit, “Management and control of domestic smart grid technology”, IEEE Transactions on Smart Grid, Vol. 1, 2010, pp. 109-119.

[4] P. Asmus, “Microgrids, Virtual Power Plants and Our Distributed Energy Future”, Electricity Journal, Vol. 23, 2010, pp. 72-82.

[5] P. Lombardi, M. Powalko and K. Rudion, “Optimal operation of a virtual power plant”, 2009 IEEE Power and Energy Society General Meeting, PES '09 , Calgary, AB, 26-30 July 2009.

[6] D. Livengood and R. Larson, “The Energy Box: Locally Automated Optimal Control of Residential Electricity Usage”, Service Science, Vol. 1, 2009, pp. 1-16.

[7] C. S. Ioakimidis and L. J. Oliveira, “Use of the energy box acting as ancillary services”, 8th International Conference on the European Energy Market (EEM´11), DOI: 10.1109/EEM.2011.5953077, Zagreb, Croatia, ISBN: 978-1-61284-284-4, 25-27 May 2011, pp.382-388.

[8] W. Kempton and J. Tomic, “Vehicle-to-grid power fundamentals: Calculating capacity and net revenue”, Journal of Power Sources, Vol. 144, 2005, pp. 268-279.