ENERGY FLOW MANAGEMENT STRATEGY IN AN HYBRID DC MULTISOURCE SYSTEM.

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Abstract— **This paper will present energy flow management in order to optimize the voltage regulation of an hybrid electric system which may consist on a main renewable energy source (small windmill, photovoltaic) and lead-acid batteries energy storage system. This system is designed for small power use (few kW) for an islanded DC network. From the point of view of the need of a constant DC power voltage, whatever the load current fluctuation, this paper will propose to study the energy flow between the source and the energy storage source using EMR methodology (Energetic Macroscopic Representation) [1]. An experimental setup has been carried out in order to validate this approach.**

Keywords— *Renewable energy, stand-alone DC network, hybrid system, power improvement, dsPIC implementation control..*

I. INTRODUCTION

Researches about energy means were accentuated these last years to replace fossil energies by renewable energies like wind energy, solar energy, fuel cells.... A good energy management available makes it possible to optimize the power consumption of the systems and thus to improve these efficiency.

The installation of hybrid electric systems in a site depends on the natural energy resources as solar or wind. These resources are not constant [3, 4] and needs auxiliary storage system. Energy management strategies have to make their possible to choose where the electrical energy is available depending on technology constraints from the elements[1] . Once the system is set up it will then act to optimize its operation. Thus our approach will be to analyze the energy flow using EMR methodology, which will define a control strategy structure which could be implemented in a microcontroller.

II. SYSTEM DESCRIPTION

The system studied in this part (figure 1) is composed of two sources, one storage lead-acid battery 12V, one main electrical DC source (photovoltaic panel or small windmill DC generator) and an electronic load which has to simulate DC load consumers (freezer, fan, pump, lights….) The main source of energy represents the DC voltage source, when available, from solar panels or wind energy primary transforms. The battery and this main source are connected

respectively to a 18V DC bus via a boost converter and a buck converter.
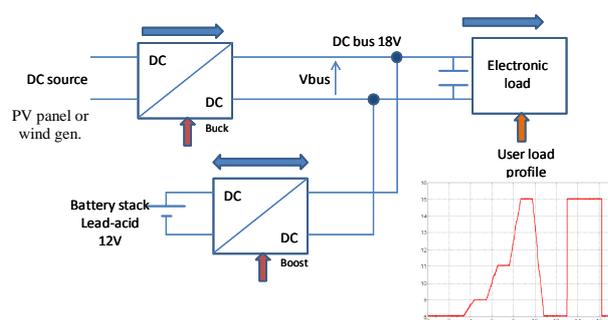
Fig. 1. System under test

The load is connected directly to this continuous bus and for the study a load profile has been proposed regarding some uses as pump motor starting, lights sets…..

III. ENERGY FLOW MANAGEMENT AND STRATEGY

In order to model an electric system, various formalisms are available among scientific publications like the bond graph, energetic macroscopic representation (EMR), energy puzzles, Power Oriented Graph (POG), Power Flow Diagram (PFD), and the informational Causal Graph (GIC). These various formalisms are described in detail in [8] and [5]. The formalism chosen to model the presented electric system is the energetic macroscopic representation (EMR). This formalism is oriented by reaching some efficient objectives like among them, the simple description on the energy flows in a synthetic way (system multi-physics) , and the design of a good support to elaborate simulation and control of the system.

The Energetic Macroscopic Representation is a formalism created within laboratory L2EP of University of Lille (France). It was developed in years 2000 [8]. Its objective is to describe the complex multiphysics systems [6]. In [7] and [5], the description of EMR methodology is articulated in 4 steps. The 1st step describes modeling according to EMR methodology (principle of action/reaction, integral causality). The 2nd step develops the analysis and the inversion of the EMR (creation

of the maximum structure of control (SMC)). The 3rd step details simplification and the estimate in other words, the passage of the SMC to the practical structure of order (SPC). Lastly, the 4th step describes the strategy of energy management.

In the following sub-chapter, we will describe in a brief way this formalism.

First step: organization of the EMR
The EMR is based on the concepts of interaction between subsystems, integral causality and generalized power variables [8]. EMR descriptive language is composed by 4 families: the source elements, conversion elements, those of accumulative elements and coupling elements. The source elements can be from various fields: electric, mechanical.... The elements of conversion are either mono or multi-physics like a transformer (conversion electric-electric, a reducer (conversion mechanics-mechanics) or an electromechanical converter (electric-mechanics). Two tables representing the various elements of the EMR are presented on figures 2 and 3 [5].

Element	Pictogram EMR	Pictogram SMC	Example
Source Element			Accumulators Supercapacitors Loads
Monophysics conversion element			Chopper Gearbox
Multiphysics conversion element			Electromechanical conversion of a pmsm
Accumulative element			Inductor Capacitor Mechanical shaft

Fig. 2. EMR symbolic representation

Second step: analysis and inversion of the EMR
The analysis of the EMR enables us to create the control maximum structure (SMC). Indeed, the EMR highlights the various adjustment inputs of the studied system. Once defining the regulated systems, using inversion rules of EMR, will provide the SMC. The SMC is control mode that one could describe like ideal. Indeed, all the variables of the system are taken into account, even if sometimes, some of them are not measurable or with difficulty. For example in the SMC, we can measure the electromotive force of an electric machine, which is not the case in reality.

Third step: translate from SMC to SPC
When the maximum structure of control (SMC) is established, we must take into account the physical constraints of the studied system such as the estimated parameters or the time used by the communication buses which transmit the data between the system and the supervisor for example. These

modifications are taken into account in the practical structure of control (SPC).

Fourth step: definition of the strategy

The strategy is defined in order to control the system as a whole system. It is represented by one or more elements in dark blue. It can take account of the various sources in presence in the system and adapt, if necessary, its order according to the availability of these last.
The representation of the various elements of the EMR is presented in the figure below (figure 3) .

Monophysics coupling element and inversion			DC voltage bus
Multiphysics coupling element			Electrical machine
Estimation block			Electrical machine EMF and torque
Strategy block			Energy management strategy

Fig. 3. EMR symbolic representation

More details are given in [8] such as for example the rules of the concatenation and the permutation of two elements of accumulation.
Several works was carried out via formalism EMR, in particular in the hybrid electric vehicle. In [7], the author develops the management of energy at the total level of a hybrid electric vehicle.

Before carrying out the experimentation on the studied system, the programming of the various converters must be carried out. For that, several steps are necessary.

The first step consists in creating the maximum structure of control (SMC) of each converter with Matlab-Simulink ® software. The EMR (real model) and the SMC (integrated in the control board) are linked by the different values necessary for the drive operation (various inputs such as for example the 18V bus voltage and the output which is the duty cycle of the chopper). The inputs are of analog type and the output is PWM. Before implementation in the control board of the converter, signal conditioning of measurements is needed and also software compilation of Matlab Simulink ® EMR tool is performed in order to act in the control dsPIC system in real-time operating mode. in the software.

EMR and SMC descriptions are presented on figure 4
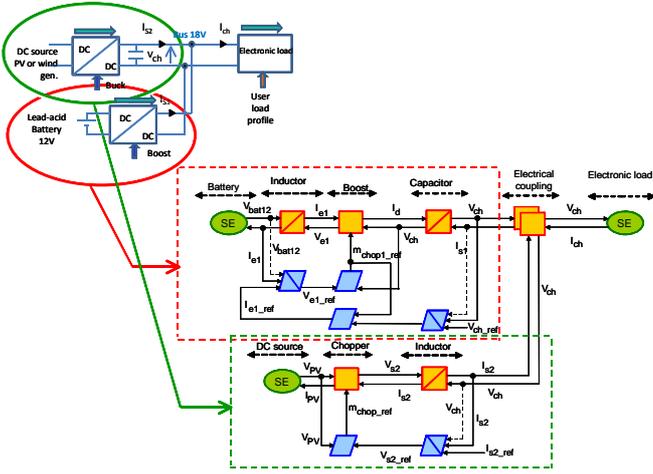
Fig. 4. EMR symbolic representation

Figure 4 shows the translation between the electric symbolic schema and its EMR symbolic representation. One can observe the energy flows and electric values and the control loops. Implementation of this representation has been made using Matlab-Simulink special graphic library which has been developed in L2EP laboratory in Lille and Femto-St laboratory in Belfort. Simulation has been carried out using a load profile which emulates some load variations with soft rising demand (soft slope) and hard rising demand like starting a motor.

Simulations have been made during a short time (60s) due to limited resources in Ram memory implementation on the dsPIC board for the experimental setup.
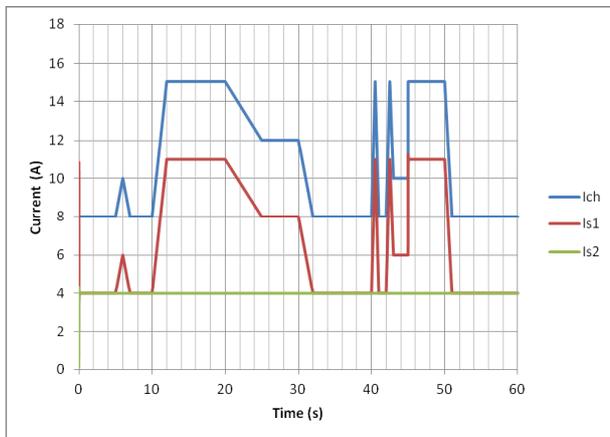
Fig. 5. Simulated currents

One can be shown that current required by the load is provided by the battery assuming the DC source delivers a constant current.

The load current I_{CH} is the sum of the current from the battery I_{S1} and the current I_{S2} from the DC generator (photovoltaic panels or wind turbine).

During these variations of the load corresponding to consumer load switching the bus voltage remain constant as shown on figure 6.
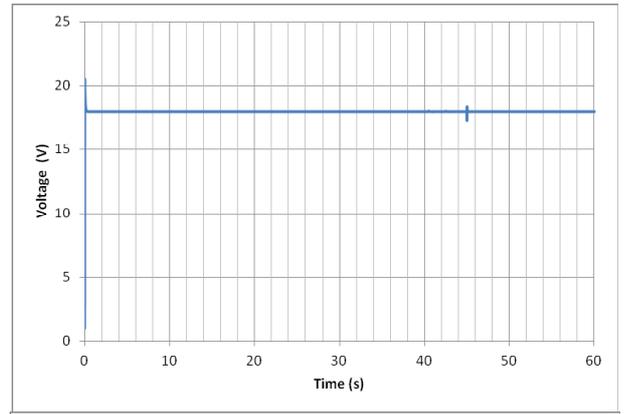
Fig. 6 . Simulated 18V DC bus voltage

IV. EXPERIMENTAL SETUP AND RESULTS.

Figure 7 shows the experimental setup where the main source (PV or windmill generator) are emulated by a programmable DC power supply and the consumers are represented by a programmable electronic load. This figure shows the two converters which use MOSFET switches. Lead-acid battery has been used.
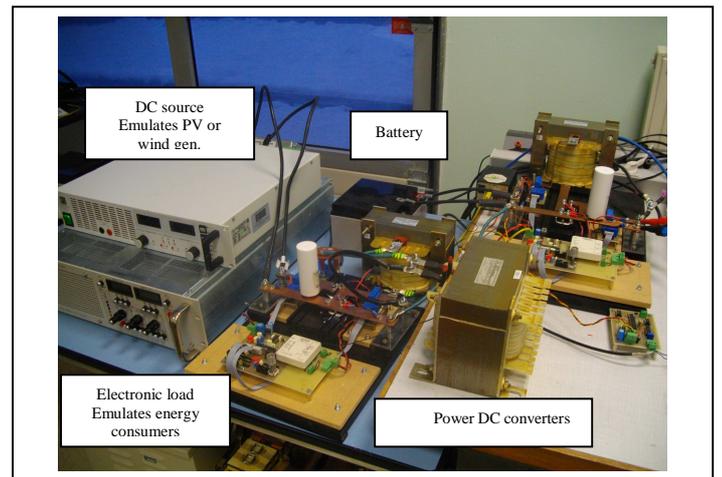
Fig. 7. Experimental setup

One can see on this figure that two DC-DC converters has been used. These converters are classical buck or boost converters designed with MOSFET transistors and ultra-fast recovery diodes.

The principal source (buck in regulation running) is seen like a disturbance from the point of view of the 18V voltage regulation. The goal of this configuration will be to validate the system behavior studied by comparing simulation results with experimental one.

This synoptic of figure 8 shows the methodology used to implement real-time software in the dsPIC control board, from the EMR studied which uses MATLAB-SIMULINK software.
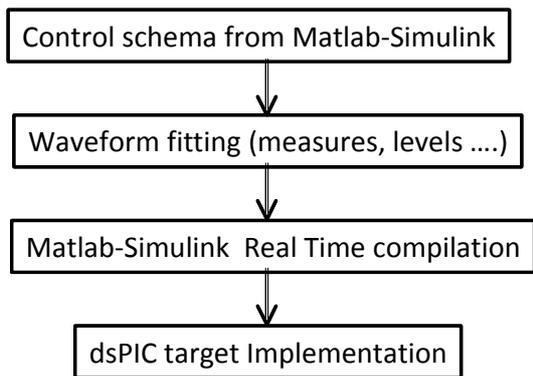
Fig. 8. Synoptic of dsPIC implementation methodology

Moreover in order to pickup the different experimental values (voltage, current) Labview-NI tool has been used.

Current sensors and voltage sensors has been connected between the experimental setup and the PC main controller with Labview interface.
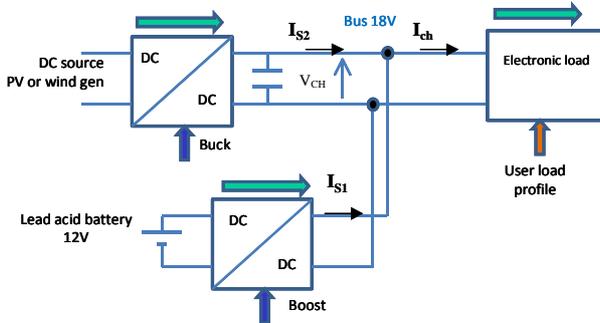
Fig. 9. Final electrical schema with measured values

The objective of this configuration is to validate the regulation of the DC voltage bus via its associated converter and 12V battery, whatever the current required by the load. The results of simulation and experimentation show that the voltage is well controlled whatever current consumption. Moreover simulated and experimental results are very closed.
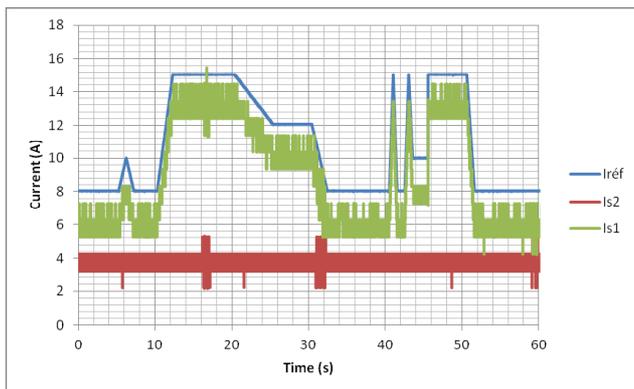
Fig. 10. Experimental currents

Observing experimental results in figure 10, shows that some ringing phenomena occur. These phenomena are really independent from the general behaviour of the system because they are caused by the acquisition system that is not really optimized in terms of EMC environment. A further setup will be more performing with better filtering.

However one can observe that current is reacting very close to the pattern current model that emulates load variations.
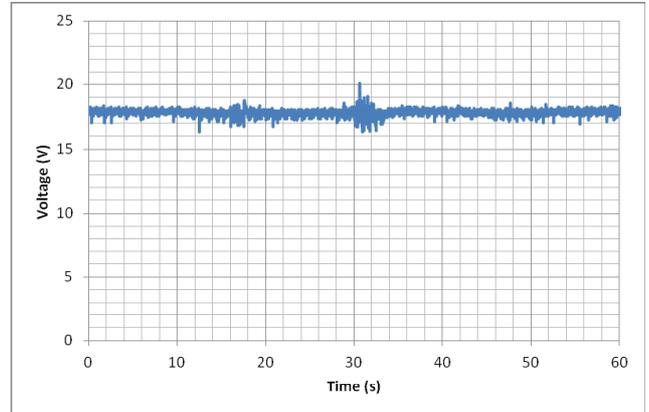
Fig. 11. Experimental DC bus voltage

As current is requested by the load, DC bus voltage is maintained constant at around18V, assuming a very good quality in voltage network.

V. CONCLUSION

The goal of this study is the experimental validation in simulation on a system representative of energy exchanges between 2 different voltage sources. This system is composed of a 12V battery storage system, a main electrical source from renewable energy and a load representing electrical consumers. The results of simulation and the experimentation show that the voltage is well controlled in this configuration and that their evolutions are similar. It is the same for the results for simulation and experimentation on the currents: the different currents change in the same way and correspond to their references.

As a final conclusion, the results obtained in simulation and experimentation on the device are in good agreement. EMR methodology is a good way to analyze energy flow and to define a control strategy which may be implemented in a microcontroller in order to have an efficient control of energy regarding load variations imposed by consumers.

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