

# E.M.R. - An Energy-Flow Based Methodology Dedicated for the Control of Multiphysics Systems.

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Today, more research and development is being conducted related to hybrid systems. In these systems the idea is to manage energy flows between more than two sources of a different nature (electrical, thermal engine, electrochemical source), through complex paths and identifying an efficient control is not an easy task.

## ● The EMR Principle

A few years ago, a French research team from the L2EP (a laboratory from University Lille1, Sciences and Technologies) developed a new methodology. This methodology is based on the analysis and representation of energy flows in complex systems and is called Energetic Macroscopic Representation (EMR). It has been developed to propose a synthetic description of electromechanical conversion systems, but has also been used for other types of conversion systems.

## ● An Application Example

An example of EMR is presented in Fig. 1 (orange elements). It is an elevator (car, passengers and counterweight). Supercapacitors and their power electronics interface are also connected to the main DC bus in order to save energy instead of systematically dissipating it in braking resistors. The green pictograms represent the sources of the system. They can be either generators (upstream source) or receptors (downstream source). The rectangles with an oblique bar describe accumulation elements. These are used to represent components with internal accumulation of energy (inductance, capacitor, inertia, etc...). There, the causality principle between the inputs and the output result in all cases of an integral relation. This is a key point of this methodology. The rectangular elements are conversion elements. They represent an energy conversion without energy accumulation (power converter, gear box, etc...) and they have (eventually) tuning inputs (red pins) to adjust the conversion between input and output variables. Depending on the nature of the conversion (monophysical or multiphysical), they are depicted by square or circular pictograms. In all cases, energy losses can also be included inside each element. At least, the overlapped pictograms represent coupling elements. They allow the representation of energy distribution (parallel connection of electrical branches for example). They do not have any tuning pin. The energy distribution is then only defined by their internal description. All these elements are connected through exchange vectors according to the principle of action and reaction. The scalar product of the action and reaction vectors yields the power exchanged by the connected elements. The analysis of energy flows from one source to another one through various elements is then made accordingly to the respect of energy conservation.

## ● The System Energy Flow Representation

The system control can be deduced from its EMR, by the analysis of a possible tuning path. This path connects the chosen tuning input of the global system to the desired global output of the system. Considering the example in Fig. 1, one of the possible tuning paths is indicated with the superimposed yellow arrow.

An associated control path can then be obtained by inversion of each EMR element within the tuning path: from the reference variable (the desired final output of the tuning path) to the tuning one. It leads to the so-called Inversion Based Control (IBC) of the system. It appears on Fig.1 (blue parallelograms). While the conversion and the distribution pictograms can be inverted directly, please note that the direct inversion of accumulation elements is strictly forbidden, because it will lead to a derivative function. This is the reason why the IBC of an accumulation element must be defined as a controller (PI for example), represented as a blue parallelogram with an oblique bar, to respect the physical integral causality.

Regarding the particular example in Fig.1, the main interest of the IBC is that the main control scheme appears immediately, following a methodological approach with the respect of the physical integral causality. Here, only 4 conventional controllers are needed, which can be designed as usual. This underlines that this system in Fig. 1 has many different couplings. One of them is the DC bus with the voltage  $U_c$ . It is a key node for the energy flows in this system. It appears on the IBC with a distribution element, driven by a distribution factor  $k_w$ . This factor must be adjusted to determine if the supercapacitive accumulator and/or the braking resistors must be enabled, and in which proportion. The distribution factor is a necessary function of the supercapacitors state-of-charge (through their voltage) and of the elevator velocity (this defines its power needs).

This function-named strategy cannot be identified as the other elements of the IBC are. It makes it appear that the main problem for the control of such a system is not linked to the various controllers to implement (the IBC makes the demonstration that they can be designed conventionally), but is linked to the identification of an optimal strategy for the energy management of this elevator. This methodological approach leads to a clear identification of where one must focus their attention during the design of a system control. This is a useful method for all engineers and researchers. This methodology is also well adapted for pedagogical activities. Various research teams currently use this tool for a wide range of applications: wind energy conversion systems, hybrid and electrical vehicles, railways applications, photovoltaic systems, fuel cells, drive paper systems, etc.

More information and references can be found on the dedicated web site <http://emr.univille1.fr>.

If you want to read the complete article please go this address: [http://www.cedrat.com/fileadmin/user\\_upload/cedrat\\_groupe/Publications/Publications/2011/08/EMR-An\\_Energy-Flow\\_Based\\_Methodology\\_Dedicated\\_for\\_the\\_Control\\_of\\_Multiphysics\\_Systems.pdf](http://www.cedrat.com/fileadmin/user_upload/cedrat_groupe/Publications/Publications/2011/08/EMR-An_Energy-Flow_Based_Methodology_Dedicated_for_the_Control_of_Multiphysics_Systems.pdf)



## E.M.R. - An Energy-Flow Based Methodology Dedicated for the Control of ... (continued)

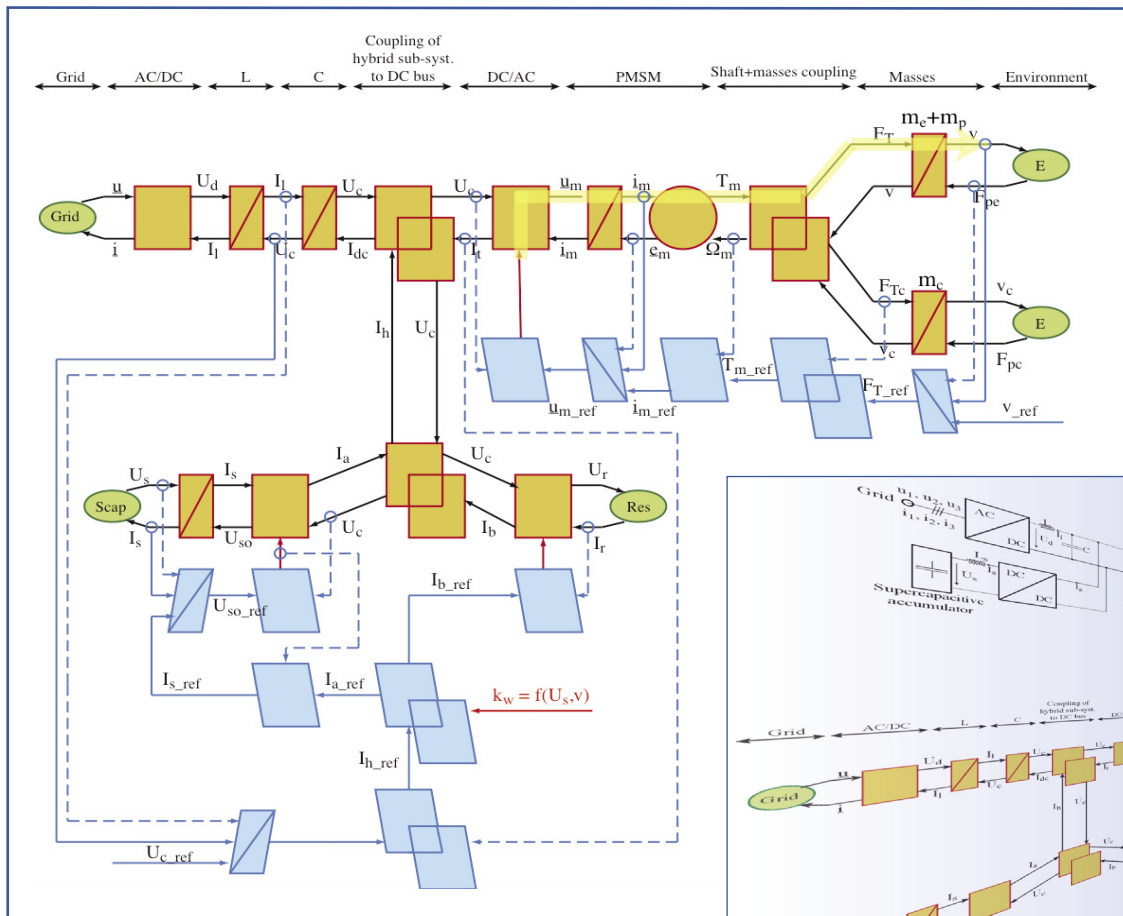


Fig. 1: Energetic Macroscopic Representation and Inversed-Based Control of an elevator with supercapacitors.

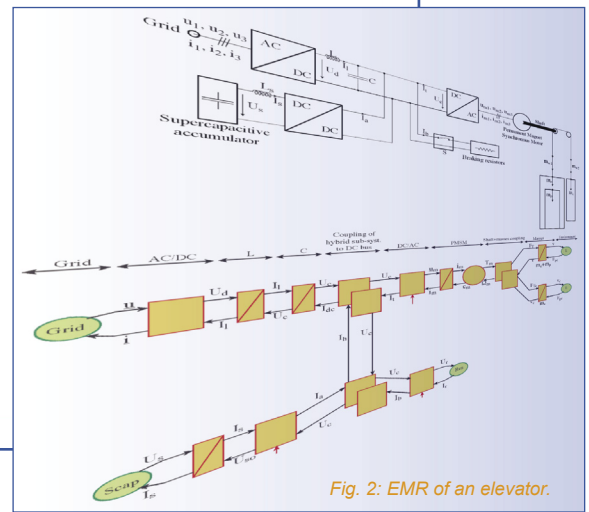


Fig. 2: EMR of an elevator.

## Portunus System Simulator : The Ideal Tool for EMR Simulation.

Thomas Barucki, Adapted Solutions.

In order to apply the EMR method to system designs, you need to use a modern simulation tool. The system simulator Portunus has all the features needed to conveniently utilize the EMR method by simulation. Defining a component model in Portunus is easy, due to the variety of modeling approaches it supports.

Portunus supports the concept of non-conservative and conservative nodes; the first ones for functional representations as block diagrams, the latter ones for structural representations as networks. This makes it easy to describe the hardware systems as they are seen in the real world – by component models and their connections (electrical, mechanical etc.). The control scheme is represented by a signal flow between blocks (same thought process as the control engineer).

You may want to use the modeling language VHDL-AMS for your first modelling choice because you can define the behavior of block diagram or network models by typing in the set of differential equations. The concept of “architectures” as it is used in VHDL-AMS can be helpful as well. It allows for the definition of several equation sets for one model. This means that you can choose between different abstraction levels – simple ones for the first test and more complicated ones for final simulations. Last but not least, VHDL-AMS is a standard specified by IEEE and supported by other simulation systems.

Building a sub-system model in Portunus is an alternative to modeling with VHDL-AMS, especially if the model contains mainly basic elements like gain or integrator. The graphical definition is very straightforward. You can also code more complicated models by using the C++ interface of Portunus which gives you direct access to values of the simulation kernel.

All model types described above may be stored in a Portunus library and used with partners. If necessary, the intellectual properties can be protected by hiding the model text.

Once the system model has been built from component models, simulations may be run in the time or frequency domain. All simulations can be done with parametric studies which are controlled either by the Portunus parameter variation panel or by a script (written by the user). If you choose to use a script, you can also use it to tune the controller parameters. Results can be sent to other programs by a mouse-click or by a script.

Adapted Solutions is currently developing a dedicated library with block diagram models for the IBC design to make EMR system design in Portunus even more convenient. We will publish a notification as soon as it has been completed.

