

# The Use of the CHDN to Model Elevator System Powered by Supercapacitors

M. Chami<sup>\*\\*\*\*</sup>, B. Blunier<sup>\*\*</sup>, A. Djerdir<sup>\*\*</sup>, A. Miraoui<sup>\*\*</sup>, and J. Saadi<sup>\*\*\*</sup>

<sup>\*</sup>SeT, Belfort, France

<sup>\*\*</sup>L2ES, Belfort, France

<sup>\*\*\*</sup>LAP, Casablanca, Morocco

E-mail: mouhcine.chami@utbm.fr

**Abstract** - The Component Hybrid Dynamic Nets CHDN is a graphic model for hybrid dynamic systems. The CHDN allows an individual representation of every component in the hybrid system. On the base of this methodology a software tool dedicated to electrical engineering simulation has been developed. So, the aim of this paper is to present a brief review of the model's structure and to describe the developed software which has been called SimRDH. In order to show the abilities of our tool, an elevator system powered by supercapacitors has been studied. Comparison with SIMPLORER simulations shows very good agreement.

**Keywords**—Elevator; Component Hybrid Dynamic Nets; Supercapacitors; Synchronous motor; power converters.

## I. INTRODUCTION

Hybrid systems are natural models of complex interactive networks such as manufacturing, communication, power, and transportation systems. Hybrid systems are characterized by complex interactions between continuous dynamics and discrete events. Components such as generators, machines and loads have a continuous behavior, while other components such as tap-changing transformers, switched shunts, power switches, and protective devices contains some event-driven behaviors. The Component Hybrid Dynamic Nets is a graphic model for the hybrid dynamic systems [1] [2]. In this model continuous components (resistor, inertia, tanks) or switched ones (transistor, diodes, valves) are explicitly and graphically developed. In this paper, a brief review of this model is given at the beginning of the section II. Thus, the SimRDH software tool based on this model and allowing simulation of electro mechanical hybrid system is presented [3][4]. So, the CHDN model developed for each components of the studied application is well described. Finally, the results of simulation using SimRDH and validated by Simplorer are developed.

The aim of studied application [see Fig.1] is to present how supercapacitors can be used for power smoothing and power restitution in elevator applications [5][6]. Supercapacitors characteristics make them more attractive than batteries to supply transient power demands during acceleration and deceleration.

## II. THE CHDN MODELING AND SIMRDH

### A. General presentation of the CHDN

Component Hybrid of Dynamic Nets (CHDN) is a graphic model allowing a unified representation for each compo-

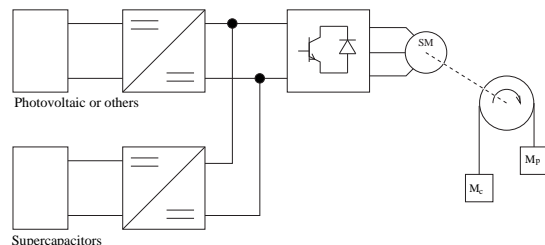


Fig. 1. The modeled device

nent of a system and its structure.

It is composed of two parts described below.

### A.1 CCDN:

Component Continuous Dynamic Nets (CCDN) which allow a representation at the component level of continuous dynamic systems. The CCDN, as Bond Graph [7][8], allows a unified representation of dynamic systems (Electrical, Mechanical, Hydraulic, etc). The CCDN has an analogous presentation of continuous Petri nets [9] (Places - Transitions - weighted arcs) as shown at Fig.2.

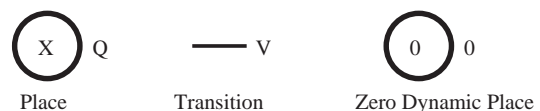


Fig. 2. The nodes of CCDN

- Places: two categories of places exist:
  - dynamic places: to every one of these places is associated a marker representing one of the state variables weighted by a dynamic component of the system,
  - zero dynamic places: for which the marker is always zero (it is a particular case of the previous definition, for which the associated ponderation is equal 0);
- transitions: The transitions are permanently validated; a firing variable is associated to them and can be proportional or independent of the state;
- Weighted arcs: connect the places to the transitions. They are oriented in the direction of the positive flows. The weight of these arcs corresponds either to some constants or to some static components.

In every CCDN scheme as shown on the Fig.2, the global marker of place  $P_i^c$  is called  $M_i$  and it is given as follows:

$$M_i = M(P_i^c) = Q_i \dot{X}_i \quad (1)$$

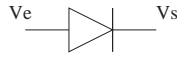
where

$X_i$  : the state variable associated to  $P_i^c$   
 $Q_i$  : the weighting associated to  $P_i^c$

The weight and state variable of zero dynamic place is represented by a zero.

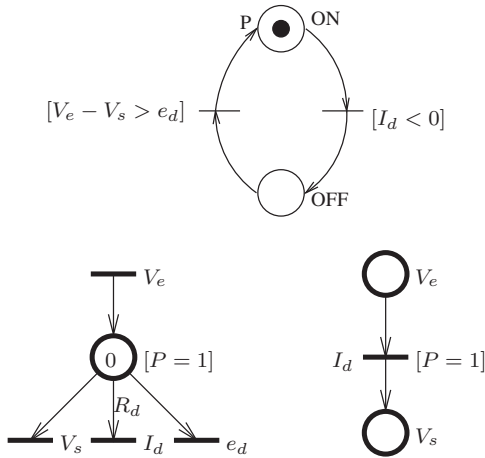
#### A.2 Petri Net:

The discret part of component is modeled by Petri Net with variable topology. The CCDN and Petri Net can influence each other thanks to crossing influence functions. This influence may be applied at the level of the transitions as well as at the null dynamic places. The CHDN model of a diode, shown in Fig.3, illustrates these influences.



$$\begin{aligned} V_e &= V_s + e_d + R_d I_d & \text{if Diode is ON} \\ I_d &= 0 & \text{else} \end{aligned}$$

(3-a)Diagram of a diode and continuous equation



(3-b)CHDN model of Diode

Fig. 3. Diagram and electric model of a diode in conduction

$P$  : number of mark in the place "ON"  
 $[...]$  : condition of crossing influence

If  $P$  is equal to 1, the place and transition in CCDN is valid. The equivalent equation is valid too. The use of CHDN is easy and permits using different level of component. It integrates easily the default of discret component. This model includes a topology representation of the modeled device allowing a direct generation of the system equations

by a simple evaluation of the whole system's places. This approach is original in the simulation of electrical systems. Using this model for simulation is too attractive.

#### B. SimRDH

SimRDH (*SIMulateur à Réseau Dynamique Hybride à composants*) is developed simulation tool for hybrid systems. It is implemented in a Windows environment with the DELPHI programming language [3], [4]. The simulator uses an original approach to generate a global model of the system based on CHDN.

SimRDH attempts to calculate all variable values (state and intermediate variables) of CHDN model. These variables values can be visualized by a specific editor.

SimRDH software may be presented by the bloc diagram given in Fig. 4.

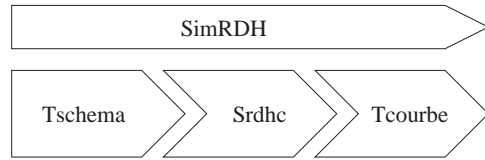


Fig. 4. Bloc diagram of the SimRDH Software

The functionalities of these blocs may be summarized as follows:

- **Tschema**: this module is a graphic user interface which consists of a workspace and block diagram toolbox. Right clicking on an element brings up a pop-up menu with inputs that include the element name and its properties and its CHDN model.
- **Srdhc**: this module tests the switches (Petri Net part of the model) and builds the model of the system corresponding to appropriate configuration. This model is then reduced by elimination of static equations. The optimal form obtained after reduction is then numerically solved by trapezoidal algorithm with a fixed step. The methodology of simulation is shown at Fig.5. The vector  $S$  represents the vector of source (effort and flow). The vector  $I$  represents all validate places variables and transition variables of a global models. It can be written as follows:

$$I = \begin{pmatrix} \dot{X}(t) \\ Z(t) \end{pmatrix} \quad (2)$$

where

$X(t)$  : state variables vector  
 $Z(t)$  : intermediate variables vector

The matrix  $G$  and  $H$  represent the weight  $Q$  associated of all places and the weight of all arcs entering and outgoing of all places.

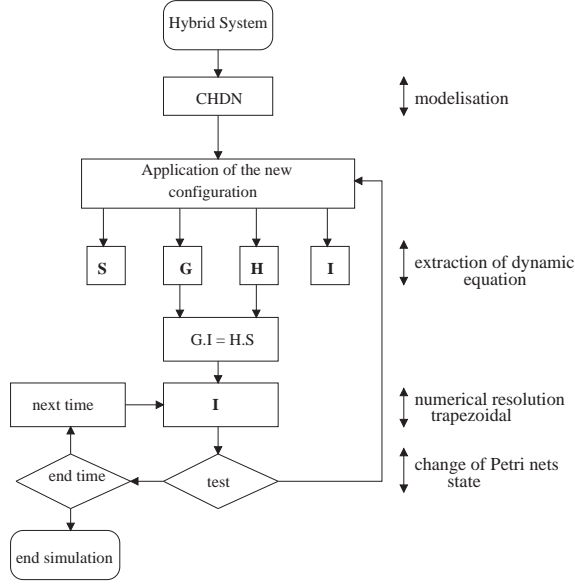


Fig. 5. Flow chart of simulation in SimRDH

• *Tcourbe*: this module allows the user to have a graphic representation of the main variables composing the system. With some functions, such as data points on/off, auto-scale, and a mouse driven zooming feature, user can also select maximal and minimal values for x-axis and y-axis separately. Furthermore data is written to a file in standard ASCII format, and can be plotted by more sophisticated plotters available in other software tools such as Matlab [10].

### III. DESCRIPTION OF THE APPLICATION

Elevators have typical load cycles characterized by a low-energy balance between up and down movements. However, they have a high power demand during acceleration in the up direction, as well as a high power restitution in the down movement, especially during deceleration [11]. On the one hand, the strongly modulated power demand represents an availability problem of the feeding network. On the other hand, the traditionally used braking resistors in the frequency converter of the variable speed drive are the cause of a high amount of wasted energy. Even if the solution using a regenerative rectifier circuit appears as evident for saving energy. However, it has to be noted that such a solution for saving energy does not solve the problem of the high power peaks appearing on the power grid. It does not solve the induced voltage variations or flicker effects either. To solve that particular problem, as well as the difficulties related to the pricing policy of reinjected energy, a solution with energy storage is a good solution. A schematic overview of the drive converter with storage interface is given in Fig.6.

The synchronous motor is supplied with the DC/AC converter presented in Fig.7

The elevator and supercapacitor models are given in section

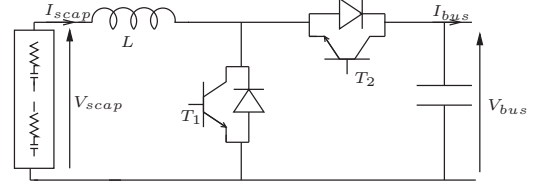


Fig. 6. Supercapacitor boost/buck converter

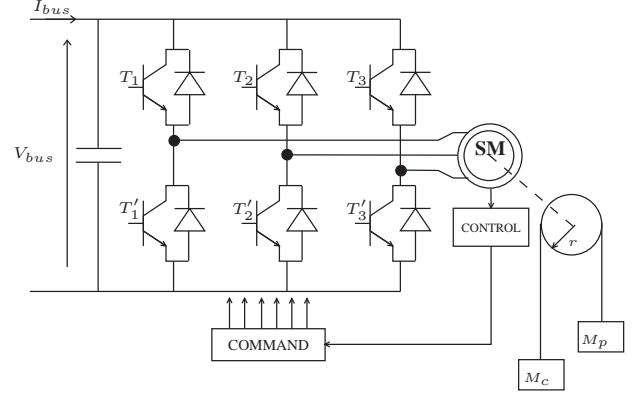


Fig. 7. converter for motorisation system

III-A and III-B respectively.

#### A. Elevator model

The equations below represents the synchronous motor model.

##### 1) Dynamic Equations :

###### (a) Electrical equation:

$$\begin{aligned} L_s \dot{I}_a &= V_a - R_s I_a + K \Omega \sin(\theta_e) \\ L_s \dot{I}_b &= V_b - R_s I_b + K \Omega \sin(\theta_e - 2\pi/3) \\ L_s \dot{I}_c &= V_c - R_s I_c + K \Omega \sin(\theta_e - 4\pi/3) \end{aligned} \quad (3)$$

###### (b) Mechanical equation:

$$\begin{aligned} J \dot{\Omega} &= \Gamma - f \Omega - \Gamma_r \\ \dot{\theta}_e &= p \Omega \end{aligned} \quad (4)$$

###### (c) Electromagnetic torque equation:

$$\begin{aligned} \Gamma &= -K I_a \sin(\theta_e) - K I_b \sin(\theta_e - 2\pi/3) \\ &\quad - K I_c \sin(\theta_e - 4\pi/3) \end{aligned} \quad (5)$$

(d) Resistant torque: By carrying out a forces assessment of the system charges counterweight given in Fig.7, it is

possible to calculate the resistive torque on the shaft of the machine [6]:

$$\Gamma_r = (M_c - M_p)gr + (M_c + M_p)r^2\dot{\Omega} \quad (6)$$

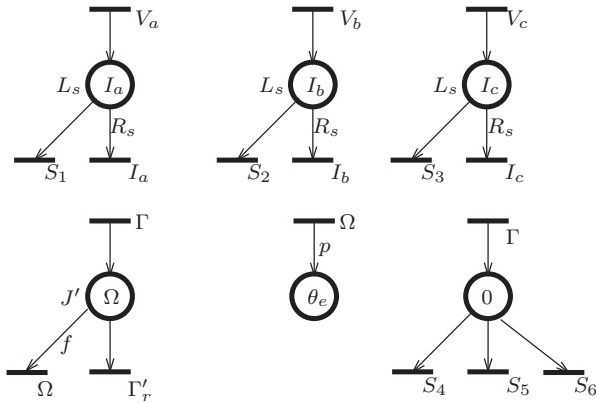
Expressions (4) and (6) give

$$(J + (M_c + M_p)r^2)\dot{\Omega} = \Gamma - f\Omega - (M_c - M_p)gr \quad (7)$$

where

$I_a, I_b, I_c$	: stator currents
$V_a, V_b, V_c$	: stator voltage
$L_s, R_s, J$	: machine parameters
$f$	: mechanical friction
$\Omega$	: rotor speed
$\theta_e$	: electrical angle of rotor
$\Gamma$	: electromagnetic torque
$\Gamma_r$	: resistance torque
$M_c$	: mass of load
$M_p$	: counterweight
$g$	: gravity acceleration
$r$	: radius of the pulley
$\dot{X}$	: derivative of $X$

2) CHDN model: the equivalent representation of equation (3)(5)and (7)using CHDN models are given bellow :



where

$$\begin{aligned} S_1 &= -K\Omega \sin(\theta_e) \\ S_2 &= -K\Omega \sin(\theta_e - 2\pi/3) \\ S_3 &= -K\Omega \sin(\theta_e - 4\pi/3) \\ S_4 &= -K I_a \sin(\theta_e) \\ S_5 &= -K I_b \sin(\theta_e - 2\pi/3) \\ S_6 &= -K I_c \sin(\theta_e - 4\pi/3) \\ J' &= J + (M_c + M_p)r^2 \\ \Gamma_r' &= (M_c - M_p)gr \end{aligned}$$

## B. Supercapacitors model

The complete supercapacitors model [12] presented in Fig.8 is not necessary to implement every time in simulations. Some assumptions may be made according to the needs of applications. Indeed, leakage inductances  $L$  and resistor  $R_f$ , the slow branch effect ( $R_2$  et  $C_2$ ) may be neglected in the case of elevator applications. So, this approximation is acceptable for charge-discharge cycles frequency varying from 1 Hz to 100 kHz. Thus, the supercapacitor element is assimilated to an ideal capacitor connected in series with the resistors  $R_1$ .

A new model is useful for most of the studies and developments on the application side. Such a model used in simulation is presented in Fig.9.

The capacitance of the supercapacitor is not constant. It can be modeled as follows :  $C_1 = C_0 + \underbrace{C_v \cdot U}_{C_u}$

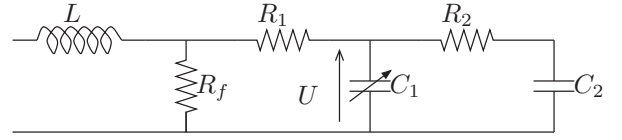


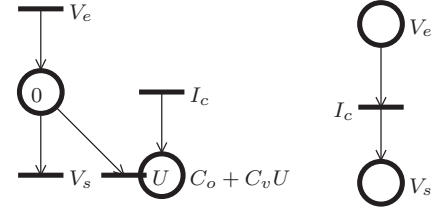
Fig. 8. three branches model of supercapacitor

$$v_e \left| \left( \leftarrow v_s \right. \right.$$

$$I_c = (C_0 + C_v U) \frac{dU}{dt}$$

$$U = V_e - V_s$$

(9-a)Diagram of supercapacitor and the mathematical equation



(9-b)Model of dynamic part

Fig. 9. CHDN model of supercapacitor

## IV. SIMULATION WITH SIMRDH

In order to show the abilities of our software, we use it in simulation of the different operating mode of the modeled device (Fig.1). The simulation is done for an elevator with a car weight of 630 kg, balanced with a counterweight of 350 kg. The others characteristics are given in the Table I. In the next subsections, we expose the simulation representing the elevator in the up/down courses.

### A. Elevator simulation

1) Circuit presentation: a DC/AC converter is used to supply the synchronous machine as shown in Fig.10. A PI

Parameters	Value
Speed (up/down)	1.0 m/s
Acceleration (maximal)	$0.8 \text{ m.s}^{-2}$
Travel height	$20 \text{ m @ } 1.0 \text{ m.s}^{-1}$
Radius of the pulley ( $r$ )	0.1 m

TABLE I  
ELEVATOR CHARACTERISTIC

controller is used to control the speed. The command signal delivered by this controller is injected in the command bloc. The motor is loaded at start time with :

$$(M_c - M_p)gr \approx 309 \text{ N.m.}$$

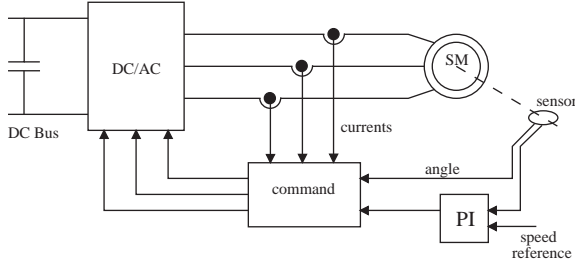


Fig. 10. SimRDH circuit description

The whole application is simulated using SimRDH software tool. Parameters of synchronous motor are given in Table.II.

Parameters	Value
$L_s$ (Stator cyclic inductance)	2.0 mH
$R_s$ (Resistance)	$0.02 \Omega$
$K$ (EMF constant)	$5.318 \text{ V.rad}^{-1}.\text{s}^{-1}$
$J$ (Inertia)	$0.9 \text{ Kg.m}^2$
$p$ (Number of poles)	5

TABLE II  
PARAMETERS OF SYNCHRONOUS MOTOR

2) Simulation results and validations: Figure 11 gives the actual and reference speed of rotor and the three phases currents of synchronous motor.

### B. Supercapacitor – DC bus simulation

1) Circuit presentation: The supercapacitors are connected to the DC Bus via a 2-cadrant DC/DC converter, as shown in Fig. 12. A PI controller is used to control the DC Bus voltage. The command signal delivered by the hysteresis applied on the gates of the two transistors  $T_1$  and  $T_2$ .

2) Simulation results and validations: Figure 13 presents simulation responses in the two phases charge discharge

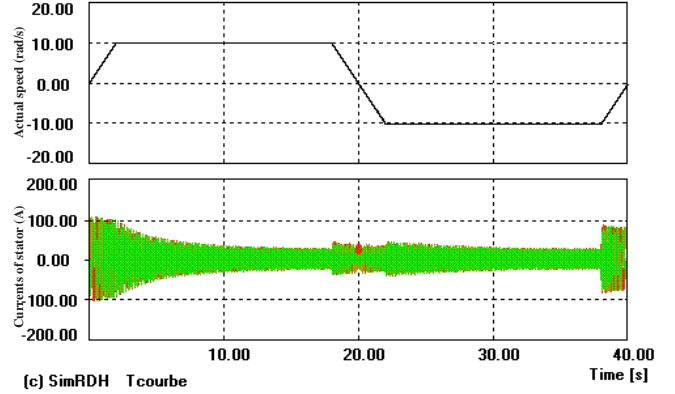


Fig. 11. SimRDH results simulation

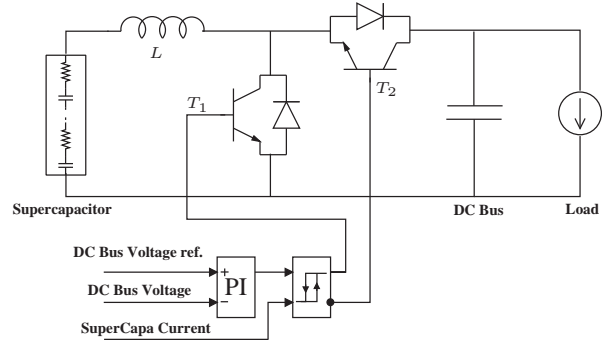


Fig. 12. SimRDH circuit description

cycle of supercapacitors corresponding of the down/up courses of the elevator. It shows that the supercapacitors compensate the load current and take the DC Bus voltage constant.

It may be clearly seen that the supercapacitor ensures well the current reversibility. The difference of initial and final charge of supercapacitor is due to the circuit losses.

## V. CONCLUSION

We have proposed, throughout this work, a new tool of modelling and simulation for the hybrid systems. This tool allows a representation of every component of the system, either continuous or discrete. SimRDH is a general simulation tool for electromechanical hybrid systems; it permits several level of precision in the simulation also to integrate defaults on components. In this paper we prove that this tool can be easily used to simulate electromechanical systems. An application to permanent magnet synchronous motor feed by a converter using supercapacitor pack was studied showing the autonomy of the pure electrical run-

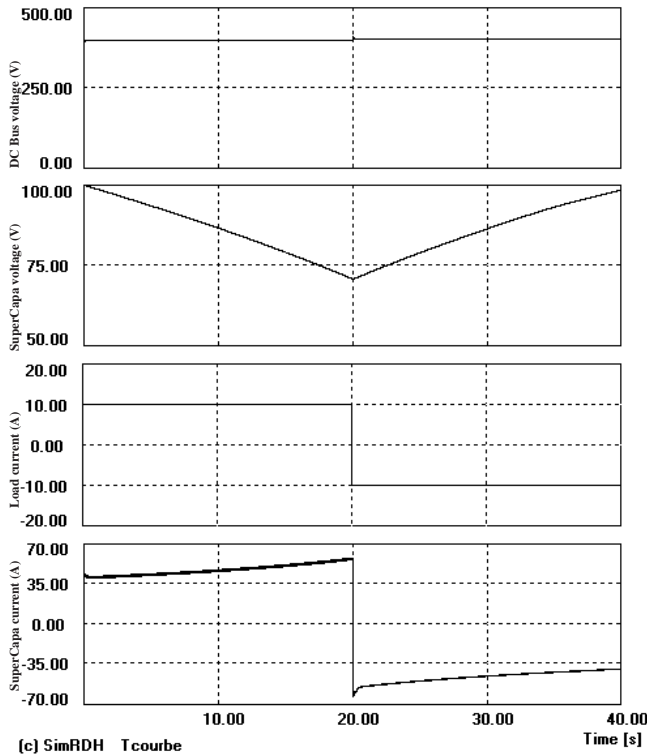


Fig. 13. SimRDH results simulation

ning mode of the elevator.

## REFERENCES

- [1] J. Saadi. *Diagnostic et modélisation de défauts au sein d'une association convertisseur - machine*. PhD thesis, Mohamed V University, Casablanca, Morocco, 1994.
- [2] J. Saadi, T. Bennani, and H. Alla. Component hybrid dynamic nets. In *IFAC/IFIP Conference on Management and Control of Production and Logistics*, pages 211–216, Septembre 1997.
- [3] M. Chami and J. Saadi. Logiciel de simulation des convertisseurs statiques sans a priori. In *CD ROM Proceedings of the Fourth International Conference on Applied Mathematics and Engineering Sciences (CIMASI 2002)*, Casablanca, Morocco, Octobre 2002.
- [4] M. Chami, A. Djerdir, J. Saadi, and A. Miraoui. The use of the CHDN to model a permanent magnet synchronous motor powered by ultracapacitors : Electrical vehicle application. In *CD ROM Symposium IEEE Vehicle Power and Propulsion*, Paris, France, Octobre 2004.
- [5] A. Rufer and P. Barrade. A supercapacitor-based energy-storage system for elevators with soft commutated interface. *IEEE transactions on industry applications*, 38(5):1151–1159, Sesp./Oct. 2002.
- [6] B. Blunier, A. Djerdir, and A. Miraoui. Modélisation et simulation d'un ascenseur entraîné par une machine synchrone à aimants permanents alimentée par un banc de supercondensateurs. In *Conférence Nationale sur le Génie Electrique*, pages 179–184, Tiaret, Algeria, 2004.
- [7] P. C. Breedveld. Multibond graph elements in physical systems theory. *Journal of Franklin Institute*, 1:1–36, January/February 1985.
- [8] P. J. Mosterman, J. O. Campbell, A. J. Broderon, and J. R. Bourne. Design and implementation of an electronics laboratory simulator. *IEEE Transactions on Education*, 39(3):309–313, August 1996.
- [9] R. David and H. Alla. Continuous petri nets. In *CD ROM 8th European conference on theory and application of Petri nets*, pages 275–294, Saragossa, Espagne, June 1987.
- [10] B. R. Hunt, R. L. Lipsman, and Jonathan M. Rosenberg. *A Guide to MATLAB: for Beginners and Experienced Users*. Cambridge University Press, October 2001.
- [11] A. Kulkarni, H. Nguyen, and E. Gaudet. A comparative evaluation of line regenerative and non regenerative vector controlled drives for ac gearless elevator. In *CD ROM IEEE-IAS Annu. Meeting*, Rome, Italy, 2000.
- [12] L. Zubieta and R. Bonert. Characterization of double-layer capacitors (dlcs) for power electronics applications. *Industry Applications Conference, Thirty-Third IAS Annual Meeting. The 1998 IEEE*, 2:1149–1154, 1998.