Monitoring of the systems modelled by bond graphs multi-energies

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Abstract

This work consists of a representation of the systems thermofluides by the approach of the bond graphs multi-energies. In fact, we go even a possibility of checking the property structural of monitorability of all the components bond graph, directly starting from the model bond graph multi-energies, without the need for generating analytical relations of redundancies or any other numerical calculation.

Key words: *Bond graph, multi-energy Bond graph, causality, multi-causality, multigraphe, Monitoring ability , operation of coupling*

1. Introduction

The bond graph (bg) methodology is widely presented for modelling the purpose, but only few papers deals with monitoring of the systems using the bond graph tool.

Tagina exposed in [16] a method which produces analytical redundancy relations (ARRs) directly from the bond graph modelling.

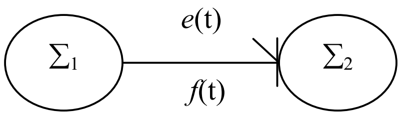
A RRA is a relationship between a set of known variables (of the measured or deduced variables). This determination of analytical relations of redundancies is based on the analysis of the causal path. The innovative interest is the use of only one representation (the bond graph) for modelling and monitoring the system.

In this article, we develop this method in the case of the non linear multi-energy systems.

After having defined the methodology of the bond graphs mono-energies in the second section, we will see the generalisation of the bond graphs multi-energies in the third section. The fourth section is devoted to the study of the monitoring ability of all the components in the general case by using the multi-energies bond graphs by introduction of the theory of the multigraphes. We finish finally by a conclusion.

2. Bond graph

Bond graph introduced by Payter [7][4][5], is a graphical Language indicated especially for the description of the various processes. It models the transfers (exchanges) of energy by a network of bonds of powers called bonds. A bond is a feature (bond) whose end is an half-arrow. The direction of the half-arrow indicates the direction of the power whereas the entities *e(t)* and *f(t)* related to the bonds are the effort and flow. The phenomena of dissipation of energy, storage and inertia are represented in bondgraph and independently of their physical nature, by the elements *R, C* and *I* They are dependent between them by junctions " 0 " when they are subjected to the same effort and by junctions " 1 " when they are subjected the same flow.



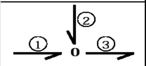
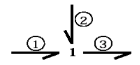
When two systems are in interaction, Σ_1 apply to Σ_2 a " effort " *e(t)*. Σ_2 reacts by sending to Σ_1 a " flow " *f(t)*. The effort imposed by Σ_1 is a data for Σ_2 .

The relations of cause for purpose within the system are highlighted by the causal feature placed perpendicular to the bond. The feature indicates by defect the direction in which the effort is known. The concept of causality in bond graph makes it possible to solve the algorithmic level of modelling

2.1. Basic Elements of the Bond graph tool

The bond graph language is a graphic language conceived specifically for the description of the processes which operate energy. A graphic notation is necessary in order to provide a concise description of the whole process on a level of abstraction higher than the equations describing the transfers of energy between the elements. Moreover, the bonds graphs also accentuate the structure of the model, making a layout between the model and the rather intuitive system.

The elements constituting the bond graph language are represented with their constitutive relations in the table below:

Symbol	Definition	Name
Se $\xrightarrow[f]{e}$	$e = e(t)$	Source of effort
Sf $\xrightarrow[f]{e}$	$f = f(t)$	Source of flow
$\xrightarrow[f]{e}$ **R**	$\Phi_R(e, f) = 0$	Resistance
$\xrightarrow[f]{e}$ **C**	$\Phi_C(e, q) = 0$ $\Phi_C(e, \int f(t)dt = 0$	Capacitance
$\xrightarrow[f]{e}$ **I**	$\Phi_I(f, p) = 0$ $\Phi I(f, \int e(t)dt = 0$	Inertance
$\xrightarrow{①}$ **TF :1/m** $\xrightarrow{②}$	$e_1 = m.e_2$ $f_2 = m.f_1$	Transformer
$\xrightarrow{①}$ **GY : r** $\xrightarrow{②}$	$e_1 = r.f_2$ $e_2 = r.f_1$	Gyrator
	$f_1 + f_2 - f_3 = 0$ $e_1 = e_2 = e_3$	Common effort junction
	$e_1 + e_2 - e_3 = 0$ $f_1 = f_2 = f_3$	Common flow junction

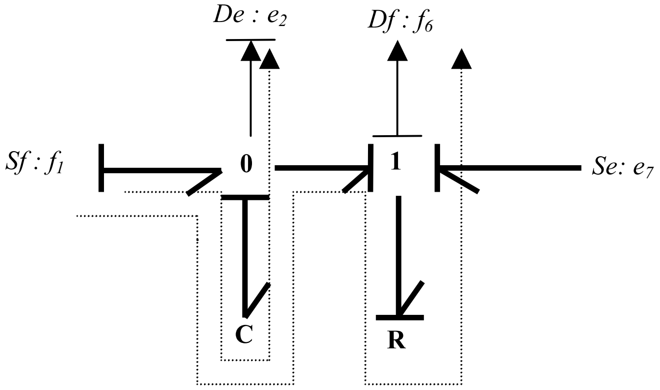
The bond graph is a graph in which causal loops and causal ways, traversed are defined while following the propagation of information effort or flow, and this whatever the direction of the half-arrows.

2.2. Definitions

Definition 1. (causal path). A causal path is an alternation of elements and bonds such two bonds adjacent at the same top have one opposite causal orientation The variable followed along the way is is the effort or flow. In order to change variable, one could pass by a passive element *GY* or a passive element (I, C or R)

Let us consider the example of the bond graph according to where *Sf* and are indicated respectively sources of flow and effort and *De* and *Df* are detectors of effort and flow. The causal ways are given by:

Sf: f_1	**De:e_2**	1 – 2 – C – 2 – 3
Sf: f_1	**Df:f_6**	1 – 2 – C – 2 – 4 – 6 – R – 6 –5
Se: e_7	**De:e_2**	7 – 6 – R – 6 – 4 – 2 – C – 2 – 3
Se: e_7	**Df:f_6**	7 – 6 – R – 6 – 4 – 5

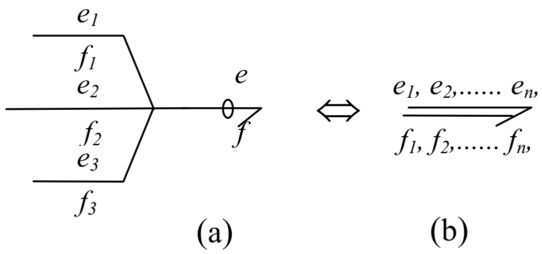


Chemin causal dans le cas d'un bond graph mono-énergie

Definition 2. (generalised causal path) a generalised causal way is a causal path which can follow bonds of energy or signals of information, or both. The generalised causal way is clean if it contains only bonds of energies, it is known as unsuitable if it contains in the last a bond of information.

3. Modelling by the Bond graphs multi-energies

The technological processes are characterised by the interaction of multiple phenomena, like thermals, hydraulics and chemical. These three forms of powers are represented by a bond (and only one), which will at the same time carry information on three energies. This is called *bond with coupled energy* and all the system will be called *bond graph with coupled energy.* The coupling of these three energies is represented by a bond surrounded by a ring as indicated on (a) or by a double feature (b) like indicated on the following figure:



(a) (b)

Multi- énergies bond graphs représentation

The thermodynamic system is one of other systems, which simultaneously require the intervention of several kinds of energies. These systems are in the majority of times being very sensitive to the failures and which should be supervised and controlled as for the case of the systems mono-energies.

3.1. Monitorability study in the multi-energies case

Observability and controllability analysis of physical processes in linear case using bond graph mono-energy methodology are developed in [14]. By using the approach of the bond graphs, it is possible to determine directly on the model bond graph if the elements are monitorables or not, without the need for generating analytical relations of redundancies or then determination of the vectors of signatures.

Some proposals were given in of the mono-energies bond-graphs case [18] [17], other extensions in the case of the multi-energies bond-graphs, but only for the monitoring of the sources of control[9].

Definition 3. A variable is monitorable iff it is possible to detect and to isolate all the faults that may affect it.

We give a proposition given in [23] for monitoring ability of sensors:

Proposition 1: If the number of sensors is higher than 1, then all sensors are monitorable. Indeed, if *n* is the sensors number, then it comes that there are *n* independent ARRs.

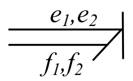
We present also a proposal given in [9] and [17] for the monitoring of the sources of control of the systems modelled by linearized bond graphs multi energies by using the courses of the causal ways generalised [12].

Proposition 2: Two control sources S_j and S_i in thermodynamic linearised bond graph model are not monitorables iff: (a) the covered of generalised causal path linking the source S_j to any sensor D_l contains the covered causal path from the source S_i to the same sensor D_l, (b) the causal path between elements S_j-D_l that are not listed in S_i-D_l did not mentioned in any causal path or loop when the causal path is removed from the monitored bond graph.

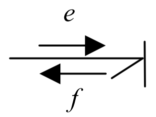
Before carrying out the monitoring in the multi-energies case, we initially will present the generalisation of causality in this same case

3.2. Multi-energy causality *(multi-causality)*

A multi-energy bond graph is represented by:

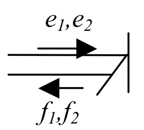


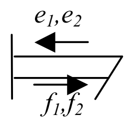
we know according to the definition of causality that the causal feature follows by default the direction where the effort is known



But, when we generalise, (case of 2-energies), we are face to two cases:

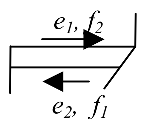
a)

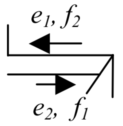




The first case where all the efforts follow the same direction, the concept of causality does not change it stills the same one as in the mono-energy case;

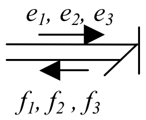
b)





However, when at least one of the effort has a direction opposed to that of the other efforts, the causal feature in this case will be cut into two, one indicating the direction of the first efforts and the other, it indicates the direction of the other remaining efforts. Consequently, in both cases of figures, we will be face to 2 distinct causal ways.

Now let us see the case of 3 energies:



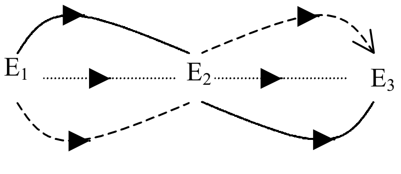
If all *the* e_i $i = 1$ *to* 3 have the same direction, we return to the case (a), on the other hand when a some number of e_j $j \neq i$ has a direction opposed to that of the other e_i, case similar to (b), the causal feature is also cut out into two.

In fact, if the efforts do not have all the same direction, the causal feature will be always cut into two. That is due to the fact that we have always two variables of power e_i and f_i for each kind of energy E_I

Causality multi-energies leads us to introduce a new concept, that of the multi-links between the various components of the bond graph and that because of the multi-causal ways which exist between elements.

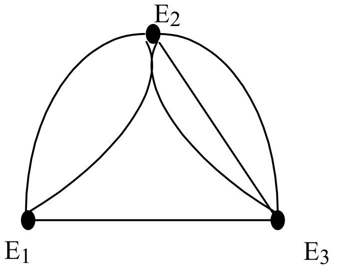
3.3. Multigraphs

Knowing that the causal ways follow the direction of the causal feature, it comes that to pass from any element bond-graph to another, we can follow various distinct ways, this leads us to introduce the concept of multi-graph MG = (NR, A) where the unit NR is a set of the nodes which represent the bondgraph elements, and A the set of the arcs which represent the causal paths or rather links binding these elements.



Definition4 A multigraph represents is a graph in which several edges are allowed between two nodes of this graph ([5], [4], [14], [22], [21])

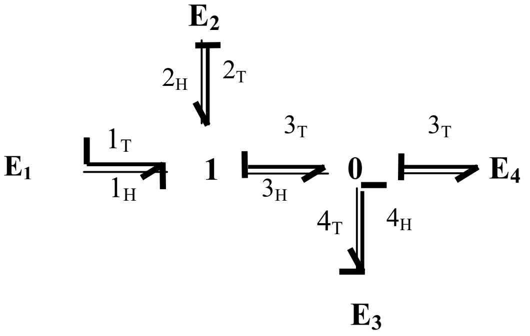
Some authors require that the multigraphes do not have any loop ([5], [4], [22]), some allow them explicitly ([6], [16]) but of others do not include not clarified ([14], [4])



***Definition* 5:** A multigraph is a graph whose edges are not ordered pairs of nodes, and the same pair of nodes can be connected by multiple edges.

3.4. Case of the bond graphs multi-energies

We illustrate this part by a small example. Consider the following bond graph 2-energies hydraulic and thermal:

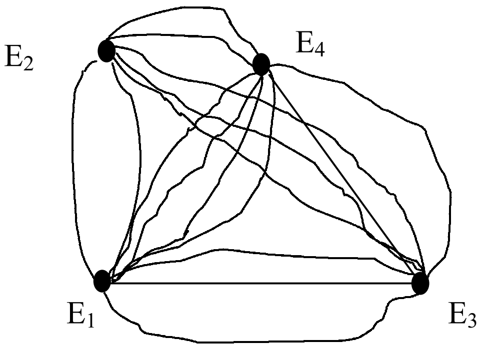


If we list some ways binding the elements two by two:

(E1,E2)={(E1,1T,1,2T,0,3T,E4,3T,0,3H,1,2H,E2),
(E1,1H,1,2H,E2),...}
(E1,E3)={(E1,1H,1,2H,E2,2H,1,2T,0,4H,E3),(E1,1T,1,2T,
0,3T,E4,3T,0,4T,E3),
(E1,1H,1,2H,E2,2H,1,2T,0,3T,E4,3T,0,4T,E3),
....}
(E1,E4) = { (E1,1H,1,2H,E2,2H,1,2T,0, 3T,E4),
(E1,1T,1,2T,0,3T,E4),
(E1,1H,1,2H,E2,2H,1,2T,0,3T,E4),
(E1,1T,1,2T,0,4H,E3,4T,0,3T,E4),...}
(E2,E3) = { (E2,2H,1,2T,0,4H,E3), (E2,
E2,2H,1,2T,0,3T,E4,3T,0,4T,E3),
(E2,2H,1,3H,0,4H,E3), ..}

(E2,E4) = { (E2,2H,1,2T,0,3T,E4),
(E2,2H,1,3H,0,4H,E3,4H,0,3T,E4),...}
(E4,E3) = { (E4,3T,0,4T,E3),
(E4,3T,0,2T,1,2H,E2,2H,1,3H,0,4H,E3)}

Without continuing the remainder of the possible ways and if we constitute the graph corresponding, we see clearly that we obtain well a multigraph

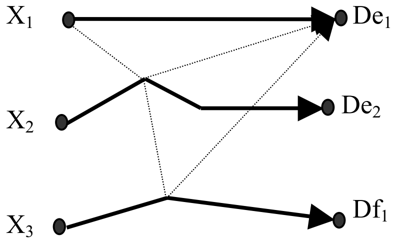


So we can use the theory of the multi graphs in the study of the bond-graphs multi-energies.

4. Study of the monitoring ability of the components in the multi-energies case

Using bond graph approach, it is possible to determine directly from bond graph model if elements to be monitored are monitorable with any need to generate the Analytical Relations of Redundancy (ARRs) or the signature faults.
In a way similar to proposal 3 giving higher, we give the next proposition which makes it possible to confirm if any element of a bond graph multi-energy model is monitorable or not:
Proposition3: Two elements E_j and E_i in a thermodynamic linearized bondgraph model are monitorables iff: (a) the generalised causal path linking a source S_l to the element E_j does not contain any causal way generalised from the same source S_l to element E_i; (b) the generalised causal way linking the element E_j to any detector D_l does not contain the causal way from the element E_i towards the same detector D_l
This proposition is in fact an interpretation of the existence of a relation of coupling between the elements bond graph to be monitoring and the detectors.

We can rewrite this proposition in this different form:
***Proposition* 4** So that a system is monitorable, it would be necessary that: (a) all the components of the model bond graph of this system are related to at least a detector, (b) there exists a coupling between the set of the variables to be monitoring (unknown) and the set of the detectors.
We can illustrate that for the following example:
Example 2:



We present in what follows, an additional proposal which makes it possible to affirm if a system multi-energy is monitorable or not**.**

Proposition 5 a multi-energies system is monitorable iff: (a) it is observable (all its variables are related to the detectors by at least a causal path), (b) for both variables of the schedule of conditions, the row of the matrix obtained after concatenation of the matrices of observability (because case multi) corresponding to the variables considered, that is full. The variables are taken two by two.

If all the matrixes obtained are of full row, we can say that the system does not present a problem of localisation of failure (or faults). Otherwise, if the row of one of the matrices is not full, that means that the two variables in question have not disjoined ways. Consequently, it is not possible to monitor them. In this case, our system presents a problem of monitoring.

As remedy for this kind of problem is to add an additional detector binding one of the two variables.

5. Conclusion

The methodology of the bond graphs is essentially used for the modelling of the systems, few work which approached the monitoring of the complex systems by using the bond graph tool. Our work consisted in presenting an effective method of monitoring of the thermodynamic systems complexes directly on the bond graph multi-energies model by course of the multi-causal ways.

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