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Robust Supervision of Industrials Systems by Bond Graph and External Models

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ABSTRACT

This paper considers the Robust Supervision of Industrial Systems (RSIS) by bond graph (BG) and external models (EM). The bond graph is used for the detection and isolation of fault affecting sensors, actuators or physical components of the process. The external models structure the industrial process, according to several modes of operation (degraded and normal). The switching from one operated mode to another mode is described by a graph called management mode operation graph. It represents the man-machine interface system. The logic functions are controlled by the availability of services and therefore the state of technological components. Thus, the availability of services (necessary for conducting a mission) will be provided by the monitoring algorithm based on BG at management operation graph. The combined representation BG-EM as behavioral and functional modeling for Robust Supervision system design is applied to a three tank system.

Keywords: Robust supervision, Industrials systems, Bond graph, External models.

I. INTRODUCTION

Recently, industrial systems are being increasingly complex in response to technological advancement. Consequently, it becomes imperative to introduce new supervision models adapted to technological systems, with the aim to ensure their normal operation and reaction in of a failure case. Therefore, the fault detection; diagnosis and reconfiguration algorithms are needed to provide operators sufficient criteria for decision [1] and [2].

Two kinds of information are considered for the reliability and availability of technological processes. The first one concerns the Fault Detection and Isolation (FDI) and the second indicates the possibility continuing controlling the process in the normal or degraded operation (Fault Tolerant Control (FTC) : accommodation or reconfiguration). From the industrial point of view, the supervision GUI (Graphical User Interface) is seen in terms of functions based on algorithms model (analytical or expert). The functional models describe the system, without taking into account the physical components and dynamic behavior. In the present from the industrial point of view, the supervision GUI (Graphical User Interface) is seen in terms of functions based on algorithms model (analytical or expert). The functional models describe the system, without taking into account the physical components and dynamic behavior. In the present paper, it will be shown, how the bond graph (because of its graphical, structural and causal properties) methodology can be used as complimentary tool for obtaining both the behavioural and the diagnostic models. The supervision of uncertain systems has been the subject of several research works in recent years [3].

Dauphin-Tangy and al [4] are proposed two methods for modelling uncertainties by using bond graph approach. The first method is based on describing parameter uncertainties as bond graph elements, and the second method introduces the LFT form (Linear Fractional Transformation) for uncertainties modelling. The innovative interest of the present paper is the use of the bond graph tool for modelling and robust fault supervision, taking into account the parameter uncertainties. In this way, by applying the bond graph methodology using LFT model, it becomes possible to obtain physical knowledge of the systems and to improve their monitoring by deducing residuals fault indicators and consequently, to insure the best safety able to detect and to isolate imperfections. This paper is organized as follows: Section 2 deals with in the first part of this paper, we present the robust supervision system based on bond graph and external model. In the second part, the developed methodology is applied to a real hydraulic system.

II. SUPERVISION MODELLING

A. Bond graph Model

An industrial process has a highly complex behaviour because of the mutual interaction of several phenomena that implement different kind of energy (mechanical, electrical, hydraulics, thermodynamics, chemical, etc.). So the bond graph is an excellent tool to model these systems. It has been defined by Henry Paynter 1961 [5], subsequently developed by Karnopp in 1975 [6] and Rosenberg in 1983 [7]. The bond graph explicitly displays the power system phenomena such as storage, transformation and dissipation energy [8] and [9].

The concept of power P(t) is described by the following equation:

$$P(t) = e(t).\ f(t) \tag{1}$$

Where e(t) and f(t) are the effort and the flow respectively. This equation illustrates the energy transfer in the system using power links. A link power is symbolized by a half-arrow, whose orientation indicates the direction of power transfer. Thus, the figure 1 shows the power transfer from subsystem A to subsystem B.

Fig.1. BG power transfer

This tool is largely used in different fields to solve various kinds of problem such as structured analysis, control problem and monitoring [10] and [11].

B. FDI System by Bond graph

A method to generate FDI algorithms by BG based on causal path is proposed by [12]. The objective is to explore all paths at the junction of sources and sensors. The methodology is then extended by [13] [14] to design a supervision system, as showed in figure 2.

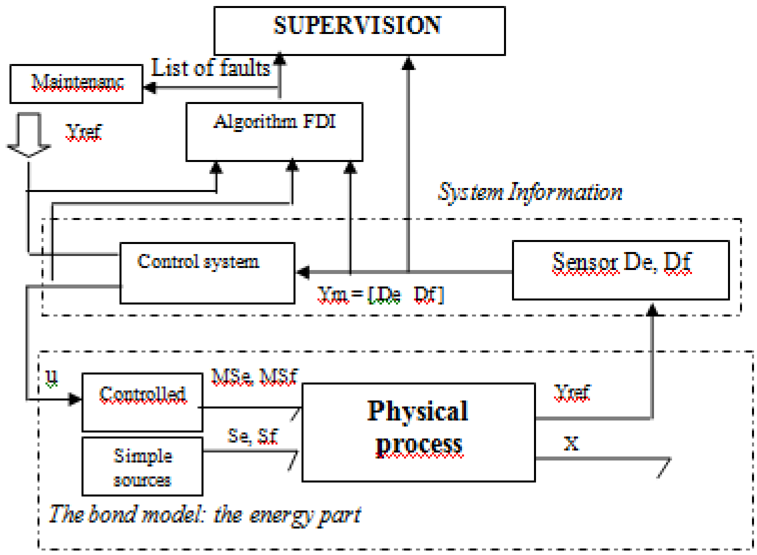

Fig.2. Band graph representation of a system of supervision

Consider a system which is described by a set of constraints S represented by (2):

$$S = f\,(F, Z, \theta) \tag{2}$$

Where F: system model, Z: set of variables, θ set of parameters.

The relationship between the system model F and the variables Z, leads to a bipartite graph which form a matrix linking the known variables, the unknown variables and constraints. The Analytical Redundancy Relationship (ARR) is a relationship between the known variables. This relation is determined from the bond graph model in the form:

$$f\,(K) = (D_e, D_f, S_e, Sf, MS_e, MS_f, \theta) \tag{3}$$

where

- D_e, D_f are effort and flow sensors.
- S_e, and Sf are effort and flow sources.

- MS_e and MS_f are modulated effort and flow sources,
- θ represent a set of parameter.

The residual symbolized by R (formed by evaluation of each ARR) can be written as the following form:

$$R - f(K) = 0 \tag{4}$$

K is the set of known variables (sources and measured values given by detectors). The coherence of each residual is tested by using a direct comparison between its value and a threshold.

C. External models

The industrial systems consist of a set of equipment interconnected with each other. A hardware failure of one or more of these elements can venture conducting a portion of the objectives for which the system was designed, and then it should prevent users by generating alarms. The latter must be sufficiently synthetic to express clearly to the operator the nature of failure and its consequences. The external model which is proposed by [15] is considered here. This model is based on the notions of services, missions and operating modes.

1) Services

The industrial systems consist of a set of equipment (heat exchanger, engine pump…), which are organized so that systems can achieve the objectives for which they were designed:

a) The low level: These are basic services; they are directly interfaced with the process (pumps, valves, sensors…).
b) The high level: These are compounds services; they are composed by basic services (cooling, unit auxiliary water…).

2) Missions

The basic services (low level) are associated with each other to define compounds services and they realize a mission. A hardware failure means the unavailability of some basic services and may call the continuation of certain missions.

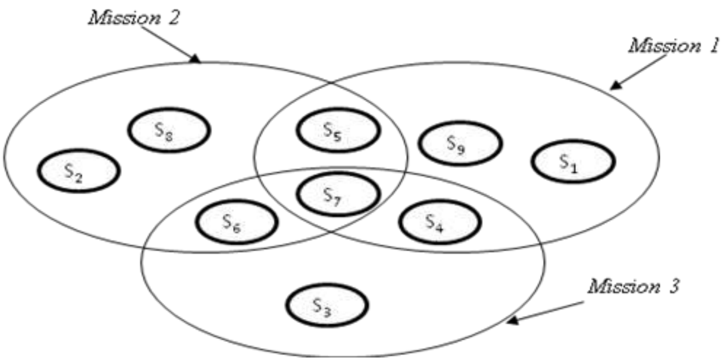

Fig.3. Services and missions

S_i: service i

- **Mission 1**: S_1, S_4, S_5, S_7, S_9
- **Mission 2**: S_2, S_5, S_6, S_7, S_8
- **Mission 3**: S_3, S_4, S_6, S_7

Each mission has a lot of services. And, we can find the same service in the different mission. For example, the service S_7 is found in three missions.

3) Operating modes

The missions lead and manage the systems in accordance with the specifications. But at a given moment, only a subset of these missions is necessary to meet the targets. Each of these sub-systems is called an operating mode. An operating mode (OM_i) is a set of services represented by the following relationship:

$$OM_i = (S_1, S_2, \ldots S_n) \tag{5}$$

4) Management modes graph

The operating modes are connected to execute what we call management modes graph. The demand for change from one mode to another mode must be shown for security reasons because the system can fail on an operating mode OMj when some services are not available. The switching is represented by a boolean variable bij. The set of operating modes and the switching conditions bij are described by a graph named User Operating Mode Management (UOMM) in figure 4.

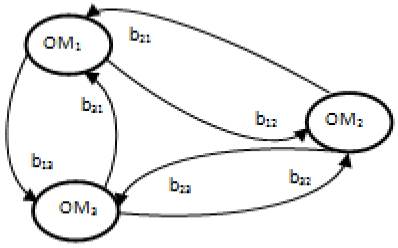

Fig.4. User operating mode management

D. Bond Graph and External Models

The use of BG and external model as a combined approach to supervise a process is proposed by [16].

1) Meaning services and missions using the bond graph

The services as defined in the external models are represented by bond graph elements. The services offered by energy source equipment (mechanical (engine), thermal (heat resistance, potential or kinetic energy of a fluid) and water (pump)) are represented by sources of effort or flow. The services offered by the functional role of the equipment (store, process, transport, etc.) are represented in the bond graph by R, C, TF and GY elements. It should be noted however that the services in bond graph can be quantified by constituent equations deduced from BG model. The missions represented by services sets are to meet all the objectives set by the specification, and of course they are based on services provided by lower level equipment.

2) Operation Modes by BG model

A system performs a coherent action which is called an operating mode. Each operating mode OM_i corresponds to a bond graph model BGM_i.

III. ROBUST SUPERVISION USING A BOND GRAPH

III. 1. Construction of a bond graph model

Two methods are proposed by G. Dauphin-Tanguy and C. Sie Kam [17] to build parametric uncertainties by BG. The first is to represent uncertainty on bond graph element as another element of the same type, causally related to the nominal element or the rest of the model. These uncertainties are kept in derivative causality when the model is in full preferential causality not change the order of the model. The second method is the LFT form (Linear Fractional Transformations) introduced on mathematical models by R. Redheffer [18].

The multi leaps graphs physical aspect comes from the fact that from any physical system, it is possible to obtain an independent graphical representation of the studied physical realm. Building a bond graph model can be done in three levels:

- The technological level
- The physical level
- The structural and mathematical level

III. 2. Representation LFT

Linear fractional transformations (LFT) are very generic objects used in the modeling of uncertain systems. The universality of LFT is due to the fact that any regular expression can be written in this form after A. Oustaloup. [19] and Alazard D. et al. [20]. This form of representation is used for the synthesis of the control laws of uncertain systems using the principle of the μ-analysis. It consists in separating the nominal part of a model of its uncertain part as shown in figure 5.

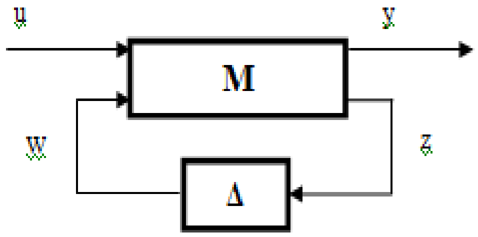

Fig.5. Representation LFT

The ratings are grouped in augmented matrix as M, supposedly clean, and uncertainties whatever their type (parametric structured and unstructured uncertainties, modeling uncertainty, measurement noise ...) are combined in a matrix structure Δ diagonal.

III. 3. Modeling BG elements LFT

Turning the LFT form requires that the model be clean and observable C. Sie Kam. The bond graph methodology allows for manipulation of causal check these properties directly on the bond graph model.

Property 1.1: A bond graph model is proper if and only if it contains no dynamic component derived causality when it is in full preferential causality, and conversely C. Sweat & al. [22].

Property 1.2: A bond graph model is structurally observable in a state if and only if the following conditions are met:

- On the bond graph model integral causality, there is a causal path between all dynamic elements I and C in full or causality De and Df sensors;
- All dynamic components I and C admit a causal derivative on the bond graph model preferred derivative causality. If I or C dynamic elements remain integral causality, dualisation sensors De and Df should help put them in derivative causality.

The modeling of uncertain parameter to linear systems was developed in C. Sie Kam, we invite the reader to view the references for details on the modeling of uncertain BG elements (R, I, C, TF and GY). We therefore limit this part to show the two methods of modeling uncertain BG elements and the advantages of BG-LFT for robust supervision.

III. 3. 1. BG element with multiplicative uncertainty

The introduction of a multiplicative uncertainty on e.g. element R in causality gives resistance:

$$e_R = R_n(1+\delta_R)f_R = R_n f_R + \delta_R R_n f_R = e_n + e_n + \delta_R e_n = e_n + e_{inc} \quad (6)$$

With:

- R_n : The nominal value of the element R;
- δ_R : The multiplicative uncertainty parameter;
- e_R et f_R : Represent respectively the effort and the flow in the element R ;
- e_n et e_{inc} : Respectively represent the effort made by the nominal setting and effort introduced by the additive uncertainty.

Unlike the force introduced by an additive uncertainty with respect to the parameter (equation (6)), the force provided by a multiplicative uncertainty (equation (6)) is a function of the force provided by the nominal parameter. This is an important property for the parametric identification step and the supervision step.

III. 3. 1. 1. Resistive element with a multiplicative uncertainty

The bond graph model equivalent mathematical model of equation (6) is given in figure 6.

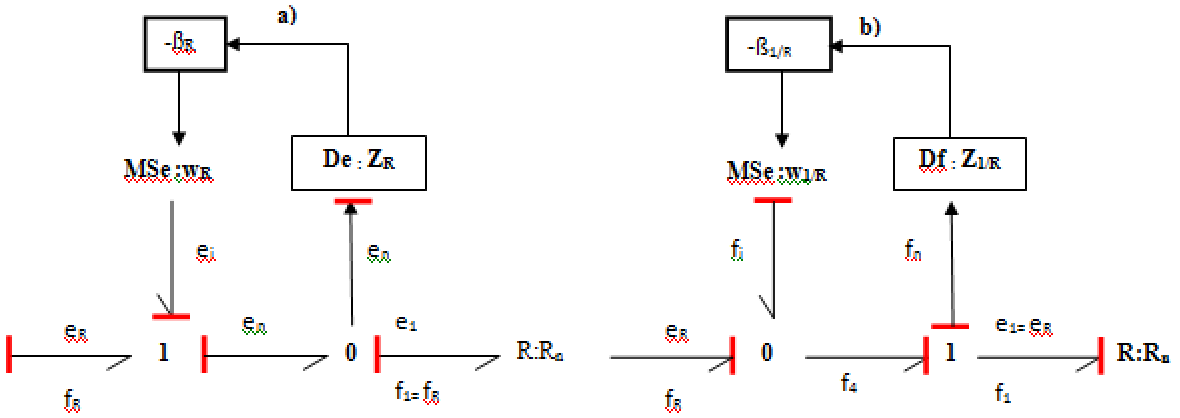

Fig.6. a) BG-LFT model of an element resistance with multiplicative uncertainty, b) BG-LFT model of an element conductance with multiplicative uncertainty.

III. 3. 1. 2. The storage element of uncertainty with a multiplicative

- Parts I and C in derivative causality

The bond graph model equivalent mathematical model of equation (6) is given by the figures 7. a) and 7. b).

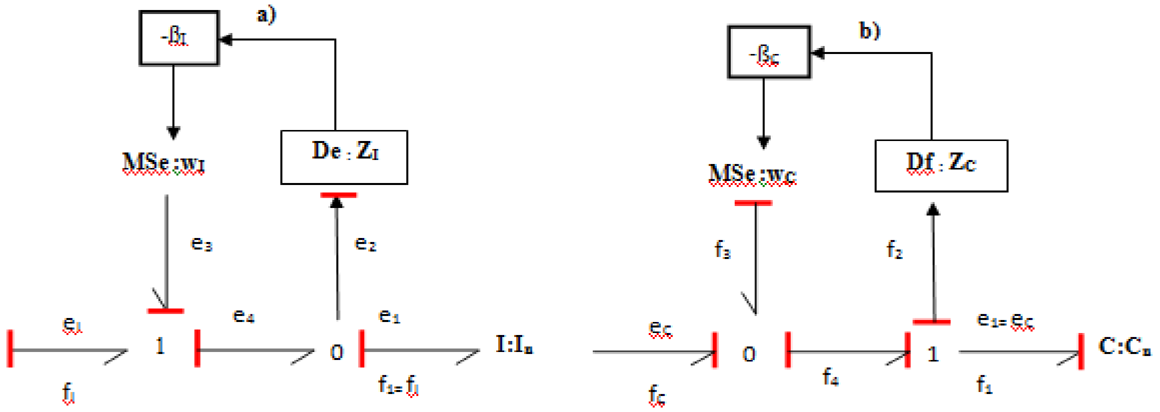

Fig.7. a) BG-LFT model of an element I preferred in derivative causality, b) BG-LFT model of an element C preferred derivative causality.

III. 4. Construction of a model BG-LFT

Full BG-LFT can then be represented by the diagram in figure 8.

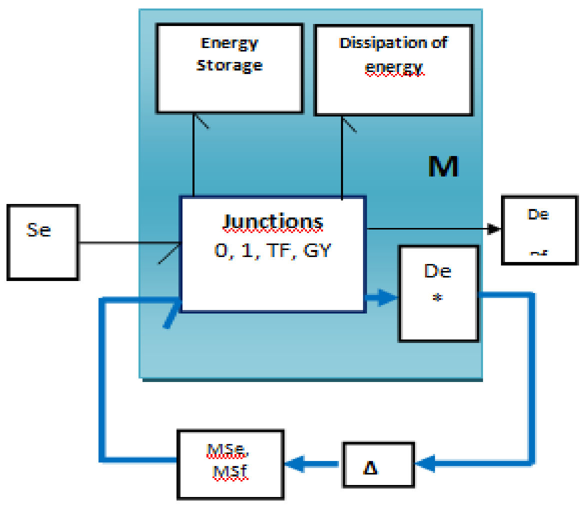

Figure.8. Representation of a BG-LFT

III. 5. Generate robust residuals

The generation of robust analytical redundancy relations from a clean bond graph model, observable and over determined is summarized by the following steps:

1st step: Checking the status of the coupling on bond graph deterministic model derived preferential causality; if the system is over determined, then continue the following steps;
2nd step: The bond graph model is made into LFT;
3rd step: The symbolic expression of the RRA is inferred from equations junctions. This first form will be expressed by:

- For a junction 0:

$$\sum b_i f_{inc} + \sum \dot{Sf} + \sum w_i \qquad (8)$$

- For a junction 1:

$$\sum b_i e_{inc} + \sum \dot{Se} + \sum w_i \qquad (9)$$

With $\sum \dot{Sf}$ the sum of sources flows due to the junction 0, $\sum \dot{Se}$ the sum of the effort sources related to junction 1, b = ± 1 depending on whether the half-arrow into or out of the junction and e_{in} and f_{in} purpose are unknown variables.
4th step: The unknown variables are eliminated by browsing the causal paths between sources and detectors or unknown variables;

5th step: After removing the unknown variables, are uncertain as ARRs (10):

$$RRA : \Phi(\sum \dot{Se}, \sum Sf , De, Df , \tilde{De}, \tilde{Df} , \sum w_i , R_n , I_n , C_n , TF_n , GY_n) \qquad (10)$$

- TF_n and GY_n are nominal data elements and modules, respectively TF and GY .
- R_n, C_n and I_n are nominal data elements R, C and I.
- $\sum \dot{w}_i$ is the sum of modulated inputs corresponding to uncertainties on the junction-related items.

IV. HYDRAULIC SYSTEM BY BOND GRAPH MODELLING

The considered system is the hydraulic system of ACS laboratory depicted in figure 9.

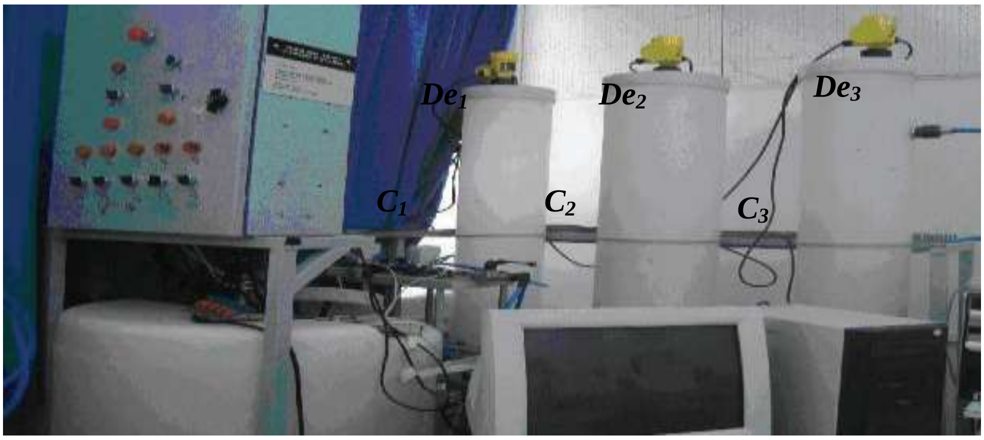

Fig.9. Hydraulic system of ACS laboratory

It is composed by:

- A submerged hydraulic pump feeds the two reservoirs C_1 and C_3;
- Three storage tanks fluid C_1, C_2, C_3;
- Five (ON/OFF) valves Rv_1, Rv_2, Rv_3, Rv_4 and Rv_5;
- Three level sensors De_1, De_2 and De_3 placed respectively above the reservoirs (C_1, C_2 and C_3).

A. Missions and services

A non-exhaustive list of missions and services associated with the hydraulic system is illustrated in table I.

Table II: List of Missions and Services of Hydraulic System

Nb	Missions	BG elements
1	To fill the three tanks C_1, C_2, C_3 with both flow pump	Sf_1, Sf_2, C_1, C_2, C_3, Rv_1, R_2, R_3, R_4, R_5, De_1, De_2 and De_3
2	To fill the three tanks C_1, C_2, C_3 with only flow Pump	Sf_1, C_1, C_2, C_3, Rv_1, Rv_2, Rv_3, Rv_4, Rv_5, De_1, De_2 and De_3
3	To stop the pump and drain the tanks C_1, C_2 and C_3	R_3, R_4 and R_5
4	Maintenance	-

The different operating modes of the process are:

- Normal mode (**OM_1**): The system operates in a normal mode (missions 1, 2, 3 and 4);
- Failed mode (**OM_2**): The system is supplied with only the flow pump **Sf_1** (missions 2, 3, and 4);
- Stopped mode (**OM_3**): The installation is drained by valves R_3, R_4 and R_5 (emptying the installation) and a set of tests (missions 3 and 4).

Each operating mode (OM_i) is represented by a bond graph model BGM_i, and then there are three models:

- **BGM_1: OM_1** (missions 1, 2, 3, and 4);
- **BGM_2: OM_2** (missions 2, 3, and 4);
- **BGM_3: OM_3** (missions 3 and 4).

The management mode graph of the installation is represented by figure. 10.

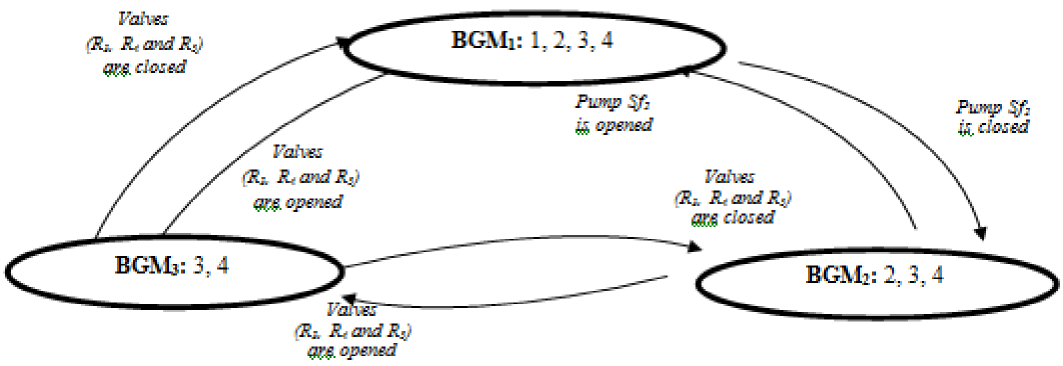

Fig.10. Management mode graph

B. Bond graph model

The both physical quantities characterizing the hydraulic system are the flow and pressure which correspond to the flow and effort in terminology bond graph. Using the bond graph methodology, the various elements of the system are modelled as follows (fig 11.):

- The pump is modelled by a flow source Sf ;
- The tanks are modelled by storage-elements C;
- The valves by restriction-elements R;
- The various connections between components system

are modelled by "0" junctions in the case of equal pressure and "1" junctions in the case of equal flow.

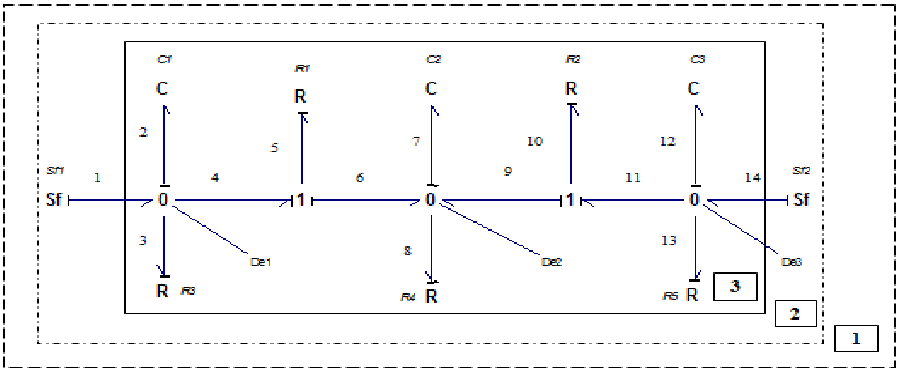

Fig.11. Bond graph model of the hydraulic system in the different modes (1, 2 and 3)

C. FDI by BG modelling

In Table IV, shown below, it is given the structural equations deduced from BG modelling of process (figure 6). By combining the equations presented in table III to eliminate unknown variables, we can generate the set of residuals in which the appeared variables (from sensors actuators) are all known.

Table III: Structural Equations for Normal Mode

N	Junction	Structural equations
1	Junction 0_1	$f_1 - f_2 - f_3 - f_4 = 0$ $e_1 = e_2 = e_3 = e_4 = De_1$
2	Junction 0_2	$f_6 - f_7 + f_8 - f_9 = 0$ $e_6 = e_7 = e_8 = e_9 = De_2$
3	Junction 0_2	$f_{13} - f_{11} - f_{12} - f_{14} = 0;$ $e_{11} = e_{12} = e_{15} = e_{14} = De;$
4	Junction 1_1	$f_3 = f_5 = f_6$; $e_3 - e_5 - e_6 = 0$
5	Junction 1_2	$f_8 = f_{10} = f_{11}$; $e_{11} - e_{10} - e_8 = 0$

For example, the junction 0_1 equation as follows:

$$R_1 = f_1 - f_2 - f_3 - f_4 \quad (6)$$

By replacing the flow f_i by its expression deduced by its behaviour equation (generated from the BG) components, allows to write the residual R_1 as:

$$R_1 = Q_1 - C_1 \frac{dDe_1}{dt} - \frac{De_1}{Rv_3} - \frac{(De_1 - De_2)}{Rv_1} \quad (7)$$

The equation (7) shows the residual r_1 is are sensitive to elements (Q_1, C_1, De_1, De_2, Rv_1 and Rv_3). Consequently, when fault is occurred in each elements described above, the residual becomes different of zero R_1.

The junction 0_2 gives us as equation:

$$R_2 = f_6 - f_7 + f_8 - f_9 \quad (8)$$

According to these relations, one can deduce the residual equation R_2:

$$R_2 = \frac{(De_1 - De_2)}{Rv_1} - C_2 \frac{dDe_2}{dt} + \frac{(De_3 - De_2)}{Rv_2} - \left(\frac{De_3}{Rv_4}\right) \quad (9)$$

The equation (9) shows the residual is sensitive to elements (C_2, De_1, De_2, De_3, R_1, R_2, R_3 and R_4).

The junction 0_3 gives the following equation:

$$R_3 = f_{13} - f_{11} - f_{12} - f_{14} \quad (10)$$

So we can deduct the residual r_3:

$$R_3 = Q_2 - \frac{(De_3 - De_2)}{Rv_2} - C_3 \frac{dDe_3}{dt} - (\frac{De_3}{Rv_5}) \quad (11)$$

The equation (11) shows the residual is sensitive to elements (Q_2, C_3, De_2, De_3, Rv_2 and Rv_5).

The set of residual is grouped in the table IV. We obtain a boolean matrix. The columns are associated to the residuals R_1, R_2 and R_3 and the lines are the boolean signatures of the monitored components.

Table IV: Signatures Faults for Normal Mode

	Q_1	Q_2	C_1	C_2	C_3	Rv_1	Rv_2	Rv_3	Rv_4	Rv_5	De_1	De_2	De_3
R_1	1	0	1	0	0	1	0	1	0	0	1	1	0
R_2	0	0	0	1	0	1	1	0	1	0	1	1	1
R_3	0	1	0	0	1	0	1	0	0	1	0	1	1

The lines of the table below show the sensitivity of each residual for each element. For example, when a fault is occurred in the tank C_1, only the residual R_1 is sensitive.

D. Simulation results

The evolutions of residuals in normal operation mode are presented in figure 12.

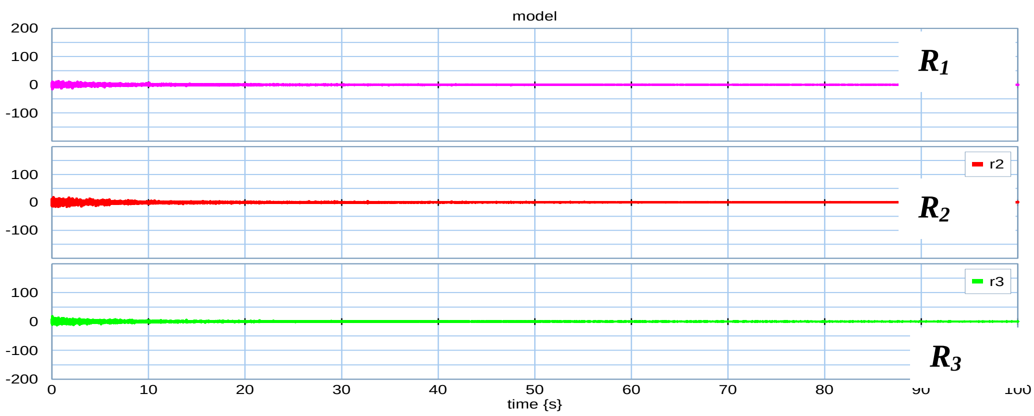

Fig.12. Residuals in normal mode

A fault in the tank C_1 is occurred on the system in the interval time [4s 6s]. Figure 13 shows that the residuals R_1 is sensitive to this fault. So the latter is detected.

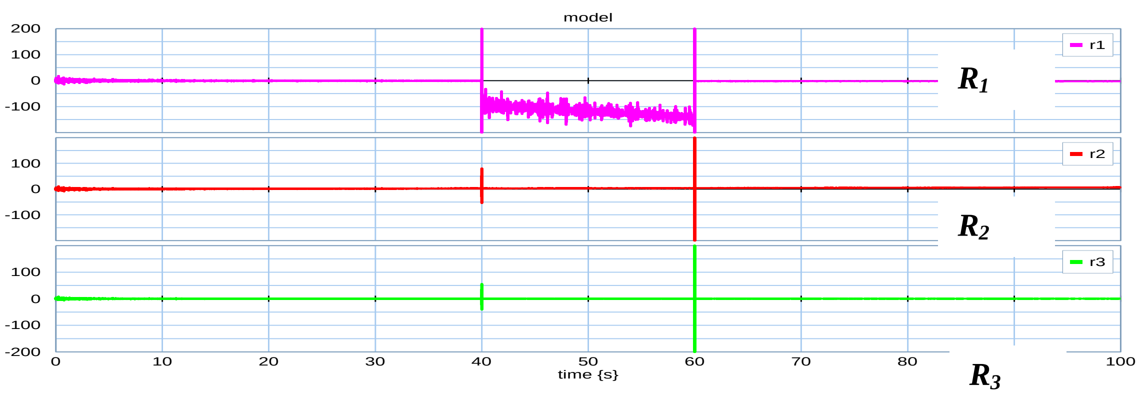

Fig.13. Residuals in anormal mode

E. Decision procedure

We suppose that the system is in the normal operating mode (OM_1). If the tankC_1 is not available because of a fault, only the residual r_1 will be sensitive to this fault. The normal operating mode (OM_1) should be rejected as this service provided by the decision-making procedure is not available. The transition to the reduced operating mode (OM_2) will also be rejected because this service is an element of this operating mode, so the switching to the stop mode (OM_3) is authorized. When the bond graph model of each mode is determined, we will decide to make the reconfiguration of the system at each fault. If there is no fault, the FDI of system is repeated.

F. Supervision BG-LFT

Figure 14 shows the BG-LFT approach hydraulic system with sensors for each junction.

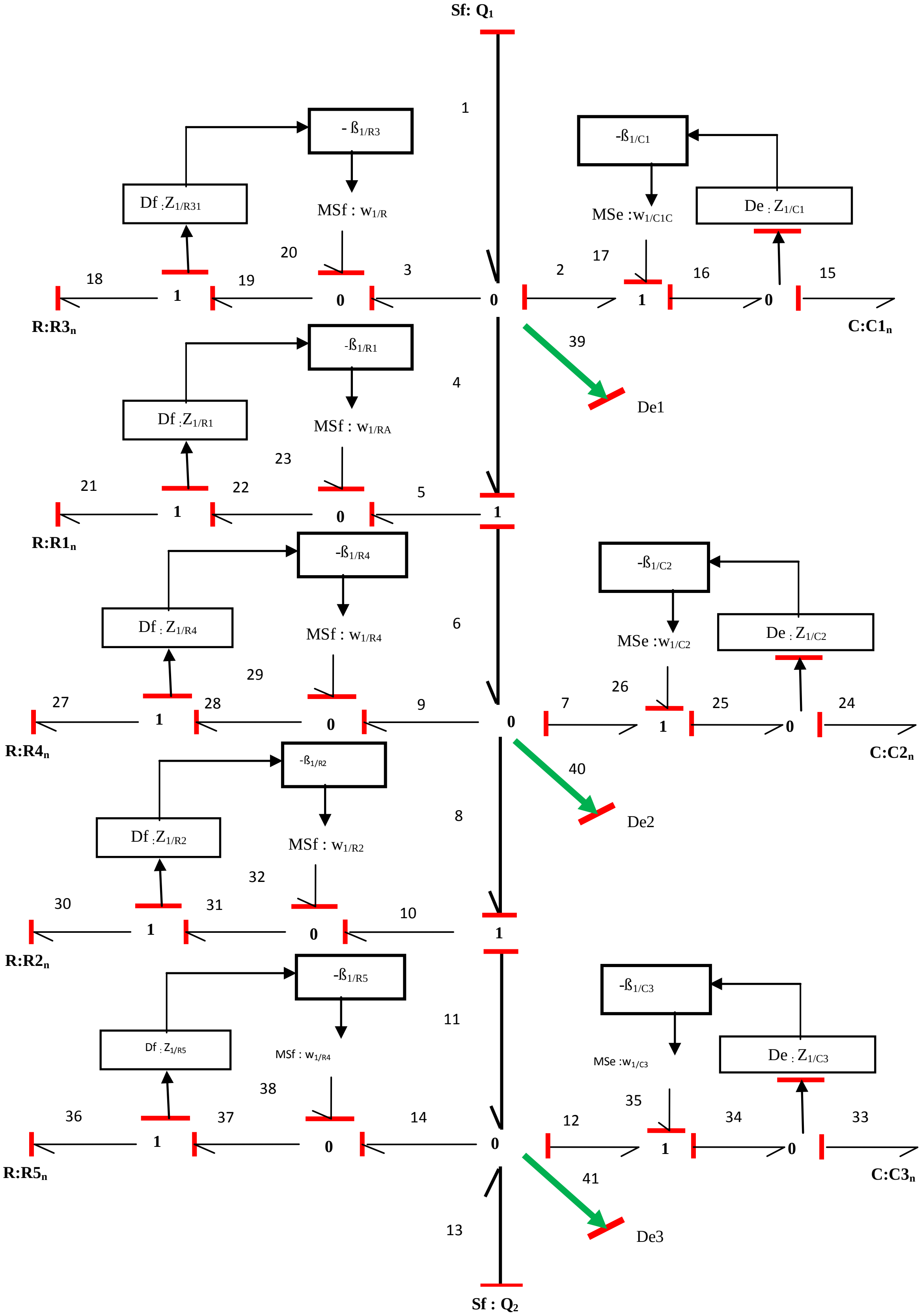

Fig.14. BG-LFT approach hydraulic system with sensors

Figure 15 shows the BG-LFT approach hydraulic system with sensors dualised for each junction.

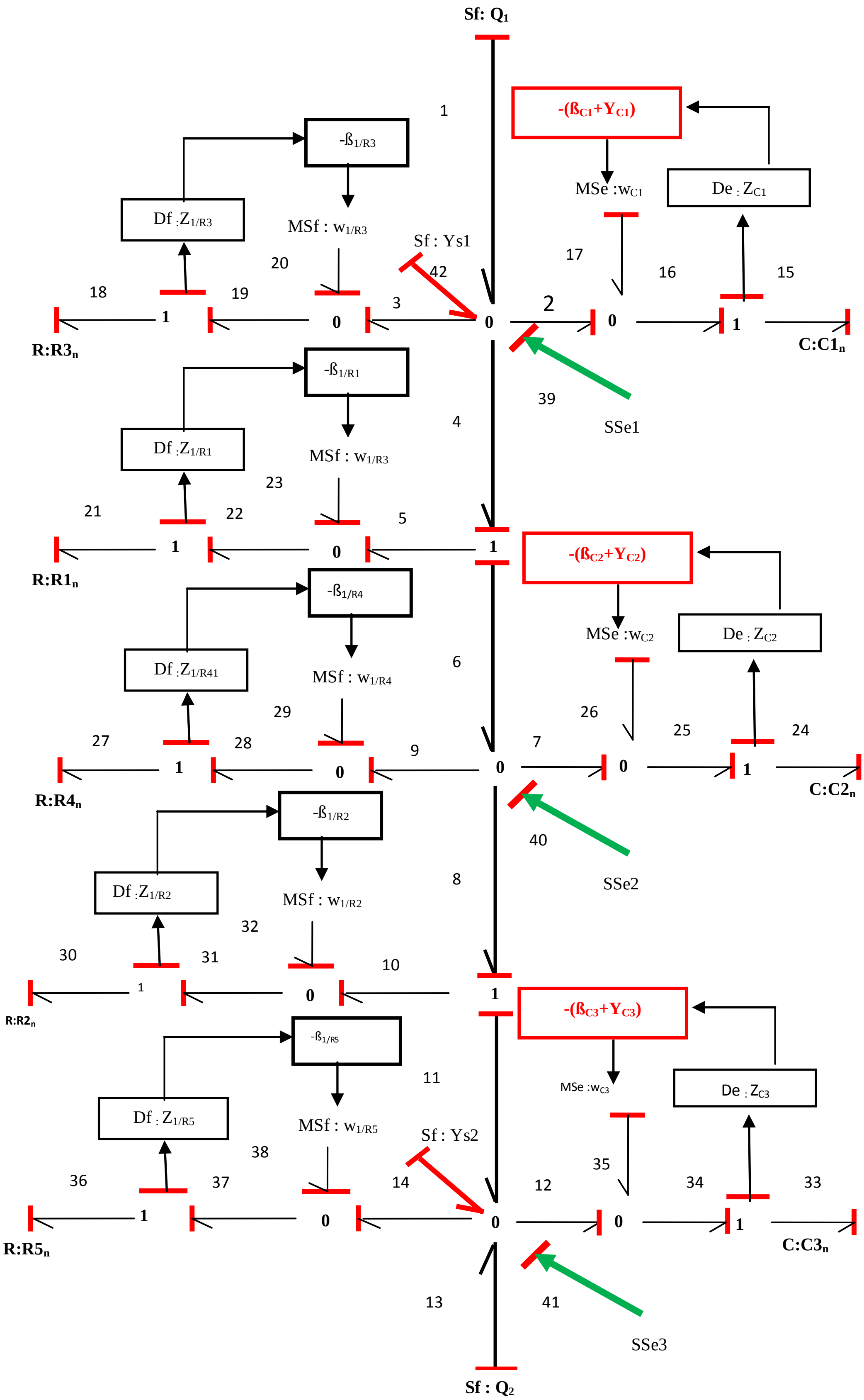

Fig.15. BG-LFT approach hydraulic system with sensors dualised

For example, the junction 0_1 gives us as equation:

$$R_1 = f_1 - f_2 - f_3 - f_4 + Y_{s1} + w_{1/Rv3} + w_{C1} + w_{1/Rv1} \quad (12)$$

According to these relations, one can deduce the residual equation R_1

$$R_1 = Q_1 - C_1 \frac{d\,SS\,e_1}{dt} - \frac{SS\,e_1}{Rv_{3n}} - \frac{(SS\,e_1 - SS\,e_2)}{Rv_{1n}} + Y_{S1} + w_{1/Rv3} + w_{C1} + w_{1/Rv1} \quad (13)$$

The equation consists of two parts: the first part is the normal evolution of the residual r_{1n} and the second part represents the residual uncertainty related to the evolution of the parameters d_1:

$$\begin{cases} R_1 = r_{1n} + d_1 \\ r_{1n} = Q_1 - C_1 \frac{d\,SS\,e_1}{dt} - \frac{SS\,e_1}{Rv_{3n}} - \frac{(SS\,e_1 - SS\,e_2)}{Rv_{1n}} \\ d_1 = Y_{S1} + w_{1/Rv3} + w_{C1} + w_{1/Rv1} \end{cases}$$

The junction 0_2 gives us as equation:

$$Rr_2 = f_6 - f_7 + f_8 - f_9 + w_{1/Rv3} + w_{C1} + w_{1/Rv1} \quad (14)$$

According to these relations, one can deduce the residual equation R_2:

$$R_2 = \frac{(SS\,e_1 - SS\,e_2)}{Rv_1} - C_2 \frac{dSS\,e_2}{dt} + \frac{(SS\,e_3 - SS\,e_2)}{Rv_2} - \left(\frac{SS\,e_3}{Rv_4}\right) + w_{1/Rv4} + w_{C2} + w_{1/Rv2} \quad (15)$$

The equation consists of two parts: the first part is the normal evolution of the residual r_{2n} and the second part represents the residual uncertainty related to the evolution of the parameters d_2:

$$\begin{cases} R_2 = r_{2n} + d_2 \\ r_{2n} = \frac{(SS\,e_1 - SS\,e_2)}{Rv_1} - C_2 \frac{dSS\,e_2}{dt} + \frac{(SS\,e_3 - SS\,e_2)}{Rv_2} - \left(\frac{SS\,e_3}{Rv_4}\right) \\ d_2 = w_{1/Rv4} + w_{C2} + w_{1/Rv2} \end{cases}$$

The equation (15) shows the residual is sensitive to elements (C_2, De_1, De_2, De_3, Rv_1, Rv_2, Rv_3 and Rv_4).

The junction 0_3 gives the following equation:

$$R_3 = f_{13} - f_{11} - f_{12} - f_{14} + Y_{s2} + w_{1/Rv2} + w_{C1} + w_{1/Rv5} \quad (16)$$

So we can deduct the residual R_3:

$$R_3 = Q_2 - \frac{(SS\,e_3 - SS\,e_2)}{Rv_1} - C_3 \frac{dSS\,e_3}{dt} - \left(\frac{SS\,e_3}{Rv_5}\right) + Y_{s2} + w_{1/R2} + w_{C3} + w_{1/R5} \quad (17)$$

The equation consists of two parts: the first part is the normal evolution of the residual r_{3n} and the second part represents the residual uncertainty related to the evolution of the parameters d_3:

$$\begin{cases} R_3 = r_{3n} + d_3 \\ r_{3n} = Q_2 - \frac{(SS\,e_3 - SS\,e_2)}{Rv_1} - C_3 \frac{dSS\,e_3}{dt} - \left(\frac{SS\,e_3}{Rv_5}\right) \\ d_3 = Y_{S2} + w_{1/Rv2} + w_{C3} + w_{1/Rv5} \end{cases}$$

CONCLUSION

The external model based on functional approach decomposes the industrial systems as a set of equipment, which form coherent missions organised as operating mode. The switching from an operating mode to another depends on the services provided by system components. In the present paper, it is shown, how the bond graph as a dynamic and efficient modeling tool (because of its graphical, structural and causal properties) methodology can be used as complimentary tool for obtaining both the behavioral and the diagnostic models. The supervision system design is then formed as a graph where the state represents a bond graph model (in faulty and normal mode) and the switching from one mode to another is controlled by FDI algorithms generated by BG models. The combined BG-EM approach is applied to an hydraulic system.

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