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Bond Graph Modeling, Design and Safety of the Hydrodynamics Variable Speed

Abd Essalam Badoud *, Mabrouk Khemliche
Automatic Laboratory of Setif, Electrical engineering department, University of setif 1
Maabouda city, ALGERIA

Abstract:
Hydrodynamic couplers are often assigned to a group of their own research in the classification of couplings. This is justified by the particular operating principle of hydrodynamic power transmission. The transformation between the form of mechanical energy and hydropower offers various possibilities to vary the transmission power according to precise laws. The main idea to understand and study the dynamics of real systems is the modeling. The models are simplified and abstract constructs used to predict the real behavior. We proposed to use not the bond graph approach like the single tool responsible for modeling, as that is classically proposed in the literature, but like a mechanism complementary to enrichment. With this work, we helped to develop a platform for modeling of a hydrodynamic variable speed transmission able to model its bodies and to simulate and analyze its total behavior thereafter. This paper describes the application of our qualitative fault detection and isolation FDI approach to a hydrodynamics variable speed. We develop a pseudo bond graph model of the system and demonstrate the FDI effectiveness. We introduce the problem analysis involved in the faults localization in this process. A number of new and interesting issues have been dealt with in this paper.

Key words: Variable Speed Hydrodynamics; Bond Graph; Modeling; Fault Detection and Isolation; Simulation

1. Introduction

Due to constant modernization of production tools, industrial systems become increasingly complex and sophisticated. In parallel, an increasing demand for reliability, availability and dependability of systems have become real challenges of the third millennium. The Automatic, based on a concept system that represents a set of elements forming a structured whole, has enabled man to develop methods of supervision.

In this context, many approaches are developed for fault detection and diagnosis by different research communities in automatic and computer. The methods differ in the type of a priori knowledge about the processes they require. Thus, they can be classified broadly as methods based models and methods without models.

The transport of oil is a strategic activity whose hubs are in production station. For pumping hydrocarbons from one site to another they are pumping stations intermediate between the production site and processing sites or consumption. To ensure this mode the station is equipped with high-power pumps. The variation of pump speed directly affects the flow and discharge pressure [1]. The coupling between the drive motors and pumps is provided by a hydrodynamic coupling (speed hydrodynamics). Monitoring to ensure the last functioning and maintenance process.

Variable speed hydrodynamics are governed by the mutual interaction of several phenomena of different nature and involve technological components that implement laws from different disciplines (mechanical, thermal, hydraulic ...) [2]. That is why their modeling to their monitoring requires a unified approach.

The bond graph tool in the multidisciplinary approach is best suited for understanding physical systems is also an excellent tool for the study of

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*** Corresponding author:** Abd Essalam Badoud
E-mail: badoudabde@yahoo.fr.

supervision models. It allows its graphic nature with a unique language, highlighting the nature of power exchanges in the system, such as the phenomena of storage, processing and energy dissipation [3]. Besides its use for structural analysis and simulation modeling bond graph brings a tool for monitoring only on the analysis of its structure and causal graph to highlight its properties of monitoring.

2. Description of Variable Speed Hydrodynamic

Figure (1) shows the main components of a hydrodynamic converter speed. It consists of two main parts : the primary wheel called pump and turbine wheel called secondary [2].

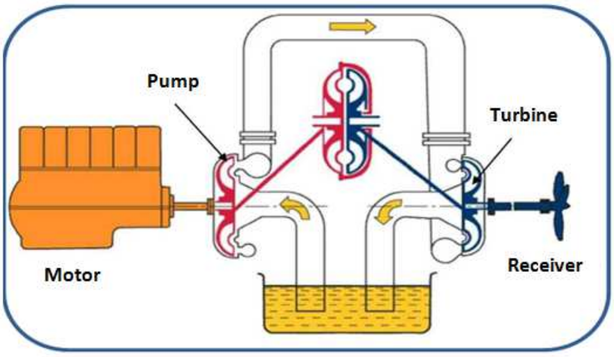

Fig. 1 Operating principle of the converter VOITH Turbo Coupler

The principle of hydrodynamic power transmission is based on the interaction between a pump and a turbine. In a Turbo coupler, this principle is achieved by using two wheels to blades. Together with an enveloping shell, these wheels provide a workspace in which the fluid circulates.

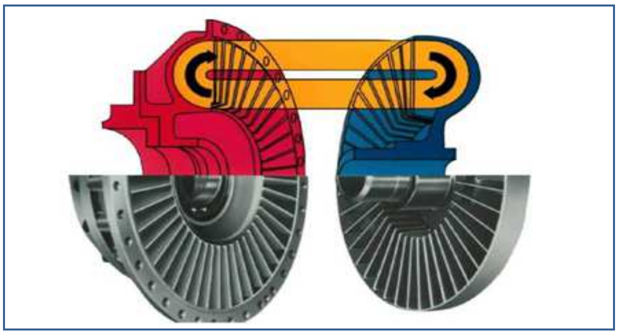

Fig. 2 Essential Components

The actual energy transmission is not wear any because the energy transmitting elements do not touch. The only parts that wear out are components such as bearings and seals. The drive mechanical energy motor is converted into fluid kinetic energy in the wheel-service pump [3]. This kinetic energy is again transformed into mechanical energy in the turbine wheel (Fig.2).

3. Bond Graph Approach

The bond graphs are an independent graphical description of dynamic behavior of the physical systems. This means that the multi domains systems (electrical, mechanical, hydraulic, acoustical, thermodynamic and material) are described in the same way [3].

The bond graphs are based on energy exchange [4].

Analogies between domains are more than just equations being analogous; the used physical concepts are analogous. Bond Graph is a powerful tool for modeling systems, especially when different physical domains are involved [5], [6].

The major advantages of bond graph modeling are that in such modeling a topological structure is used to represent the power/energy characteristics of engineering systems, and the systems with different energy domains are treated in a unified manner. A topological representation, such as a bond graph, offers great advantage at the conceptual design level, since quantitative details are not required prematurely. In addition, the graphical representations of the complex models are easy and clear. They are the easiest way for a engineers group to communicate the description of energy flows in dynamic systems [7], [8].

Since a bond graph is an unambiguous representation of an energy system, it is possible for a computer program to automatically generate the equations for dynamic analysis of the system [9]. The bonds in bond graphs model represent the power coupling, such models apply to mechanical translation and rotation, electrical circuits, thermal, hydraulic, magnetic, chemical, and other physical domains. They are especially useful in systems which function in coupled domains, such as electromechanical systems [10].

4. Words Bond Graph of Process

In this work, we will use an approximate model of the hydrodynamic variable speed. By using the formalism bond graph, we can model each physical part of Figure 1 in a unifying way. The modules of calculation (order) can be represented by equations by using the concept of signal. The bond graph with words of this complete car is presented at the figure 3.

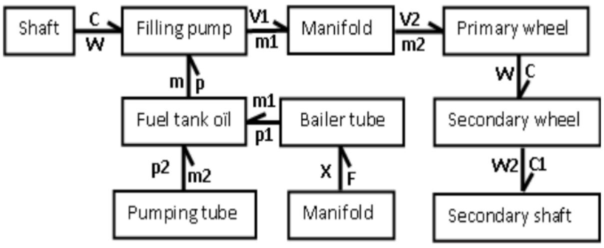

Fig. 3 Words bond graph

5. Variable Speed Hydrodynamic Diagnosis

FDI methods can be broadly classified into two categories, namely, data driven approach and model based approach [11].

The former requires transforming a large amount of historical data into a priori knowledge for building a diagnostic system; the latter requires a mathematical model governing system behavior and it works by evaluating system behavior using parameter values and sensor data from the monitored system.

The first step of model based approach is to generate a set of residuals called Analytical Redundancy Relations (ARRs) which express the difference between information provided by the actual system and that delivered by its normal operation model [12]. ARRs are static or dynamic constraints which link the time evolution of known variables when the system operates according to its normal operation model. ARRs have to be sensitive to fault sand in sensitive to perturbations.

In practice, there is a distinction between the detection of fast-acting, possibly safety-critical faults, and faults which are non-safety-critical and slower to develop, for example due to wear. The former are most likely to be detected by state-estimation and instantaneous comparison of prediction with measurement, while the latter are detected using parameter estimation techniques which require a certain time window and excitation of the system.

5.1. Bond graph model of hydrodynamic variable speed

The bond graph model of the global system (proposed system) is given in the figure (4)

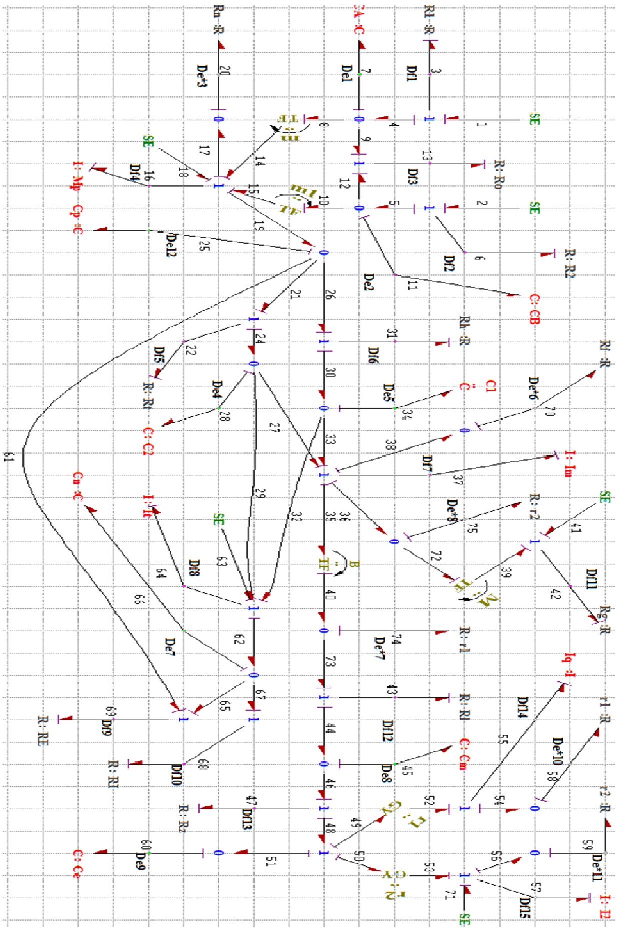

Fig. 4 **Bond graph model of hydrodynamic variable speed with virtual placement of sensors**

Fault detection is a well studied area in many disciplines by the very nature that FD is essential to safe operations. The companion problem of FI also has been studied and is a much more difficult problem. Simply stated, a fault is a malfunction of the system because of some unexpected change. The malfunction disturbs normal operation and if unchecked may further deteriorate the system's performance [13]. While a fault is considered no normal behavior, in contrast, a failure is when a process is unable to perform its required functions. Generally, a fault is minor when compared to a failure, but most failures tend to stem from ignored or undetected faults [14].

There are different ways to classify faults according to various standards. Faults can be characterized by their temporal features:

Drifting faults occur slowly overtime (minutes to hours), such faults usually are linked to component usage and drift in control parameters.

- Intermittent faults are present only for very short periods of time (seconds to minutes), but sometimes they can have disastrous consequences.
- Abrupt faults are dramatic and persistent, and are usually accompanied by significant deviations from steady state operations.

6. Analytical Redundancy Relations:

An ARR is a static or a dynamic constraint which links the time evolution of the known variables when the system operates according to its normal operation model. It can be derived from a set of equations or constraints by eliminating the unknown variables. For this, various structural analysis or polynomial approaches can be used. In linear cases, the elimination of unknown variables can be performed by using projection techniques leading to parity space residuals (note that a residual is a result of a numerical evaluation of its corresponding ARR). However, eliminating the unknown variables is not always an easy task, especially for nonlinear systems.

ARR are obtained from the behavioral model of the system through different procedures of the unknown variables elimination. The aim of these sections is to provide an optimal sensors placement method on the bond graph model in order to make all components monitored. We assume that the faults are not multiple and may affect only components. Let given a bond graph model obtained from physical process (fig. 4). We suppose that the sensors are not placed yet on the bond graph model.

Let x_i and y_j the binary variables to express the potential sensor placement on the junction nodes such as:

$$X_i = \begin{cases} 1 \text{ if the i}^{\text{th}}\text{sensor is placed on the i}^{\text{th}} \text{ "0"} \\ 0 \text{ otherwise} \end{cases} \tag{1}$$

$$Y_i = \begin{cases} 1 \text{ if the j}^{\text{th}}\text{sensor is placed on the j}^{\text{th}} \text{ "1"} \\ 0 \text{ otherwise} \end{cases} \tag{2}$$

For the "0" and the "1" junction, the unknown variable (based on fixed causality) is calculated as follows:

$$\begin{cases} f_{Ci} = \phi_{Ci}\left[s\left\{(1-x_i)e_{Ci} + x_i De_i\right\}\right] \text{ ou } i = 1.N_0 \\ e_{Ci} = \dfrac{1}{s}(1-x_i)\phi_{Ci}^{-1}\left(f_{Ci}\right) + x_i De_i \end{cases} \tag{3}$$

Where s denotes the Laplace variable for a linear system

$$\begin{cases} e_{Rj} = \phi_{Rj}\left[\left\{(1-y_j)f_{Rj} + y_j Df_j\right\}\right] \text{ with } j = 1.N_1 \\ f_{Rj} = \left(1-y_j\right)\phi_{Rj}^{-1}\left(e_{Rj}\right) + y_j Df_j \end{cases} \tag{4}$$

$$\begin{cases} f_{Ik} = \phi_{Ik}^{-1}\left[\dfrac{1}{s}\left\{(1-z_k)e_{Ik} + z_k De_k\right\}\right] \\ e_{Ik} = s\left(1-z_k\right)\phi_{Ik}\left(f_{Ik}\right) + z_k De_k \end{cases} \tag{5}$$

The signature of a failure is the whole of the redundancy relations such as the failure influences these relations. Information of sensitivities and robustness desired for the residues is indexed in a binary table, called the table of the faults signatures. This one is built in the following way: when the i residue must be sensitive to the j fault, then the binary value 1 is assigned to the line and the corresponding column.

For[Y_1, X_1, Y_2, X_2, Z_1, X_3, Y_3, Y_4, Y_5, X_4, X_5, Z_2, Y_6, Y_7, X_6, Y_8, X_7, Y_9, Y_{10}, Z_3, Z_4, Z_5, X_8]= [10101100111011010111110]

The results of this placement are represented by the system of equations (6).

$$RRA_1 : SE_1 - \phi_{R1}\left[Df_1\right] - \left[De_1\right]$$

$$RRA_2 : Df_1 - \phi_{CA} SDe_1 - \frac{1}{m} Df_4 + Df_3$$

$$RRA_3 = SE_{2-} De_2 - \phi_{R2} Df_2$$

$$RRA_4 = Df_2 - \frac{1}{m_1} Df_4 - \phi_{CB}\left[sDe_2\right] - Df_3$$

$$ARR_5 = SE_{18+} \frac{1}{m} De_1 + \frac{1}{m1} De_2 - \phi_{IMP}\left[sDf_4\right]$$

$$ARR_6 = Df_5 - \phi_{Cp}\left[sDe_{12}\right] - Df_9 - Df_6 + Df_4$$

$$ARR_7 = De_{12} - De_4 - \phi_{Rt} Df_5 \tag{6}$$

$$ARR_8 = De_1 - De_2 - \phi_{Ro} Df_3$$

$$ARR_9 = De_{12} - De_5 - \phi_{Rh} Df_6$$

$$ARR_{10} = Df_5 - \phi_{C2}\left[SDe_4\right] - Df_7 - Df_8$$

$$ARR_{11} = Df_6 - Df_8 - Df_7 - \phi_{C1}\left[sDf_5\right]$$

$$ARR_{12} = De_4 - De_5 - De_8 - \phi_{\mathrm{Im}}\left[sDf_7\right] - De_6 - BDe_7$$

$$ARR_{13} = SE_{41} + \frac{1}{m} De_8 - \phi_{Rg} Df_{11}$$

$$ARR_{14} = De_7 - \phi_{RL} Df_{12} - \frac{1}{s} De_8$$

$$ARR_{15} = Df_{12} - \phi_{Cm}\left[sDe_8\right] - Df_{13}$$

$$ARR_{16} = De_8 - \Phi_{RZ} Df_{13} - r_1 Df_{14} - r_2 Df_{15} - De_9$$

$$ARR_{17} = Df_{13} - \phi_{Ce}\left[sDe_9\right]$$

$$ARR_{18} = De_7 - \phi_{RI} Df_{10}$$

$$ARR_{19} = De_7 - De_{12} - \phi_{RE} Df_9$$

$$ARR_{20} = r_1 Df_{13} - \phi_{Iq}\left[sDf_{14}\right] - De_{10}$$

$$ARR_{21} = r_2 Df_{13} - De_{11} - \phi_{I2}\left[sDf_1\right]$$

$$ARR_{22} = SE_3 + De_4 + De_5 - Df_7 - \phi_{It}\left[sDf_8\right]$$

$$ARR_{23} = Df_8 - Df_{10} - Df_9 - \phi_{Cn}\left[sDe_7\right]$$

The matrix of corresponding signature of the failures is represented by the table 1. The fault signatures are not different from each other (R_0 and C_e) and not equal to zero, then the components R_0 and C_e are not monitorable but R_1, C_A, R_2, C_B, M_P, c_p, R_t, R_h, C_2, C_1, I_m, R_g, R_L, C_m, R_z, R_i, R_e, I_q, I_2, I_t and C_n are monitorable.

Table 1 Fault signature

	R_1	C_A	R_2	C_B	M_P	C_p	R_t	R_o	R_h	C_2	C_1	I_m	R_g	R_L	C_m	R_z	C_e	R_i	R_e	I_q	I_2	I_t	C_n
ARR_1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARR_2	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARR_3	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARR_4	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARR_5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARR_6	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
ARR_7	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
ARR_8	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
ARR_9	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
ARR_{10}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0

ARR$_{11}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
ARR$_{12}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
ARR$_{13}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
ARR$_{14}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
ARR$_{15}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1

For [Y_1 , X_1, Y_2, X_2, Z_1, X_3, Y_3, Y_4, Y_5, X_4, X_5 , Z_2, Y_6, Y_7, X_6, Y_8, X_7, Y_9, Y_{10}, Z_3, Z_4, Z_5, X_8] = [10101101111011011111110]

The results of this placement are represented by the system of equations (7).

$$ARR_1 = SE_1 - \phi_{R1} Df_1 - \frac{1}{s}\phi_{CA}^{-1}\left(e_{CA}\right)$$

$$ARR_2 = SE_2 - \frac{1}{s}\phi_{CB}^{-1} f_{CB} - \phi_{R2} Df_2$$

$$ARR_3 = SE_{18} + \frac{1}{m}\left[\frac{1}{s}\phi_{CA}^{-1} f_{CA} + \frac{1}{m_1}\frac{1}{s}\phi_{CB}^{-1} f_{CB} - \phi_{1MP} Df_4\right]$$

$$ARR_4 = \phi_{Rt}^{-1}\left(e_{Rt}\right) + \phi_{Cp} sDe_{12} - \phi_{RE}^{-1} e_{RE} - Df_6 + Df_4$$

$$ARR_5 = \frac{1}{s}\phi_{CA}^{-1} f_{CA} + \frac{1}{s}\phi_{CB}^{-1} f_{CB} - \phi_{Ro} Df_3$$

$$ARR_6 = De_{12} - De_5 - \phi_{Rh} Df_6$$

$$ARR_7 = \phi_{Rt}^{-1}\left(e_{Rt}\right) - \phi_{C2} sDe_4 - \frac{1}{s}\phi_{\mathrm{Im}}^{-1} e_{\mathrm{Im}} - Df_8$$

$$ARR_8 = \phi_{Rh}^{-1}\left(e_{Rh}\right) - Df_8 - \phi_{\mathrm{Im}}^{-1}\left(e_{\mathrm{Im}}\right) + \phi_{C1} sDe_5$$

$$ARR_9 : SE_{41} + \frac{1}{m} De_8 - \phi_{Rg} Df_{11}$$

$$ARR_{10} : De_7 - \phi_{RL} Df_{12} - \frac{1}{s}\phi_{Cm}^{-1} f_{Cm}$$

$$ARR_{11} : \phi_{Cm}^{-1} f_{Cm} - \phi_{Rz} Df_{13} - r_1 Df_{14} - r_2 Df_{15} De_9$$

$$ARR_{12} : \phi_{Cn}^{-1} f_{Cn} - \phi_{RI} Df_{10}$$

$$ARR_{13} : r_1 Df_{13} - \phi_{RIq} Df_{14} - De_{10}$$

$$ARR_{14} : r_2 Df_{13} - \phi_{I2} sDf_{11} - De_{11}$$

$$ARR_{15} : SE_3 + De_4 + De_5 - \phi_{Cn}^{-1} f_{Cn} - \phi_{It} sDf_8$$

$$ARR_{16} : Df_{13} - \phi_{Ce} De_9$$

$$ARR_{17} : De_7 - De_7 - \phi_{RE} Df_9 \tag{7}$$

Table 2 Fault signature

	R$_1$	C$_A$	R$_2$	C$_B$	M$_P$	C$_p$	R$_t$	R$_o$	R$_h$	C$_2$	C$_1$	I$_m$	R$_g$	R$_L$	C$_m$	R$_z$	C$_e$	R$_i$	R$_e$	I$_q$	I$_2$	I$_t$	C$_n$
ARR$_1$	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARR$_2$	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARR$_3$	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARR$_4$	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARR$_5$	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARR$_6$	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARR$_7$	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
ARR$_8$	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
ARR$_9$	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
ARR$_{10}$	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
ARR$_{11}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
ARR$_{12}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
ARR$_{13}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

ARR_{14}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
ARR_{15}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
ARR_{16}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
ARR_{17}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

The matrix of corresponding signature of the failures is represented by the table 2. It is noticed that the structures of the residues are different and the signatures of the defects are also different and no-null. Then all the components are detectable and isolable thus monitoring with nineteen sensors only.

7. Simulation Results

Simulation is a means complementary to the experiment and analytical calculation to solve equations which we cannot find the solution. Simulation is less expensive and more rapid that the experiment; it is in full evolution.

For the faults detection of our system we use the precedent Analytical Redundancy Relations (ARRs). We create the faults on monitoring components with this software fault here is considered in the total absence or the deviation of the nominal value given out by the component to monitor.

7.1. Sensitivity of detector Df6

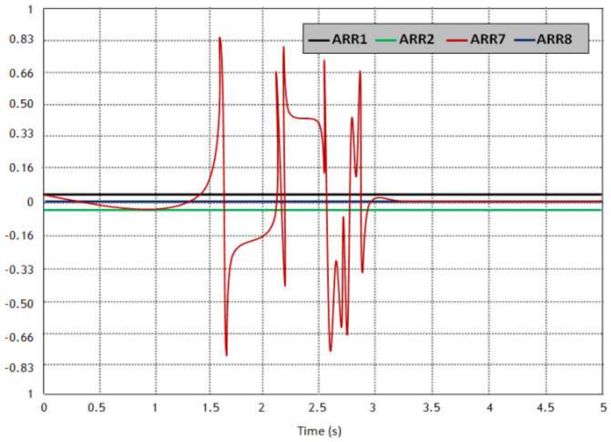

Fig. 5 Sensitivity of detector Df6

The numeric values of components are not considered, only their presence or absences in the relation are taken in account with evaluation term the operators (+, -). It is the qualitative approach for bond graph monitoring. In the first time, we create a fault between the instant t= 1.5s and t= 3 s.

The failure on R_t is characterized by the presence of the detector Df6 in the analytical redundancy relation ARR7. We note that the residual ARR7 is sensitive to the failures which affect Rt, but residuals ARR1, ARR2, ARR3, ARR4, ARR6, ARR8, ARR9, ARR10, ARR11, ARR12, ARR13, ARR14, ARR15, ARR16 and ARR1è are equals to zero.

7.2. Sensitivity of detector De1

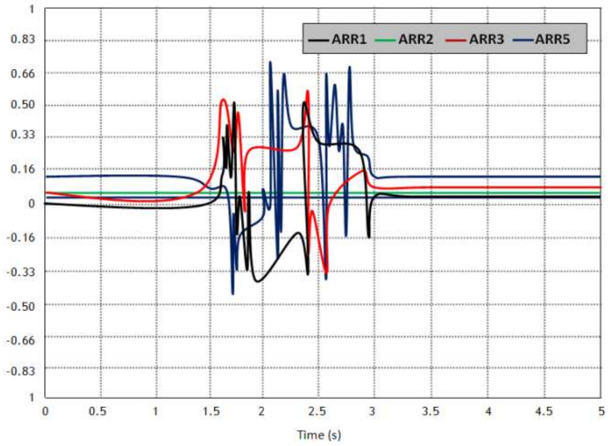

Fig. 6 Sensitivity of detector De1

The figure (6) shows the response of the residues. It is noted that residues ARR1, ARR3 and ARR5 presents a short change compared to its initial states between the moments t1=1.5s and t2=3s but turns over in their initial state from t=3s and other residues ARR2, ARR4, ARR6, ARR7, ARR8, ARR9, ARR10, ARR11, ARR12, ARR13, ARR14, ARR15, ARR16 and ARR17 remain invariant (constants). If we refers to the signature of the C1 component given to table II we notes that this result is in conformity with what is envisaged; i.e. that in the event of failure of the C1 component theses residue ARR1, ARR3 and ARR5 will be sensitive.

7. Conclusion

Methodology bond graph enabled us to model, in a homogeneous way, the complex systems. They are based on the transformation of the matter and energy, for the hydraulic, mechanical, electric and thermal systems analysis. Coupled with the possibilities offered by the bond graph, this vision facilitated the approach system of the monitoring. This last was accomplished by using the tool bond graph, which appears adapted best then for the knowledge of such physical systems and particularly the complex systems. It provides directly to the user original information.

The generation of analytic redundancy relations (RRAS) by the bond graph approach presents some interesting characteristics: they are simple to understand, since they correspond to variables and relationships that are displayed by the bond graph model image of the physical process, these relationships are deducted directly from the graph, they can be generated in symbolic form and therefore suitable for computer implementation. The search for optimal case we took a lot of time for the combinatorial difficulty in the calculations. Getting to watch twenty-three (23) components monitoring are monitoring with only seventeen (17) sensors.

References

[1] P. Beneteau; Hydrostatique Hydrodynamique, transmission de puissance, Cours et applications. Sciences industrielles STS. Ellipses, 2003.

[2] H. HÖLLER, Coupleurs hydrodynamiques. Documentation Voith Turbo, 2010.

[3] Badoud Abd Essalam and Khemliche M, Modeling, Analysis And Simulation of The Variable Speed Hydrodynamics By Bond Graph, Second International Conference on Systems and Information Processing ICSIP’11; Guelma May 15-17, 2011

[4] A. Mukherjee, r. Karmakar. (2000). Modelling and Simulation of Engineering Systems Through Bond Graph’. Norosa Publishing House.

[5] Borutzky,W. (2010). Bond Graph Methodology: Development and Analysis of Multidisciplinary Dynamic System Models. Springer Verlag.

[6] Yang, D. & Sueur, C. (2012). Input and state observability for ltv bond graph models. 7th Vienna International Conference on Mathematical Modelling,Vienna, Austria, February 15-17, 2012 .

[7] Gawthrop, P., Bevan, G. Bond graph modeling — A tutorial introdution for Control engineers. IEEE Control System Magazine, 27(2), 24–45, 2007.

[8] K. Medjaher, A. K. Samantaray, B. Ould Bouamama, Bond graph model of a vertical U-tube steam condenser coupled with a heat exchanger, Simulation Modelling Practice and Theory 17 (1) (2009) 228–239.

[9] Beers C. D, Manders E. J, Biswas G and Mosterman P. J, Building efficient simulations from hybrid bond graph models, in 2nd IFAC Conference on Analysis and Design of Hybrid Systems 2006.

[10] T. Ersal, H. K. Fathy, J. L. Stein, Structural simplification of modular bond graph models based on junction in activity, Simulation Modelling Practice and Theory 17 (2009) 175–196.

[11] Chang Boon Low Danwei Wang Arogeti, S. Ming Luo, Quantitative Hybrid Bond Graph-Based Fault Detection and Isolation, IEEE Transactions on Automation Science and Engineering, Vol. 7, n. 3, pp. 558–569, 2010.

[12] Arun K. Samantaray, Belkacem Ould Bouamama, Model-based Process Supervision, A Bond Graph Approach, Spring, 2009.

[13] Commault, C., Dion, J. M., & Agha, S. Y. (2008). Structural analysis for the sensor location problem in fault detection and isolation. Automatica, 44, 2074–2080.

[14] Samantaray, A. K., & Ghoshal, S. K. (2008). Bicausal bond graphs for supervision: From fault detection and isolation to fault accommodation. Journal of the Franklin Institute, 345(1), 1–28.