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Modeling and fault diagnosis of Engine Ignition Systems using bond graph approach

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Abstract: This paper discusses the fundamentals of an engine ignition system modeling using bond graph approach and its mathematical interpretation and physics for the different stages of motor operation. Other topics covered in this paper show that fault detection and localization of the defects in the engine ignition system with lighting presented by its bond graph model. One of the original points is that this work treated the utilization of fault detection and isolation method (FDI). A new method is proposed to avoid the exploration of all the combinations for its application to the diagnostic of this system operation and to determine the gravity of a detected failure. The causal paths help us in this procedure in order to generating the analytical redundancy relations ARR at each step from constitutive and structural junction relations. This is shown through an algorithm for monitoring the system by sensors placements on the corresponding bond graph model. The diagnosis performances are controlled by a sensitivity analysis of these residues, making it possible to define indices of sensitivity, and detectability indices of the defects.

Key words: Modeling, Bond Graph, Engine ignition system, Sensors Placement, Detection, Localization.

1. Introduction

The engine is a machine for converting the chemical energy from the combustion process of a certain quantity of fuel gasoline and oxidizer air into mechanical energy. Given its operating autonomy, the engine ignition system remains the most used in automotive power train systems [1]. However, even under optimal conditions, the automotive motor today can achieve a yield of about 36%for a gasoline engine and 42% for a diesel engine. That is to say, on average, a greater part of the energy supplied by the fuel is lost in the form of heat dissipated into the atmosphere. In addition, additional constraints are added to this drawback [2].

The latter concern economic and environmental regulations are more stringent. These new requirements are due to the fact that transport systems are one of the largest sources of air pollution. On the other hand, depletion of global oil resources is accompanied by increasing fuel prices, which is becoming increasingly unacceptable to consumers [3].

Improving the safety of systems mainly based on fault detection and isolation algorithms, which consist primarily of comparing the actual behavior of the system with reference describing behavior normal operation, or describing different kinds of defects while minimizing false alarms, non-detection and the delays in the detection of defects [4], [5]. Performance degradation diagnostic algorithms are mainly due to the imperfect knowledge of parameter values of the models and their random variations. The current generation diagnostic systems use single-signal techniques. They ensure the validity of measurements returned by each sensor by comparing them to threshold levels of operation. They generally correspond to short-circuit or open-circuit values.

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In particular, many papers on model-based FDI were published over the last decade, using both signal and process model-based methods [6]-[8].

Unsurprisingly, these show that the more accurate the model is at describing the engine behavior, the better its performance will be in detecting anomalous conditions. Unfortunately, an accurate and complete mathematical model of such a complex thermodynamic system is usually unavailable, typically because of the assumptions introduced to reduce mathematical complexity. Hence, FDI schemes that relate to first principle engine models are costly to develop, while current alternatives tend to be mathematically complex or require considerable a priori knowledge to be incorporated into the monitoring scheme.

In this paper, the use of bond graph identification is proposed through a real process for finding a viable solution to the FDI problem. Regarding the interest of bond graphs for monitoring systems, industrial systems are governed by a number of physical phenomena and various technology components, which is why the use of the bond graph tool that is based on an energy analysis and multi physics is well suited. By its graphical structure, bond graph tool allows causal and structural analysis directly on the model.

The FDI method proposed in this work is based on the use of a bond graph tool. This method is particularly suitable for multi-physical systems, where several types of energy are involved. The use of bond graph allows easily deriving analytical models, eliminating the unknown variables and generating ARRs. The elimination process is based on the exploitation of the causal and the structural properties of bond graph.

The layout of the paper is as follows: the first section provides an overview on the description and the operating of thermal motor. The second section will be devoted to the bond graph modeling and simulation of the process. The third section focuses on the qualitative and quantitative methods most used in the literature for monitoring systems that will be followed by exposure of the algorithm for generating the ARR by the bond graph approach. Finally, this paper also presents conclusions.

2. Four stroke engine

Four stroke engines perform each engine operation in an individual stroke of a piston; the piston descends with an intake valve open, and fresh fuel/air mixture is drawn inside. The valve closes, the piston rises, and the mixture is compressed. A spark jumps across the spark plug’s gap, igniting the mixture, and the piston is forced downward. An exhaust valve opens and the piston rises, forcing the burned remnants from the cylinder. The cycle is ready to begin again. Intake, compression, combustion, expansion, and exhaust: these are the basic requirements of an engine (fig. 1).

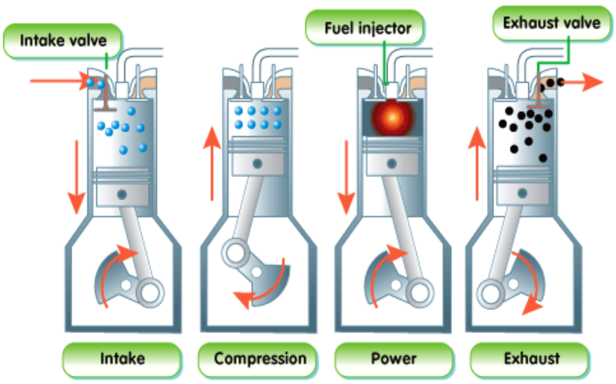

Fig. 1 Stroke cycle of a ignition engine

The four strokes of the cycle are the intake, with the descending piston drawing fuel and air in through the open intake valve; the compression stroke, ending in combustion with the piston near the top; the expansion, or power stroke, where energy is taken from the hot gases in the cylinder; and the exhaust stroke with the piston pushing burnt mixture out of the cylinder.

3. Bond graph modeling

A bond graph consists of subsystems linked together by half arrows, representing power bonds. They exchange instantaneous power at places called ports. The variables that are forced to be identical, when two ports are connected are the power variables, considered as functions of time. The different power variables are classified in a universal scheme, and are called either effort e(t) or flow f(t). Their product P(t)= e(t)*f(t) is the instantaneous power flowing between the ports [9], [10].

The main advantages of the bond graph tool for modeling purposes is summarized through few keywords, which makes this approach quite specific and justifies its use in the paper are the following:

It provides the analyst with a unified graphical language to represent with physical insight power exchanges, energy dissipation and storage phenomena in dynamic systems of any physical domain.

It allows the visualization of causality properties before writing equations, according to selected modeling hypotheses [11], [12].

3.1 Word bond graph

The block diagram obtained (word bond graph) it allows to know how the energy flux flows but also the type of generalized variables used (e and f).

The power flow is exchanged between each connected subsystem is the product of variables power P which is one type of "generalized effort".

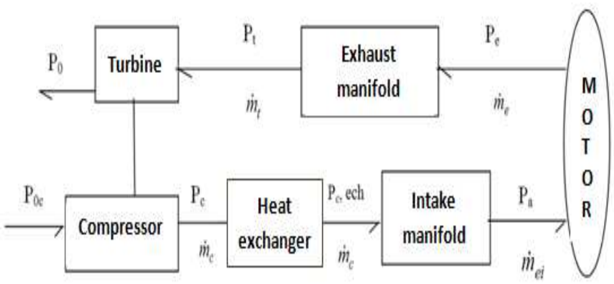

Fig. 2 Word bond graph

3.2. Modeling of valves

In fact to improve the operation of the engine, the opening and closing of the valves are shifted but is studied here a simplified case. The cam has a very important role in opening diagrams and closing of the valves, it is she who is the cause of: advanced to the opening admission (AOA), advanced to the opening the exhaust, delay on closing for admission, delay on closing the exhaust. The valves are actuated by rockers themselves controlled by the cams.

The rockers are used to amplify the movement of the cams to increase valve lift and therefore the flow. Due to the very gradual cam profile, lift and valve closure is very slowly. This is why they are not likely to hold them or be struck by the piston during the crossover period. The exhaust valves are about 70% larger than the inlet valves. Indeed the temperatures are higher during the exhaust and a larger valve allows better heat dissipation. Thus, in case of need of a larger work we use two small valves. They are of two types: intake and exhaust valves.

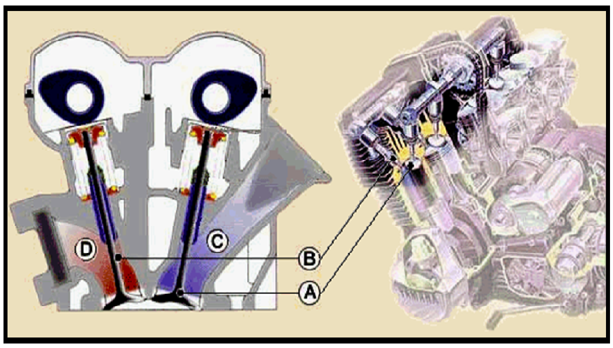

Fig. 3 Intake and exhaust valves

The intake valve (A) allows fresh gas (C) to enter the combustion chamber from the carburetor or injector.

The exhaust valve (B) allows flue gas (D) out of the combustion chamber to the exhaust.

The valves must remain closed to seal the combustion chamber during the compression and combustion of fresh gas.

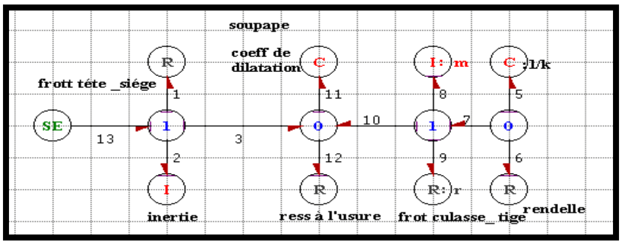

Fig. 4 Bond graph model of valves

3.3. Modeling of combustion chamber

The combustion chamber is the area inside the engine where the fuel/air mixture is compressed and then ignited. It is generally formed on one side by the shape cast into the cylinder head, and on the other side by the top of the piston. When the piston is at top-dead-center the chamber is at its smallest dimension, and this is the time when the fuel/air mixture is at its most unstable condition and ready to be ignited. The better the combustion chamber is designed the better the engine "breathes;" that is, the more efficient the overall flow of air through the engine.

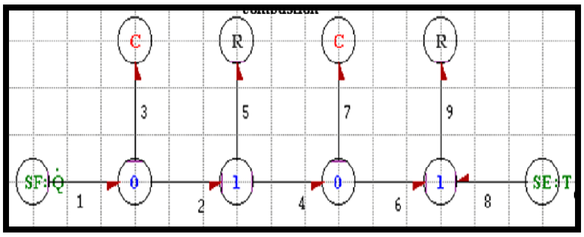

Fig. 5 Bond graph model of combustion chamber

The combustion chamber is modeled as a variable volume chamber. This room has two openings on two outdoor environments: an opening for admission (valves of admission) and one for the exhaust (valves exhaust). Medium A contains a stoichiometric air-fuel temperature and pressure (P_0, T_0). The medium E is directly open to the atmosphere (P_0, T_0).

3.4. Modeling of the piston-rod-crank

The piston-rod-crank movement in each cylinder of a spark-ignition engine achieves the crankshaft rotation from the movement of the pistons.

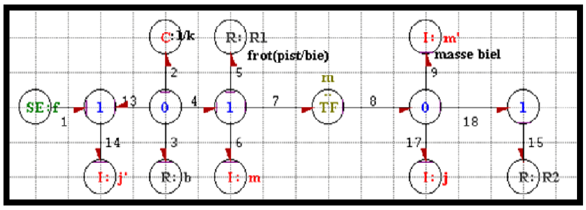

Fig. 6 Bond graph model of the piston-rod-crank

These translational movements are derived from the combustion of an air / fuel mixture under pressure into the cylinders (fig. 6).

3.5. Turbocharger modeling

The turbocharger is composed of two parts: on the one hand, a turbine which is driven by exhaust gas from the engine, and the other, a compressor, connected at its axis to the turbine, which is positioned on the air inlet duct, that is to say before the engine.

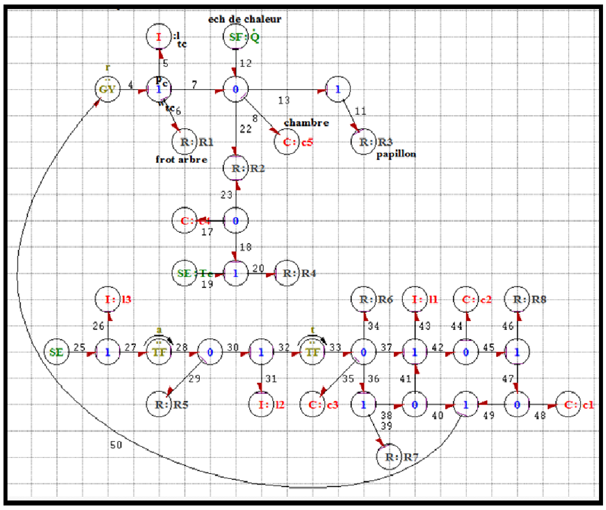

Fig. 7 Bond graph model of turbocharger

The turbocharger is also called centrifugal compressor: indeed, the turbine drives the shaft, which rotates the compressor, which by centrifugal force drives the air to the periphery and creates a depression in the center, where increasing the air pressure in the conduit.

4. Design of supervision system

The detection and the isolation of the faults on a given process consist in two main steps. The first step provides the possible inconsistencies between the process model and its actual behavior. These discrepancies are called residuals and are in fact signals resulting from the comparison between the model's outputs and the actual outputs of the process measured by the sensors [13]. This comparison can be obtained from analytical or knowledge based constraints, called redundancies. A good account of such redundancy based methods is given in [14].

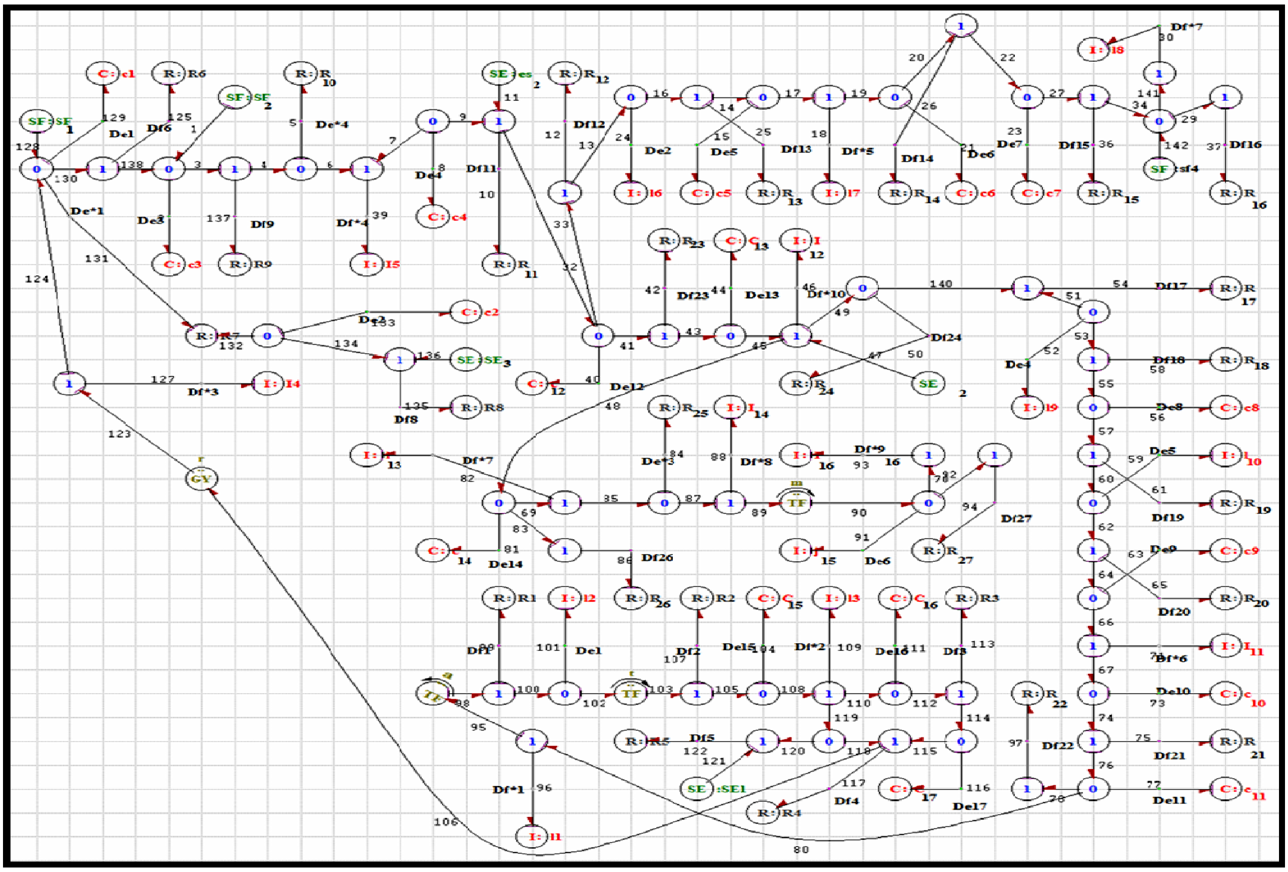

Fig. 8 Bond Graph model with virtual sensor placement

The second step in a FDI method is the decision procedure, which allows locating or isolating the fault and possibly identifying its origin. fault and possibly identifying its origin.

4.1 Generation of fault indicators

Due to structural and causal properties of the bond graph tool, a classical algorithm for generation of ARR from a bond graph model is based on causal inversion of the model, as described in [15].The determinist bond graph model of the ignition engine is given in figure (8). The virtual detectors De* and Df* are used to distinguish between the real and fictive measurements.

5. Simulation results

Failure of the engine to start easily, misfiring, poor acceleration and fuel consumption can usually be attributed to faults in the ignition system, assuming that the engine is otherwise in reasonable condition. Before making checks and adjustments to the ignition system it is important to ensure that the valve clearances have been checked and adjusted correctly.

5.1. Sensitivity of detector DF22

In the first time, we create a fault between the instant t= 5 s and t= 7 s in the twenty-two sensor (DF22).

The manifold absolute pressure (MAP) sensor is a key sensor because it senses engine load. The sensor generates a signal that is proportional to the amount of vacuum in the intake manifold. The engine computer then uses this information to adjust ignition timing and fuel enrichment.

We note that the residuals ARR22 and ARR23 are sensitive to the failures which affect R22, but residuals ARR1, ARR2 and ARR3 are equals to zero.

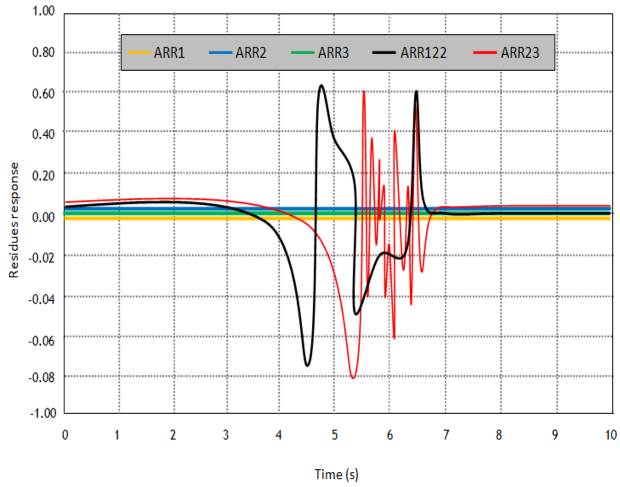

Fig. 9 Sensitivity of manifold absolute pressure Sensor (detector DF22)

When the engine is working hard, intake vacuum drops as the throttle opens wide. The engine sucks in more air, which requires more fuel to keep the air/fuel ratio in balance. In fact, when the computer reads a heavy load signal (presence of peak) from the Df22 sensor, it usually makes the fuel mixture go slightly richer than normal so the engine can produce more power. At the same time, the computer will retard (back off) ignition timing slightly to prevent detonation (spark knock) that can damage the engine and hurt performance.

5.2. Sensitivity of detector De14

We create a fault between the instant t= 4 s and t= 7 s in the thirteenth sensor (De13).

The figure (10) shows the response of the residues. It is noted that residue ARR25 present a short change compared to its initial state between t1=4s and t2=7s but turns over in their initial state from t=10s, but other residues ARR1, ARR2, ARR24 and ARR26 remain invariant. One cause of scoring of the cylinder lies in the fact that the ends of the piston pin or wristpin when loose sometimes protrude through the hole or bearing in the piston. Some pins have their bearing in the piston itself, while others, being tightly secured in the piston, have their bearing in the upper end of the connecting rod. No matter which construction is employed, the ends of the pins should never come in contact with the cylinder walls. The pin must by some absolutely positive method be kept in place. While a loose wristpin is often the cause of a scored cylinder, there are three other causes, resulting from imperfections of design or of machine work, to which scoring can be traced; namely, loose core sand, imperfectly fitted piston rings, and loosening of the pins that are used to prevent the piston rings from turning in the slots in the piston.

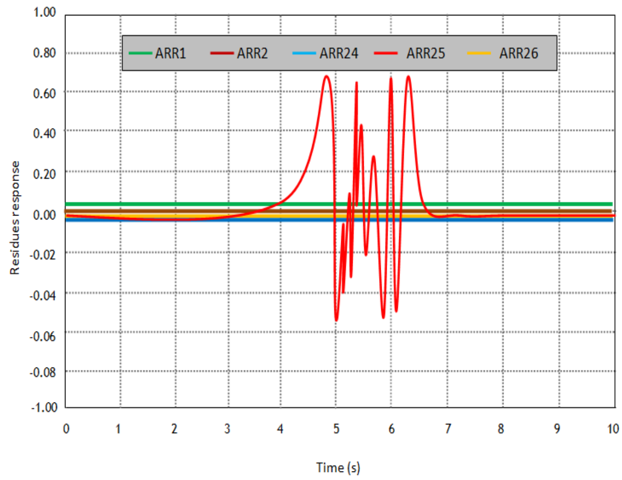

Fig. 10 Sensitivity of detector De13 (scored and leaky cylinders)

6. Conclusions

A model based FDI method is presented, where the model is built by using the bond graph tool. The method is suitable and applicable for multi-physical systems where several energy domains are involved. The most part of the work of this method consists in constructing a correct and faithful bond graph model that represents the physical phenomena of the system. Once this task performed the ARRs and residuals generation is straightforward. In this paper, causal properties of bond graphs are used to generate the elimination schemes such that direct and deduced redundancies can be expressed only in terms of known process variables.

References

[1] M. Cygnar, B. Sendyka, Determination of the Total Efficiency of Direct Injection SI Engine Working on Stratified Charge, Wydawnictwo Panstwowej Wyższej Szkoy Zawodowejw Nowym Sczu, ISBN 978-83-60822-46-3, Nowy sqcz 2008, Poland

[2] J. K. Yamaguchi, Lexus gives V6 dual-injection. 2006 Engine Special Report, Automotive Engineering International, pp. 17－20, SAE International, Warrendale 2006, United States of America.

[3] S. Kumara, M. Kumar, C. Varuna; Numerical modeling of compression ignition engine: A review, Renewable and Sustainable Energy Reviews, vol. 19, (2013) pp. 517–530.

[4] S. Simani. Fault diagnosis of a simulated industrial gas turbine via identification approach, Inter. Jour. of Ada. Control and Signal Processing 21(4):326–353, 2007.

[5] V. Venkatasubramanian. Prognostic and diagnostic monitoring of complex systems for product life cycle management: Challenges and opportunities. Computers and Chemical Engineering, vol. 29, pp. 1253–1263, 2005.

[6] C. Svard and M. Nyberg. Residual generators for fault diagnosis using computation sequences with mixed causality applied to automotive, IEEE Tra. on Sys. Man. Cyb, Part A: Sys. and Hum. 40(6):1310–1328, 2010.

[7] T. Jain, J. J. Yame and D. Sauter. Model-free reconfiguration mechanism for fault tolerance, Int. J. of Appl. Math. and Comp. Science 22(1):125–137, 2012.

[8] P. M. Marusak and P. Tatjewski, Actuator fault tolerance in control systems with predictive constrained set-point optimizers, International Journal of Applied Mathematics and Computer Science 18(4):539–551, 2008

[9] R. Sanchez, A. Medina, Wind turbine model simulation: A bond graph approach, Simulation Modelling Practice and Theory 41 (2014) 28–45.

[10] W. Borutzky, Bond Graph Modelling of Engineering Systems: Theory, Applications and Software Support, Springer New York Dordrecht Heidelberg London, 2010

[11] A. Badoud, M. Khemliche, B. Ould Bouamama, S. Bacha and L. L. Fernando Villa. Bond Graph Modeling and Optimization of Photovoltaic Pumping System: Simulation and experimental results, Simulation Modelling Practice and Theory, 36(2013), pp.84–103.

[12] D. Karnopp, D. Margolis and R. Rosenberg, Systems dynamic: A unified approach. John Wiley and Sons, 2000.

[13] V. Venkatasubramanian, R. Rengaswamy, K. Yin, S. N. Kavuri, A review of process fault detection and diagnosis. Part 1: Quantitative model based methods, Computers and Chemical Engineering, vol. 27, pp. 293–311, 2003.

[14] P. M. Frank, Fault diagnosis in dynamic systems using analytical and knowledge based redundancy a survey and some new results, Automatica, vol. 26, pp. 459–474, 1990.

[15] A. Badoud, M. Khemliche, B. Ould Bouamama, S. Bacha, Bond Graph Algorithms for Fault Detection and Isolation in Wind Energy Conversion, Arab. Jour. for Science and Engineering, Vol. 39, Iss. 5, pp 4057-4076, May 2014.