USE OF AN OBJECT ORIENTED DYNAMIC HYBRID SIMULATOR FOR THE MONITORING OF INDUSTRIAL PROCESSES

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Abstract: *PrODHyS* is a dynamic hybrid simulation environment, which offers extensible and reusable object oriented components dedicated to the modelling of processes. The purpose of this communication aims at presenting the main concepts of *PrODHyS* through the modelling and the simulation of a hydraulic system. Then, the feasible use of hybrid simulation in a supervision system is underlined.

Keywords: Object oriented software components, modelling and dynamic simulation of hybrid systems, monitoring of semi-continuous process.

1. INTRODUCTION

In a very competitive economic context, the flexibility of the system of production can be a decisive advantage. Generally, this flexibility lies on the search for a greater reactivity to a fluctuating demand, but also to many risks occurring during the manufacture. In this context, a simple failure is considered as prejudicial. This is why the fault diagnosis is the purpose of a particular attention in the scientific and industrial community. The major idea is that the defect must not be undergone but must be controlled. Nowadays, the fault diagnosis remains a large research field. The literature quotes as many diagnosis methods as many domains of application (Venkatasubramanian *and al.*, 2003).
In our case, we deal with batch and semi-continuous processes which are the prevalent mode of production for low volume of high added value products. Such systems are composed of interconnected and shared resources, in which a continuous treatment is carried out. For this reason, they are generally considered as *hybrid systems* in which discrete aspects mix with continuous ones. Moreover, the recipe is more often described with state events (temperature or composition threshold, etc.) than with fixed processing times. As a consequence, the simulation of unit operations and physico-chemical evolution of products often necessitates the implementation of *phenomenological* models. In this context, the traditional tools such as continuous dynamic simulation or discrete event simulation are not well adapted to these problems and the use of hybrid dynamic simulators seems to be a better solution (Zaytoon, 2001).
In this framework, the first part of this communication focuses on the main fundamental concepts of the simulation library *PrODHyS*. These are illustrated through the simulation of a hydraulic system used as benchmark. Then, the potentialities of *PrODHyS* for process control are underlined. Finally the design of the supervision and diagnosis module currently developped is described.

2. *PrODHyS* ENVIRONMENT

The simulation of hybrid system has led to the development of several software such as *gPROMS* (Barton *and al.*, 1994), *BASIP* (Wöllhaf *and al.* 1996), in which the hybrid aspect is described via an imperative language. In parallel, various hybrid formalisms have been defined or obtained by extension of existing discrete or continuous formalisms (Zaytoon, 2001).
In this context, the research works performed for several years within the *PSE* research department *(LGC)* on process modelling and simulation have led to the development of *PrODHyS.* This environment provides a library of classes dedicated to the dynamic hybrid simulation of processes. Based on *object concepts*, *PrODHyS* offers extensible and reusable software components allowing a rigorous and systematic modelling of processes. The primal

contribution of these works consisted in determining and designing the foundation buildings classes. The last important evolution of *PrODHyS* is the integration of the dynamic hybrid simulation kernel (Hétreux *and al*, 2003, Perret *and al*, 2004, Olivier *and al*., 2005). Indeed, the nature of the studied phenomena involves a rigorous description of the continuous and discrete dynamic. The use of differential and algebraic equations (*DAE*) systems seems obvious for the description of continuous aspects. Moreover the high sequential aspect of the considered systems justifies the use of Petri nets model. This is why the *Object Differential Petri Nets (ODPN)* formalism is used to describe the simulation model associated with each component. It combines in the same structure a set of *DAE* systems and high level Petri nets (defining the legal sequences of commutation between states) and has the ability to detect *state* and *time events*.
A detailed description of this formalism can be found in (Hétreux *and al*., 2003). Figure 1 shows an example of evolution in the *ODPN*.

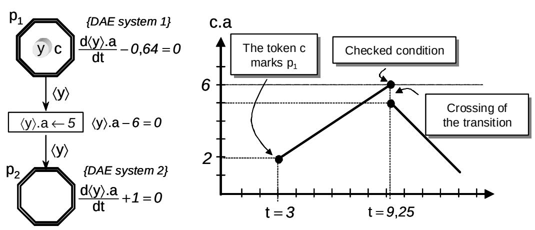


Fig. 1. *ODPN* evolution

Let us only notice that the object concepts and the Petri nets have been exploited through an *extended combined approach*. It consists in making interact these features either by "introducing objects into Petri nets" (use of individualized object tokens carrying properties and methods) or by "introducing Petri nets into objects" (description of the internal behaviour of an object).

3. PROCESS MODELING WITH *PrODHyS*

3.1 General structure of the simulation model

The simulation of a discontinuous process necessitates to model separately the *command* part (the *supervisor*) and the *operative* part (the *process*). Concerning the operative part, the specification of any device of *PrODHyS* is always defined according to two axes: a *topological* axis and a *phenomenological* axis. The topological axis defines the structure of the process (*system* vision): physical connections (material, energy, information) between the different parts of the process and hierarchical decomposition of the devices. The phenomenological axis rests on a mathematical model based on mass and energy balances and thermodynamic and physicochemical laws. Thus, the models of devices are reusable whatever the context. In addition, the *combined approach* is used to dissociate the model of material from the model of devices which contains the material. Thus, object tokens are reusable and reduce the complexity of the devices Petri nets. More details on the modelling of devices and material can be found in previous communications (Perret *and al*., 2004). On the other hand, the model of the command part is specific to the recipe and the process topology. It consists in describing the procedure of manufacture of each product. So, it specifies the assignments of resources and the sequence of tasks ordered in time necessary to the realization of each batch. All these models are merged only when a simulation model is instantiated. Thus, the size and the structure of the resulting *DAE* systems change all along the simulation, according to the actual state of the process.

3.2 Connections between « devices » PN and « recipe » PN

The exchanged signals, between the *command* part and the *operative* part, are modelled by a discrete place. The state of a signal state is associated to the marking of the corresponding place. In this framework, an entity is either an *active* device if it has one or more *signal* places (such as valves, pumps, feeds, column, captors) or a *passive* device if there is no direct relation with the recipe (such as simple tanks or reactors). These notions are illustrated on figure 2. It represents an operative sequence which permits the feed of a tank until a fixed volume is reached. The marking of the signal place of an active entity induces the evolution of its Petri net. This Petri net can itself induce the evolution of active or passive entities in cascade through the net composed with the connection of different material or energy ports.

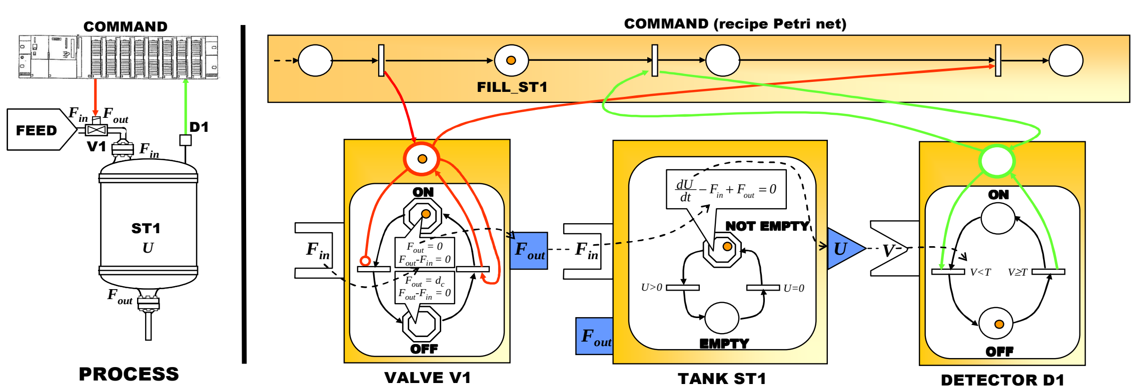


Fig. 2. Interactions between the command level and the process level

4. SIMULATION OF A HYDRAULIC SYSTEM

The considered hydraulic system (cf. figure 3) is inspired by a benchmark defined by the *AS193* "Diagnosis of the hybrid systems" (cf. www.univ-lille1.fr/lail/AS193/).

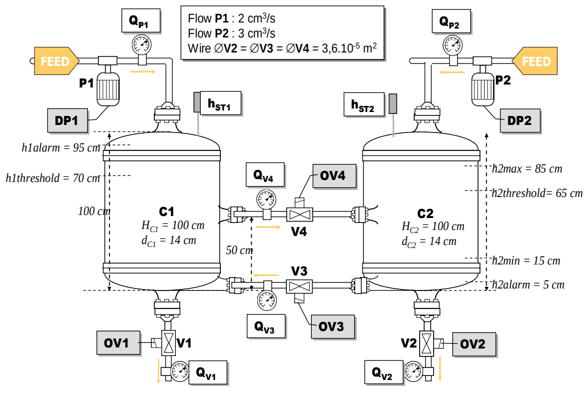


Fig. 3. *Flowsheet of the benchmark*

This system consists of two cylindrical tanks **C1** and **C2**, connected by two pipes with "on/off" valves **V3** and **V4**. The feed of the tanks is maintained by the "on/off" pumps **P1** and **P2**. The tank **C2** can be drained through the "on/off" valve **V2**. The valve **V1** is not used here. The instrumentation of the process is composed (in a maximal configuration) of 6 flow sensors and 2 level sensors.

The goal of the control device consists in maintaining the liquid level *h2* in **C2** between the heights *h2min* and *h2max* by controlling the valve **V4**. The valve **V3** is opened only when the level in **C2** is such *h2≤h2alarm*.

The implemented command is voluntarily simple. Because the command law does not take into account the level *h1* in the tank **C1**, the objective can not always be ensured. The Petri net associated with the command level is presented on figure 4:

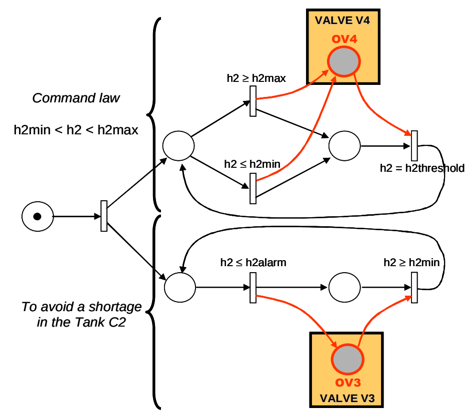
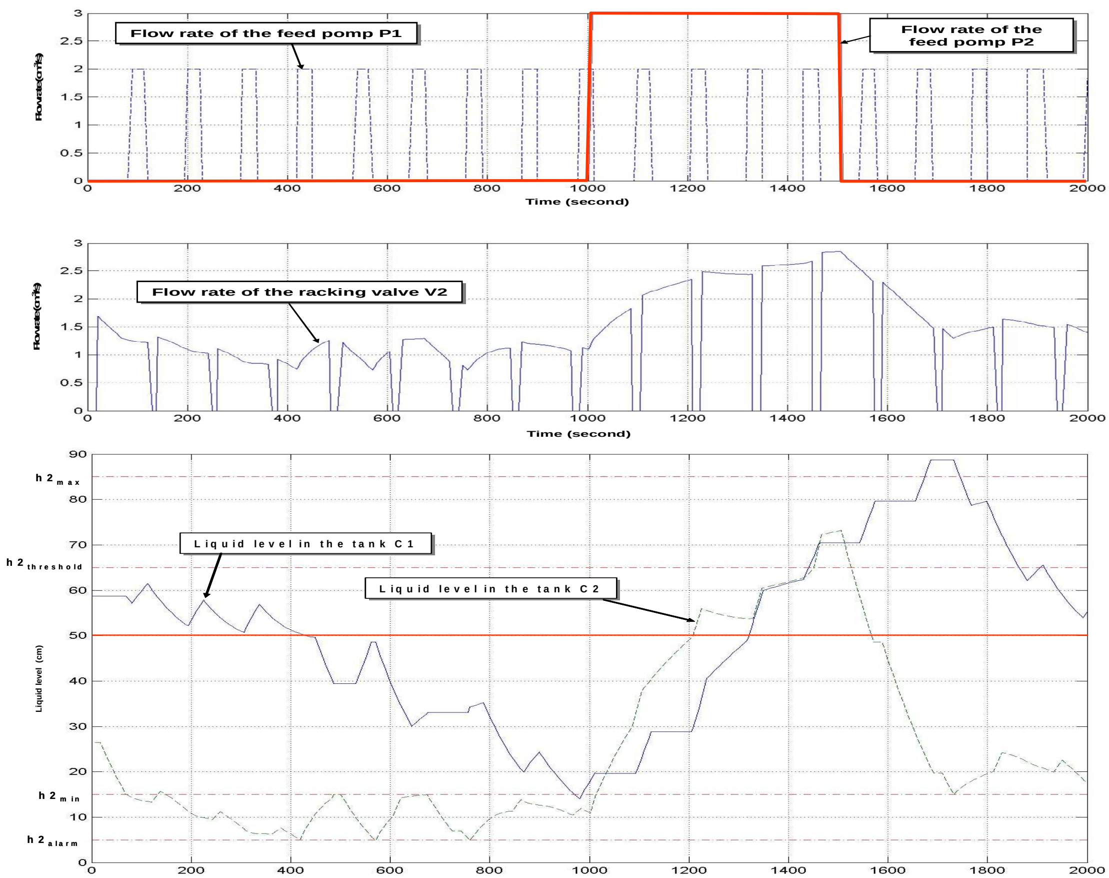


Fig. 4. *Command Petri net*

In this context, various scenarii can be simulated by action on the pumps **P1** and **P2** and the valve **V2**. For the set of parameters indicated on figure 3 and the scenario shown on the followed figures, the simulation results are presented on figure 5.



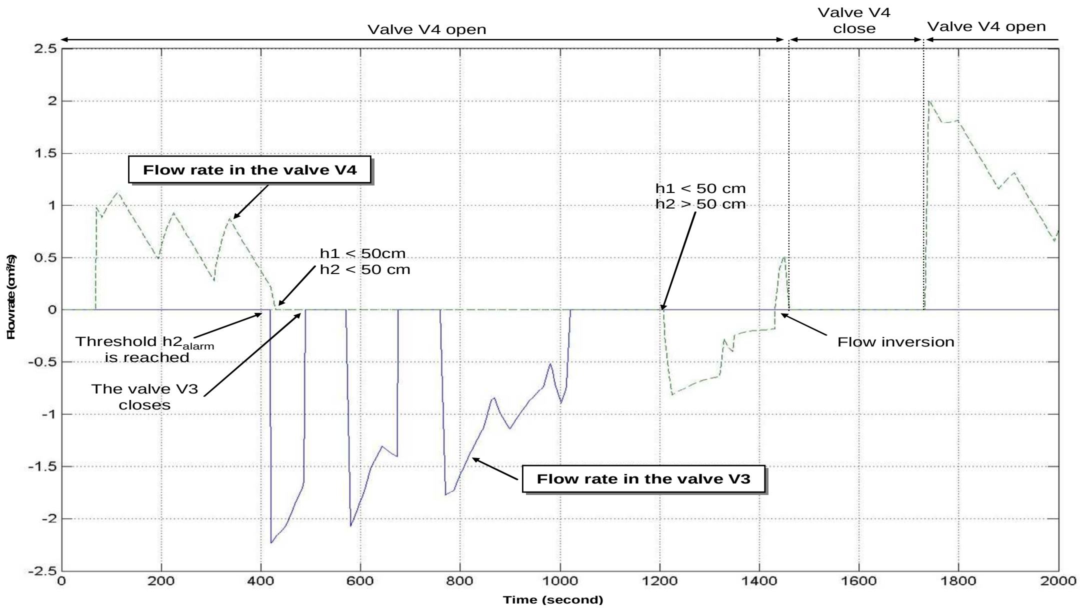


Fig. 5. *Simulation results*

5. USE OF DYNAMIC HYBRID SIMULATION IN A MODEL BASED DIAGNOSIS SYSTEM

Nowadays, for reasons of safety and performance, monitoring and supervision have an important role in process control. The complexity and the size of industrial systems induce an increasing number of process variables and make difficult the work of operators. In this context, a computer aided decision-making tool seems to be wise. For this purpose, the model of simulation of *PrODHyS* is used as a *reference* model to implement the functions of detection and diagnosis. The global principle of this system is shown on the Figure 6. In order to obtain an *observer* of the physical system, a real-time simulation is done in parallel. So, a complete state of the system will be available at any time.

5.1 Fault detection

The supervision module must be able to treat the faults of the physical systems (leak, energy loss, etc.) and the faults of the control/command devices (actuators, captors, etc.). As defined in (De Kleer *and al.* 1987), our approach is based on the hypothesis that the reference model is presumed to be correct. Thus, it is based on the comparison between the predicted behaviour obtained thanks to the simulation of the reference model (values of state variables) and the real observed behaviour (measurements from the

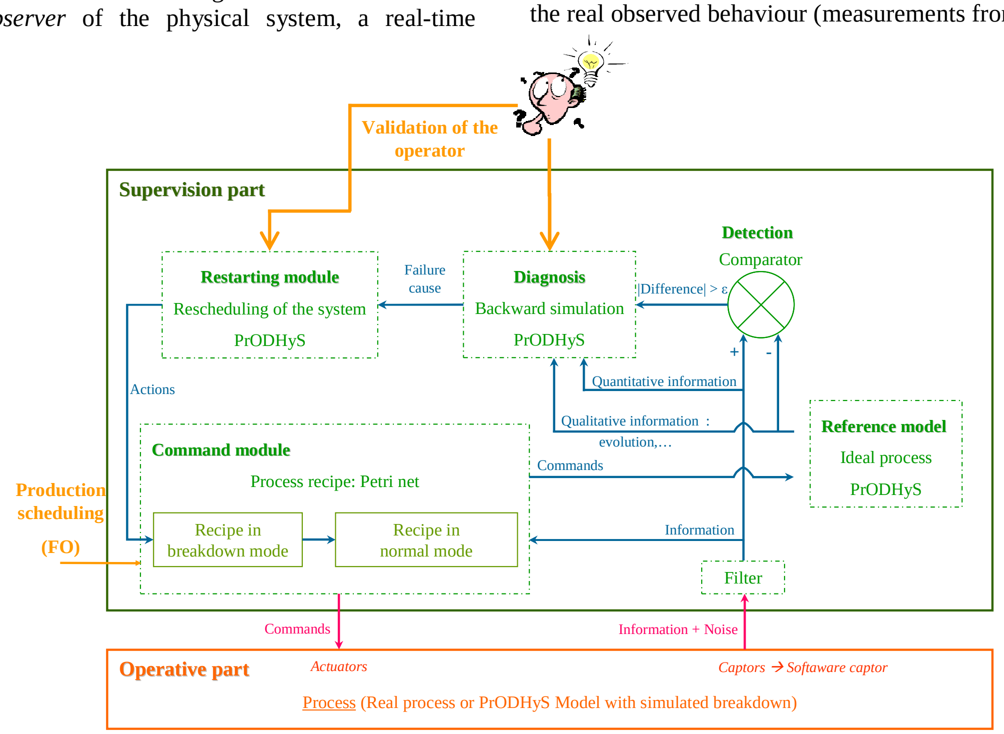


Fig. 6. *Principle of the supervision module*

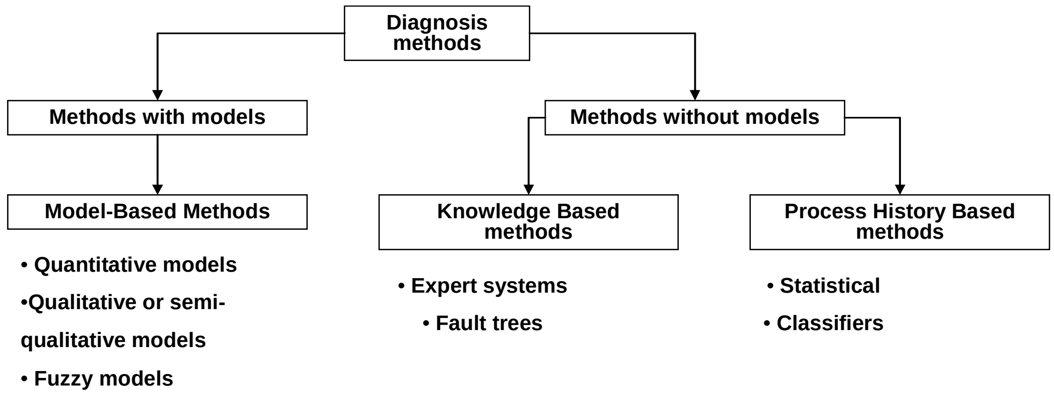


Fig. 7. *Classification of diagnosis methods*

process). Detection is realized by comparison with fixed thresholds. This method lies in the detection of the instant for which the monitored variables go beyond the bounds defined by the thresholds of the objective value (values of the variable within the reference model). Although some methods, such as detection with a variable threshold, can minimize the number of erroneous detections, (Duviella, 2005) indicates that the detection with a fixed threshold is more robust with the disturbances. In addition, a result can be obtained rather quickly and it is easy to implement and to parameterize this method.

For a consistent execution of this task, the measurements must be filtered in order to eliminate the noise. Nevertheless, the value ε, beyond which the difference between measurements and model variables is considered as a defect, remains a delicate point to evaluate. This value is often obtained from a compromise of a series of simulations, in which his value is customized.

Moreover, the evolution of the simulation must be synchronous with the evolution of the real process. However, this feature can not be always ensured. When the reference model is either ahead or late, a retiming of the reference model on the real process is then necessary in order to be able to validate a detection test.

Despite these mecanisms, let us underline the difficulty of the decision stage in the detection. Indeed, some particular states of a system can be found where a defect behaviour seems to be similar to a normal behaviour; in this condition, it is impossible to affirm the absence of defect. This is why the uncertainty on the veracity of the detection tests may lead to unsuccessful diagnosis.

5.2 Fault diagnosis

When the occurence of a defect is proven, the diagnosis stage is launched. This task must be able to determinate a possible cause, compatible with information coming from the process and the reference model. It consists generally in determining the defect components or organs of the physical system. A logical reasoning based on the knowledge available of the system is used. The fault diagnosis for the industrial processes is a large research field. Many methods and many classifications exist in the literature. Figure 7 presents a part of the classification proposed in (Venkatasubramanian *and al*. 2003). Our objective is to couple a model based method (Mosterman *and al*. 1999) with a method based on historical data. In this framework, two research ways are emphasized.

The first approach is based on a tool which integrates qualitative knowledge of the process (knowledge base). It obeys to the rules of the type « IF condition THEN cause » (classification methods). However, to refine the discrimination and the interpretation of the noticed defects, it seems to be attractive to exploit information from the simulation of the reference model, in particular the values of the state variables and the values of their derivatives. As a matter of fact, even if the measurements of the process are pertinent for the command, they are often insufficient for the diagnosis. Moreover, the simulation of the reference model allows the analysis of different scenarios and the validation (or not) of the deductions from the knowledge base.

The second approach consists to exploit the backward hybrid simulation of the process. Let us note that the Petri net is not bijective. Indeed the same final marking does not lead to the same initial marking. This induces the possibility of a conflict of transitions. The historical data of the process (from the real process and from the reference model) and the classification can solve this indeterminism by introducing probabilities in the transitions.

5.3 Modelling of defect

The implementation of this system is rather complex and it is still in development. So, in order to test our prototype, the supervised process is currently simulated with *PrODHyS.*

In this condition, the reference process (without defects) and the monitored process (with possible defects) have the same recipe: the command part doesn't change. Thus the defect appears in the modelling of the devices. The associated simulation model is build from specific *Device* objects in which the faults are defined in an intrinsic way.

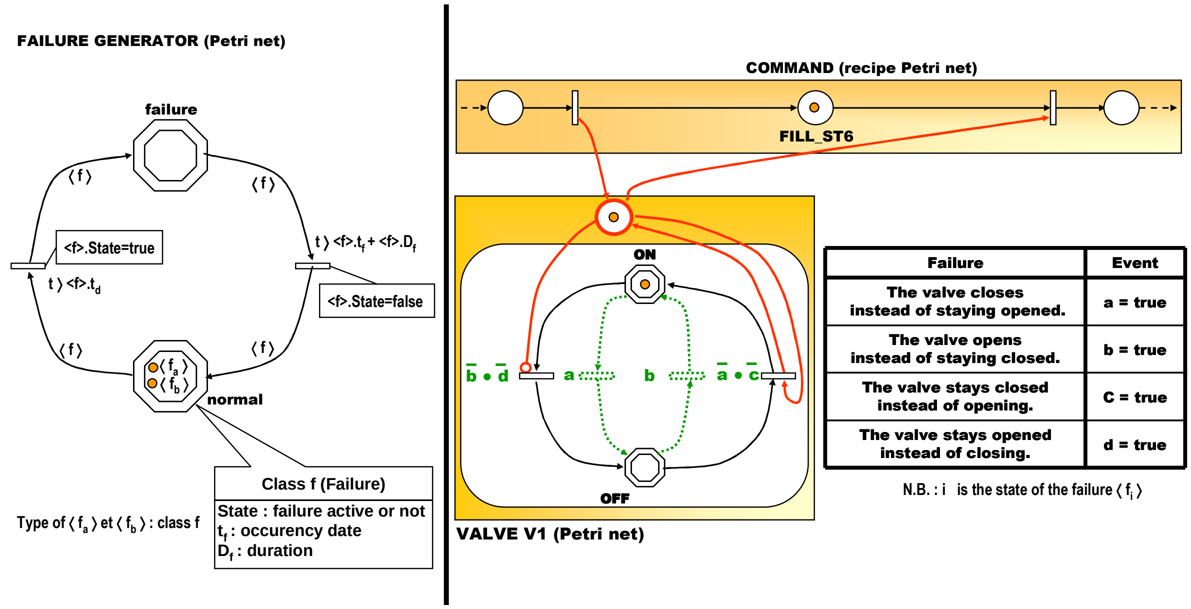


Fig. 8. *Modelling of a faulty valve*

In order to simplify the analysis of the system, the failures are generated by the simulation manager thanks to a calendar which lists the defect, its occurency time and its duration.

The figure 8 represents the modelling of a faulty valve. In the studied case, as we consider only the failures "a" and "b", the place *Normal* of the failure generator is only marked by two object tokens $<f_a>$ and $<f_b>$ (type of the objects: the class failure).

In a second time, during the validation stage, the failures are generated on autonomous and random commutations.

6. CONCLUSION

The object oriented approach brings many advantages in terms of software quality (extensibility, reutilisability, flexibility), but especially in terms of modelling thanks to a hierarchical and modular description which is both abstracted and close to reality. Based on these concepts, *PrODHyS* provides software components intended to model and simulate more specifically the industrial processes. The implementation of a formalism on high level of abstraction associated with powerful numerical methods of integration led to the construction of a robust hybrid dynamic simulator.

In this communication, the potentialities of *PrODHyS* are illustrated through the modelling and the simulation of a hydraulic process. The works in progress aim at integrating this simulation model within a model based diagnosis system. The coupling between a method of classification and a method of backward simulation is able to reduce the number of possibilities for the cause of the observed defect and to validate the possible fault.

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