INTEROPERABILITY BETWEEN THE IMPROVED METAGRAPh HAD AND GRAFCET: CASE OF THE POWER NETWORK OF CAMEROON

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ABSTRACT
This article presents the modeling and the control of the Power Network of the Southern Cameroon (PNSC). We are using the effectiveness of improved version of HAD, which allows an object modeling of hybrid and complex dynamic systems. Then we show how to derive from the models obtained, the Grafcet models of the PNSC, by implementing bridges between HAD and the reference language of Grafcet. The application to the Control and the Monitoring of the Cameroonian electrical Power Network enables us to better determine the complexity of the system, thanks to an approach structuring the various objects by taking in consideration the physical structure and the causality of their interactions. On the other hand, interoperability with Grafcet would facilitate the implementation and the synthesis of discrete or hybrid controllers.

Keywords: Grafcet, HAD, UML, Modeling, Control, Power network, Hybrid Dynamic Systems

1. INTRODUCTION
The development of the industrial systems caused some reflections on the physical, descriptive and representative behavior of the industrial processes. Today, within sight of the studies led by some researchers [1] [2] [3] [4] [5] [6] [7] [8] [9] [10] [11], it is important to note the difficulty to analyze the complex industrial systems correctly. Several approaches of description of the systems exist [9]: the Discrete Systems (DS), the Continuous Systems (CS) and the Hybrid Dynamic Systems (HDS) regrouping the two first. HAD (Hybrid Activity Diagram) is the synthesis of a breeding of knowledge and the concepts of the Control Engineering (CE) and the Software engineering (SE). The setting up of his formalism and his meta-model, is the subject of numerous research [1] [4] [7] [12] [8]. His principle is at a time to model the Discrete part and the Continuous part of a Hybrid Dynamic System (HDS), contrary to other tools like the Grafcet [23] that concentrates a lot more on the discrete part. HAD has been enhanced lately by [2] [3], in his formalism and his application field. It allows him of model more big and more complex dynamic systems. In this article, we show compatibility between the improved version of the HAD meta-graph and the Grafcet, while considering the computerization of the command of the Power Network of the Southern Cameroon (PNSC / RISC – Réseau Interconnecté Sud Cameroun). This project is interesting, since as regards to research, the electric power networks are the subject of several jobs in the scientific community [13] [14] [15] [16]. But most are about the modeling of the network, the measures, the diagnosis and the analysis of the networks in general. But the hybrid modeling problem remained an open research field.

In the structure of this article, we present the Electric Power Networks in section 2, the analysis of the hybrid computer systems and the modeling of the PNSC by HAD in section 3. Once the HAD model constructs, we present the transformations between the meta-graphs of HAD and the Grafcet, with an application to the case of the PNSC in section 4. The article ends by the conclusion and perspectives in section 5.

2. DESCRIPTION OF THE POWER NETWORK
The Electric Power Network (PN) is a set constituted of the direct current or alternative generators, of the transformers, the electric components, the equipments, the aerial and underground cables permitting to serve the subscribers in the optimal technical-economic conditions.

The Cameroon power system consists of two separate networks – the northern and southern grids.
- The northern grid is supplied by one hydro-electric generating station (Lagdo) and a thermal plant. The southern grid is supplied by two hydro-electric generating stations and four thermal power stations. Hydroelectric power accounts for 77% of the total output of 1028MVA.
- The southern grid, which produces and distributes over 91% of the total energy, is considerably more extensive than the northern grid. The rest being provided by thermal stations. The figure 1 presents the map of distribution of
the two networks on the territory of Cameroon. The PNSC is characterized by different levels of voltage, presented in table 1.

<table>
<thead>
<tr>
<th>Domains of voltage</th>
<th>Abbreviations</th>
<th>General level of voltage (kW)</th>
<th>Level of voltage to Cameroon (kW)</th>
<th>Type of Power Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High-Voltage</td>
<td>VHV</td>
<td>100 à 800</td>
<td>110 et 225</td>
<td>Transportation and interconnection</td>
</tr>
<tr>
<td>High-Voltage – B</td>
<td>HV B</td>
<td>50 à 90</td>
<td>90</td>
<td>Distribution</td>
</tr>
<tr>
<td>Medium Voltage</td>
<td>HV to MV</td>
<td>1 à 40</td>
<td>15 et 30</td>
<td>Distribution Medium Voltage (MV)</td>
</tr>
<tr>
<td>Low Voltage</td>
<td>LV</td>
<td>0,1 à 0,44</td>
<td>0,22 à 0,41</td>
<td>Distribution Low Voltage</td>
</tr>
</tbody>
</table>

Figure 1. The Cameroon electric power system [17]

Table 1. Levels of voltage of the PNSC by types of Power Networks in Cameroon

The energy produced in the Hydro-electric Control Stations is transported toward big regions of consumption by VHV networks. At the time of the passage of the current or at the time of the interruptions, the elements of the PN are governed by physical phenomena, illustrated by mathematical equations. It is the dynamic part of the PN. The set of the technical processes permitting to assure the continuous check of the PN (tele-driving or monitoring center) include some elements as: power station of measure, sensors etc.

The Hybrid Dynamic System meets in the Command of a PN on the shutter of the power adaptation. The production (input) must be adapted to the consumption (output). Thus, we must control the parameters (current, voltage, power), what requires some sensors having to fetch the output parameters to compare them to the input parameters. The Command of the PN is considered like a closed-loop system and his transfer function is characterized by the product of the mathematical equations of every object of the system in order to translate the physical and dynamic model of the system. It will be constituted of static and continuous properties of the system. This function expresses itself by the equation (1), useful for the stability, the velocity and the precision of the Network.
\[
\frac{\text{consumption}}{\text{production}} = \frac{\text{transportation}}{1 + \text{transportation} \times \text{sensor}} 
\]  

(1)

The heart of the system is the power station of measure that to every instant calculates, check and informs then with the help of his sensors and microcontrollers, on the balance between the production and the consumption, reacts on the circuit breaker in case of unbalance, via Programmable Logic Controller. Thus, as in [16], the power station of measure and his setting represent the Commands Part. The Operational Part being constituted of the circuit breakers that in High Voltage (HV), undergo the destructive effect of the electric bow, mathematically modeled by the difference equation [2]. The reader will be able to consult [18] and [19] for the establishment of the equation and his resolution.

\[
\frac{d}{dt} i_{\text{ligne}} + \frac{R_{\text{ligne}}}{L_{\text{ligne}}} i_{\text{ligne}} = \frac{e(t) - u_{\text{act}}}{L_{\text{ligne}}} 
\]  

(2)

3. ANALYSIS OF THE HYBRID SYSTEMS AND THE POWER NETWORK

3.1. Classic approaches of Description

The modeling of the Hybrid Dynamic Systems can be performed with the help of various formalisms, among whom: Hybrid State-charts, Mixed Petri Networks, Hybrid Machines, Colored Petri Networks, etc. For a description retailed of these different formalisms, the reader will be able to consult [20] [11] [9] [10] [21]. One notes as [7] that the presented above approaches don't provide the modularity and the upgradeability required for the representation of complex systems. On the other hand, these tools have more developed for theoretical research and are not always adapted to the precise representation of the physical or real systems. It is why we grant an interest to the contribution of the new approaches inspired of the Software engineering and object-oriented methods, like HAD.

3.2. Fast presentation of HAD (Hybrid Activity Diagram)

HAD meta-model is a tool adapted to the modeling of the HDS that articulates mainly around the following aspects:
- Modification of Activity Diagrams to incorporate discrete and continuous signals at the inputs and outputs
- Incorporation of structures for specifying causal relationships between components of a control system
- Convertibility between a UML specification of a hybrid model and a Grafcet of the system

With HAD, a module of activity or influence is constituted of a set of activity classes. Some of the components are presented to the figure 2.

Figure 2. Sub-classes of "ActivityModule" [4]

The notion of "ActivityClass" that we present here constitutes an organ of causality (it undergoes some influences and also exercise some influences). This aspect is illustrated to the figure 3.

Figure 3. Fundamental principle of HAD: causality [4]

For a better description of the HAD meta-model, the reader will be able to consult [3] [2] [4] [7] [12] [8].

3.3. Modeling of the Power Network

We described all models schematically corresponding HAD to the command of the PNSC (about ten), that we won't present in this article, due to a lack of space. On the other hand the reader will find all details of all these diagrams in [19] and [18]. The system being very big, we present an excerpt of the HAD models rightly to the figures 4a and 4b. On the figure 4b, the objects 15, 16, 17 and 18 show the calculations (the Grafcet doesn't make it) performed by the power station of measure serving to the starting up of one or all reserves at a time, whereas the E2 object represents a component having to influence the system of the outside: it is a switch of activation.

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Figure 4-a. Excerpt of the HAD diagram of the command system of the PN
Figure 4-b. Excerpt of the HAD diagram of the command system of the PN (following)
These HAD models respect the classic Control concepts: The objects are identified by their unique number [20]. The parallel sequences and the relations of causality are explicit as prescribed in [2] [4] [7] [9] [20], and without forgetting the delayed actions as is illustrated in the objects 19, 20, 21, and 22 of the figure 4b. HAD performs a modeling structured of abstract elements of complex and hybrid (continuous and discrete aspects) systems, encourage the modularity and the exchanges (transfers) between objects, he also shows his/her/its efficiency in the analysis and the simulation of the physical phenomena [3] [7]. The models present a more precise abstraction of the system, the operations performed preceding the command of the circuit breakers are materialized (tasks of the measure power station), the representative model of the electric bow under the shape of difference equation is present, and the links of causalities are expressed.

4. RULES FOR CONVERTING HAD MODELS INTO GRAFCET

We are going to describe the tools of transformation of the HAD meta-graph toward the Grafcet, to complete and finalize compatibility between the two metamodels, and whose principle has already been introduced in [3]. It puts in evidence and guarantees a compatibility between HAD and the Grafcet language.

To permit to achieve the objectives easily, we cut the process of passage in two phases: the Intermediate Model (IM) and the Final Grafcet Model (FM). It will present in more an advantage during the implementation of software of HAD simulation and automatic transformation HAD - Grafcet.

4.1. Conversion between HAD and Intermediate Grafcet Model


<table>
<thead>
<tr>
<th>Parallelism and Conditional Behaviour - HAD</th>
<th>Parallelism and Conditional Behaviour - Grafcet IM</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="HAD diagram" /></td>
<td><img src="image2" alt="Grafcet diagram" /></td>
<td>The ActivitySelectONs when they comprise an operation, one inserts a stage before the selection in OR and the operation is considered like being the associated action.</td>
</tr>
<tr>
<td><img src="image3" alt="HAD diagram" /></td>
<td><img src="image4" alt="Grafcet diagram" /></td>
<td>The ActivitySelectOFFs when they comprise an operation, one inserts a stage after the selection in OR and the operation is considered like being the associated action.</td>
</tr>
<tr>
<td><img src="image5" alt="HAD diagram" /></td>
<td><img src="image6" alt="Grafcet diagram" /></td>
<td>The ActivityThreadONs when they comprise an operation, the selection in AND generate two stages thereafter and the operation is considered like being the associated action.</td>
</tr>
<tr>
<td><img src="image7" alt="HAD diagram" /></td>
<td><img src="image8" alt="Grafcet diagram" /></td>
<td>The ActivityThreadOFFs when they comprise an operation, the selection in AND precede a stage and the operation is considered like being the associated action.</td>
</tr>
<tr>
<td><img src="image9" alt="HAD diagram" /></td>
<td><img src="image10" alt="Grafcet diagram" /></td>
<td>The ActivityThreads / Thread when they comprise an operation, one intersperses a stage between the two selections in AND, the operation is considered like being the associated action.</td>
</tr>
<tr>
<td><img src="image11" alt="HAD diagram" /></td>
<td><img src="image12" alt="Grafcet diagram" /></td>
<td>The ActivitySelects / Thread when they comprise an operation, the selection in AND generate two stages thereafter and the operation is considered like being the associated action.</td>
</tr>
<tr>
<td><img src="image13" alt="HAD diagram" /></td>
<td><img src="image14" alt="Grafcet diagram" /></td>
<td>The ActivityThreads / Select when they comprise an operation, one intersperses a stage between the two selections in AND and OR, the operation is considered like being the associated action.</td>
</tr>
<tr>
<td><img src="image15" alt="HAD diagram" /></td>
<td><img src="image16" alt="Grafcet diagram" /></td>
<td>The objects &quot;Begin&quot; and &quot;End&quot; disappear.</td>
</tr>
<tr>
<td><img src="image17" alt="HAD diagram" /></td>
<td><img src="image18" alt="Grafcet diagram" /></td>
<td>The ActivityClasses become the stages and the first ActivityClass that receive the message coming from &quot;Begin&quot; is considered like initial stage. The operation that it comprises is considered like an action.</td>
</tr>
<tr>
<td><img src="image19" alt="HAD diagram" /></td>
<td><img src="image20" alt="Grafcet diagram" /></td>
<td>Transition This object specifies the transition; the output message translates the condition to the receptiveness.</td>
</tr>
<tr>
<td><img src="image21" alt="HAD diagram" /></td>
<td><img src="image22" alt="Grafcet diagram" /></td>
<td>Links that join the different objects of the system</td>
</tr>
<tr>
<td><img src="image23" alt="HAD diagram" /></td>
<td><img src="image24" alt="Grafcet diagram" /></td>
<td>Link: external-object or Object – external</td>
</tr>
</tbody>
</table>

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4.2. Conversion between Intermediate Model and Final Grafcet Model

For this phase, it is sufficient to cover the intermediate Grafcet of the top downwards, while applying the following rules:
- To suppress all parallel and selective sequences not having any embedded stages.
- To perform the logic product of the Transition-conditions consecutively aligned without stages separating them.

The different cases are presented in the table 3.

<table>
<thead>
<tr>
<th>(IM) Consecutive Transition Conditions</th>
<th>(FM) Equivalence in final model</th>
</tr>
</thead>
<tbody>
<tr>
<td>a b</td>
<td>a.b</td>
</tr>
<tr>
<td>c</td>
<td></td>
</tr>
<tr>
<td>a b</td>
<td>a.c</td>
</tr>
<tr>
<td>a c</td>
<td>b.c</td>
</tr>
<tr>
<td>a b</td>
<td>a.c</td>
</tr>
<tr>
<td>c</td>
<td></td>
</tr>
<tr>
<td>a c</td>
<td></td>
</tr>
<tr>
<td>a b</td>
<td>a.b.c</td>
</tr>
</tbody>
</table>

It is necessary to specify here that all rules of conversion presented above have been examined with success on different systems [19][18].

4.3. Application in the PNSC

We are going to present the intermediate and final models for the case of the PNSC. While applying the rules and correspondences of the table 2, we get the excerpt of intermediate model of the figure 5.

For reasons of readability and simplification (of Grafcets), we are going to conduct an affectation of the equivalences of Transition-conditions that will be used for the Grafcet of the system:

- One will indicate by:
  \[ \Delta_3 > 0 \rightarrow b \]
  \[ (\Delta_1 > 0, \Delta_2 < 0) \rightarrow c \]
  \[ (\Delta_1 < 0, \Delta_2 > 0) \rightarrow c' \]
- One will indicate by: \[ \Delta_A > 0 \rightarrow f_A \]
  \[ \Delta_A = \sum S - (D - C_{A1} - C_{A2}) ; \]
  \[ \Delta_{A1} = \sum S - (D - C_{A1}) ; \]
  \[ \Delta_{A12} = (C_{A2} - C_{A1}) \]
  \[ (\Delta_{A2} > 0, \Delta_{A2} < 0 \rightarrow g_{A2}) \]
  \[ (\Delta_{A1} > 0, \Delta_{A1} < 0 \rightarrow g_{A1}) \]
  \[ (\Delta_{A12} > 0, \Delta_{A12} < 0 \rightarrow h_{A12}) \]

In an analogous way, we can have [18]:

- \[ f_B; f_B; g_B; g_c; l_B; l_c; h_B; h_c \]
- The complements are the next one:
  \[ a', b'; c'; a'; e'; f_A'; f_B'; f_C'; g_{A1}; g_{A2}; l_{A1}; l_{A2}; l_{B1}; l_{B2}; k_A; k_{B1}; k_{B2}; h_A; h_{B1}; h_{B2}; h_C \]
Synchronization of the alternator
R0=1
K0=1

Closing of the circuit breaker d0
d0=1
Uarc0 = 0

Updating of the consumption

Evaluation of \( \Delta \)
Selection of the process

\( \Delta > 0 \)
\( \Delta < 0 \)

Synchronization of the reserve R1; R1=1
(t/3/15min)
K1=1

\( d1=1 \)
Uarc1=0

Synchronization of the reserve R2; R2=1
(t/4/15min)
K2=1

\( d2=1 \)
Uarc2 = 0

Synchronization of the reserve R1; R1=1
(t/6/15min)
K1=1

Synchronization of the reserve R2; R2=1
(t/7/15min)
K2=1

\( d1=1 \)
Uarc1=0

\( d2=1 \)
Uarc2 = 0

\( \Delta_1 > 0 \)
\( \Delta_1 < 0 \)

Evaluation of \( \Delta_1 \), selection of the process

Figure 5-a. Excerpt of the intermediate model HAD-Grafcet of the PN

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Evaluation of Synchronization of the alternator

For the generation of the Grafcet FM, we present to the figure 6, just an excerpt of the final Grafcet gotten after transformation. The final Grafcet pulled of [18] is in conformity with the standards of the Control Engineering and can be implemented.
Figure 6-a. Excerpt - Final Model, Grafcet of command of the PN gotten of the HAD
Comments on the Grafcet (FM - Final Model) gotten

After this "transformation", we can say that the model gotten present more of readability (more explicit), in relation to the source mode presented in [19] [18]. For example, we observe that the stage 11 is subdivided in two stages 15 and 16. The separation (detachment) of these stages represents a simultaneous sequence. This case is illustrated to the figure 7.

Figure 6-b. Excerpt - Final Model, Grafcet of command of the PN gotten of the HAD (following)

Figure 7. Comparison between Grafcet of departure - Grafcet gotten by HAD transformation

We also observe the apparition of abstract stages as the stage 3 that brings some more clarity to the diagram. The HAD modeling can be seen under an angle of simulation. Thus, we observe more details again on this model. It is relative to the "sub programs" that explains the variation of the electric consumption in the PN.

The gotten model (final Grafcet) respects the rules of the Grafcet [23] above all. It puts in evidence the "detachment" of the objects (it presents the operational sequences of functioning of an object opposite the other). We observe the presence of the abstract stages that brings more precisions to the new Grafcet.

All this shows that the HAD-Grafcet conversion succeeds to an even more explicit model, while remaining compatible with the source Grafcet.

5. CONCLUSION AND PERSPECTIVES

In the setting of the modeling of the HDS and the PN, we applied the improved version of the HAD Metamodel, associated to the Grafcet language, in order to enhance their efficiency. To the term of the modeling of an exercise of adaptation of the apparent power constantly produced to a consumption increasing in an excerpt of the PN of Cameroon, we showed compatibility between HAD and Grafcet with satisfaction. It allows the adepts of the Grafcet to benefit from advantages of HAD in the modeling, while having the possibility to produce and to operate their traditional Grafcet, for specific needs.

In short, HAD confirms its strength between two poles:
- Enhancement of UML that he spreads for the modeling of the HDS
- Modeling of the HDS better than the Grafcet that he completes

What makes of HAD an interesting tool and whose subsequent function is to facilitate by his/her/its syntax and his structure, the implementation of a software application that is the subject of our present works. We put in practice the technical specifications and the implementation of the simulator of HAD models in order to generate the corresponding Grafcet, automatically (from a HAD diagram constructs) while implementing directly in the software the rules of conversion described.
7. REFERENCES


