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Control by RST controller of systems presented by Multimodel

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Abstract-**This paper presents a comparative study about multimodel controls by RST controller. Two structures are adopted; namely the multimodel controls obtained by fusion of local controls and multimodel controls obtained by fusion of parameters of local RST controllers. To emphasize the importance of the latter structure, a comparative study of the two structures described above is subsequently showed in a simulation example. This work proved the contribution of the RST control by fusion of parameters in improving the precision and disturbance rejection**.

***Mots clefs*— RST controller, multimodel control, fusion of locals controls, fusion of parameters.**

NOMENCLATURE

RST : a digital controller which composed by polynomials S, R and T. S means Simplify, R means Return and T means Track, it ensures regulation and tracking.
PID : Proportional-Integral-derivative
SISO : Single-input Single-output
PLC : Programmable Logic Controller

I. INTRODUCTION

Most of the encountered systems are complex. Modeling such systems is very hard, so researchers take some hypothesis to neglect some effects of some factors in order to simplify the mathematical representation. During the last decades, a new approach has appeared: the multimodel approach. It is based on the decomposition of a complex system into a set of linear simple systems. These local and simple systems form the basis of models. This approach is used for identification [1], [5], control [2], [3], [4] and diagnosis [18], [19]. In this paper, we focus on applying multimodel approach in control: we talk about “multimodel control “. It consists in developing partial controls for each local system. The multimodel control is obtained by the interpolation of these local controls [2]. Thereby, this approach makes the identification, the control and the diagnosis of a complex system easier. It allows the extension of some methods, conventionally used with linear systems, to be used with complex systems such as Luenberger’s observator [18].

Among controllers used only for linear systems, we mention the RST controller, it is a digital controller based in the determination of digital filters R, S and T. This type of controllers ensures simultaneously regulation and tracking. It allows also the rejection of different types of disturbances [9]. The technological development favors the use of digital controllers, so many researchers are interested to develop, improve and broaden their use for many types of systems [20]. In this paper, we suggest the use of two types of multimodel controls [2] with RST controllers to control and to take advantage of RST controller’s performances for nonlinear systems.

This paper is organized as follows: In the first section, the procedure of synthesis of RST controller will be presented. Then the multimodel control and their different types will be illustrated in section 3. Finally, in section 4, a simulation example will be used to implement this multimodel control in order to show its robustness and its performances with complex systems.

II. RST CONTROLLER

The technological development is in favor of digital controllers replacing analogic controllers.

The advantages of digital controllers lie on the easy modification of their parameters and structures, the parameters adaptation in real time and the ease of implementation. [10]

Many researches have been interested in the design of digital controllers [8], [11]. Others use them in some applications, such as: wind turbine control [4], regulation of a battery charger for electric vehicles [15] and blood pressure regulation [16]

The polynomial RST controller is used for single-input single-output systems (SISO) (modeled by transfer function). It is characterized by two degrees of freedom: tracking and regulation [9], [11].

The canonical structure of RST controller is illustrated in Fig.1

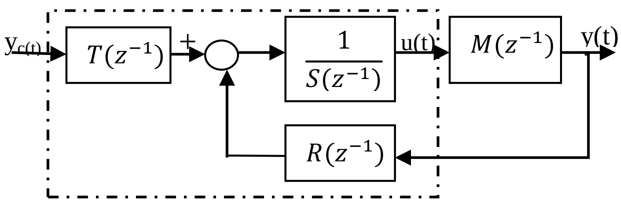

Fig.1: Canonical structure of RST controller

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Where y_c (t) is the set point or the desired tracking trajectory, y (t) is the output, u (t) is the control signal applied to model.

The controller polynomials are S (z^{-1}), R (z^{-1}) and T (z^{-1}) while M (z^{-1}) is the transfer function of process given by:

$$M(z^{-1})=\frac{z^{-d}B(z^{-1})}{A(z^{-1})} \quad (1)$$

Where $B(z^{-1}) = b_0 + b_1z^{-1} + b_2z^{-2} + \cdots + b_mz^{-m}$ as 'm' is the degree of the polynomial B and $A(z^{-1}) = a_0 + a_1z^{-1} + a_2z^{-2} + \cdots + a_nz^{-n}$ as 'n' is the degree of the polynomial A.

The design of RST controller consists of:

- Firstly, choosing the desired performances: stability, rapidity, disturbance rejection, tracking trajectory…) and writing the target model.
- Then, calculating of the polynomials R, S and T.

In [8] and [11], authors factorize the polynomials R and S into a fixed part and another part to be designed according to stability performances.

$$S(z^{-1}) = H_s(z^{-1}) * S_1(z^{-1}) \quad (2)$$

$$R(z^{-1}) = H_r(z^{-1}) * R_1(z^{-1}) \quad (3)$$

The fixed parts $H_s(z^{-1})$ and $H_r(z^{-1})$ guarantees the rejection of some class of disturbance or avoid the excitation of the control signal at some frequencies. Reference [9] shows how to determine fixed parts of polynomials R and S in order to feature some performances. Indeed, they distinguished three formulas of $H_s(z^{-1})$:

* $H_s(z^{-1}) = 1 - z^{-1}$
Where the type of disturbance rejection is a step
* $H_s(z^{-1}) = (1 - z^{-1})^2$
Where the type of disturbance rejection is a ramp
* $H_s(z^{-1}) = 1 + \alpha z^{-1} + z^{-2}$
Where $\alpha = 2 * \cos(wT_e)$ for disturbance rejection of harmonic signal.

A) Determination of polynomials degrees

The polynomial $P(z^{-1}) = p_0 + p_1z^{-1} + p_2z^{-2} + \cdots$ contains the desired poles which have to be imposed to the system. In [8], the authors emphasize the problem of choosing performances for multimodel. They proposed two new approaches to achieve a robust controller in terms of stability and performances: the multimodel pole placement and multi objective optimization.

Researchers in references [17] and [18] focused on the design of a robust controller by combining pole placement method and the study of sensitivity functions study: disturbance-input and disturbance-output, to ensure the robustness of performances and stability.

The calculation of degrees of P, R and S polynomials is determined according to the following rules [8], [9]:

$$\deg(P) \le \deg(A) + \deg(B) + \deg(H_s) + \deg(H_r) + d - 1 \quad (4)$$

$$\deg(S_1) = \deg(B) + \deg(H_r) + d - 1 \quad (5)$$

$$\deg(R_1) = \deg(A) + \deg(H_s) - 1 \quad (6)$$

B) Determination of polynomials R and S

The coefficients of R and S polynomials are obtained by resolving Bezout equation:

$$A(z^{-1})S(z^{-1}) + z^{-d}B(z^{-1})R(z^{-1}) = P(z^{-1}) \quad (7)$$

we resort so to look for $X=[s_0\ s_1 \ldots r_0\ r_1\ r_2 \ldots]^T$ and this by resolving the equation matrix:

$$X = H^{-1} * p \quad (8)$$

Where the vector 'p' presents the poles which have to be imposed, p=$[p_0p_1p_2 \ldots]^T$ and H is the Sylvester matrix [10].

C) Determination of polynomial T

During set point change, we hope that the output follows the y^*(t), the output reference. The reference transfer function presents the trajectory to track and is given by:

$$H_m(z^{-1})=\frac{z^{-1}B_m(z^{-1})}{A_m(z^{-1})}$$

The polynomial $T(z^{-1})$ assures tracking, it is chosen to ensure:

- The unitary static gain between output y(t) and output of reference model y^*(t).
- Compensation of dynamical regulation $P(z^{-1})$.

From [9], we choose $T(z^{-1}) = GP(z^{-1}) \quad (9)$

Where G=$\begin{cases} \frac{1}{B(1)} & if\ B(1) \neq 0 \\ 1 & if\ B(1) = 0 \end{cases}$

To have the same dynamic of polynomial P (that means $P(z^{-1}) = A_m(z^{-1})$), the polynomial T is calculated by :

$$T(z^{-1}) = \frac{P(1)}{B(1)} \quad (10)$$

For the design of digital PID controller, we choose $T(z^{-1}) = R(z^{-1}) \quad (11)$

D) Determination of control law

From fig.1, we can write

$$S(z^{-1})U(z^{-1}) = T(z^{-1})Y_c(z^{-1}) - R(z^{-1})Y(z^{-1}) \quad (12)$$

So, the control law u (k) is written:

$$\begin{aligned} s_0 * u(k) = & -s_1 * u(k-1) - s_2 * u(k-2) \ldots. \\ & +t_0 * y_c(k) + t_1 * y_c(k-1) + t_2 * y_c(k-2) \ldots \quad (13) \\ & -r_0 * y(k) - r_1 * y(k-1) - r_2 * y(k-2) \ldots \end{aligned}$$

E) Example of application

We propose, in this section, an RST controller model for second-order system described by the following transfer of function:

$$M(z^{-1}) = \frac{b_0z^{-1} + b_1z^{-2}}{a_0 + a_1z^{-1} + a_2z^{-2}} \quad (14)$$

So , $\deg(A(z^{-1})) = 2$, $\deg(B(z^{-1})) = 1$ and $d = 1$

By applying the equation (5), we choose the degree of P: $\deg(P(z^{-1})) = 2$

The controller which will be designed allows the disturbance rejection of type step and it does not ensure any frequency locking.

From (2) and (6), we have:

$\deg(S_1(z^{-1})) = 1 + 0 + 1 - 1 = 1$

$S(z^{-1}) = (1 - z^{-1}) * (s_0 + s_1 z^{-1})$ (15)

From (7), we calculate the degree of

$\deg(R(z^{-1})) = 2 + 1 - 1 = 2$, (16)

Where $R(z^{-1}) = r_0 + r_1 z^{-1} + r_2 z^{-2}$

The Sylvester matrix [10] used for this example with (16) and (17) is:

$$H = \begin{pmatrix} a_0 & 0 & 0 & 0 & 0 \\ a_1 - a_0 & a_0 & b_0 & 0 & 0 \\ a_2 - a_1 & a_1 - a_0 & b_1 & b_0 & 0 \\ -a_2 & a_2 - a_1 & 0 & b_1 & b_0 \\ 0 & -a_2 & 0 & 0 & b_1 \end{pmatrix} \quad (17)$$

And the vector p=$[p_0\ p_1\ p_2\ 0\ 0\ ]^T$.

The equation (8) determines coefficients of polynomials R and S: X=$[s_0\ \ s_1\ r_0\ \ r_1\ \ r_2]^T$, and we apply (10) to determine T.

In next section, we will use the RST controller to control system presented by multimodel. Therefore, we will obtain a multimodel control based on RST controllers.

III. MULTIMODEL CONTROL

To build a multimodel control, we have firstly to define in advance the basis of models, then calculate validities and eventually get the multimodel control by commutation or by fusion.

A) Determination of model basis

The principle of multimodel approach consists in the decomposition of dynamic behavior of the system to several functioning zones. Each zone is characterized by a local model that contributes, according to weighting function, to presentation of global system behavior. The set of local models presents the basis of models of the system [12]. In the literature, the most used methods for the determination of the basis of models are: the identification [5], [12], the linearization [12] and polytopic transformation [13], [14].

B) Validity computation

The validity determines the degree of contribution of a local model in the presentation of global behavior of the system. Thereby, it's considered as a sensitive factor for the multimodel approach: it determines the capacity of local model to imitate the real system behavior in the corresponding functioning zones [1], [2].

The residue is the difference between the real process output and the local output [1], [2] and [6]. So, it depends only on real output measurement and local outputs of the basis of models (see fig 2). To ensure that it is being always between 0 and 1, we normalize it by applying the following formula:

$$r_{norm\_i} = \frac{r_i}{\sum_{i=1}^{N} r_i} \quad (18)$$

with N the number of basis of models.

The validity is:

$$v_i = 1 - r_{norm\_i} \quad (19)$$

Disturbances affecting the validity may appear because of the influence of the 'good' model and 'bad' model [7]. As a remedy to this problem, it is resorted to use the notion of strengthened validity [1], [3]. Enhanced validity is calculated by the formula: $v\_renf_i = \prod_{i=1, i\neq j}^{N} (1 - v_i)$ (20)

In the example, the standard validity using reinforced

$$v\_renfN_i = \frac{v\_renf_i}{\sum_{i=1}^{N} v\_renf_i} \quad (21)$$

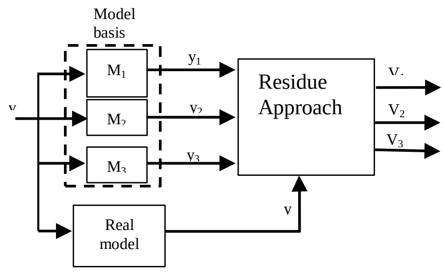

Fig.2: Calculation of validity by residue approach

C) Calculation of multimodel control

1) Commutation of controls

In [2], [3] and [4], the authors study the notion of multimodel control and distinguish two cases depending on whether validity ranges are disjoint or not. When validity ranges are disjoint, only one model is valid for each domain, this modeling is called ideal modeling. The multimodel control u_{mm} and the multimodel output y_{mm} are obtained by commutation as:

$$\begin{cases} u_{mm} = u_i \\ y_{mm} = y_i \end{cases} \text{, i=1...N and N: number of local models.} \quad (22)$$

The control u_{mm} coincides with the control of valid model in each moment and domain, it is easy to establish and to exploit but there are difficulties in determining switching rules especially when the number of models of basis is great.

The principle of multimodel control by commutation is explained in fig.3.

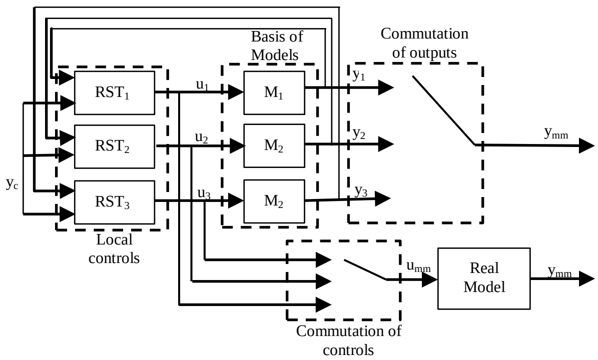

Fig.3: Switching control scheme

When validity domains have overlapping or are unknown in advance, two methods are used for obtaining the multimodel control:

2) Control by fusion of local controls

The global control is equal to the weighted sum of partial (see fig.4)

$$u_{mm} = \sum_{i=1}^{N} v_i u_i \qquad (23)$$

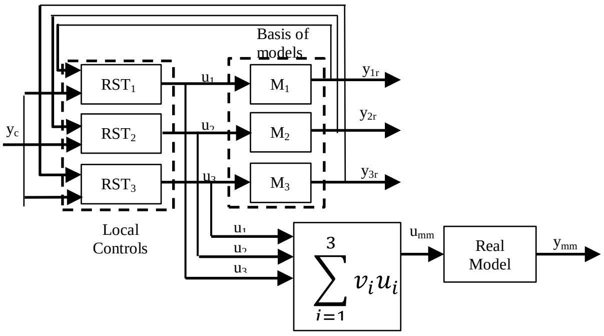

Fig.4: Fusion of local controls scheme

3) Fusion parameter control

The fusion is made at the level of coefficients of local controllers.

$$\alpha_{mm} = \sum_{i=1}^{N} v_i \alpha_i \qquad (24)$$

Where, α_i is the parameter of local controller. For example, for an RST, α_i are the coefficients of polynomials R, S and T of local RST controllers.

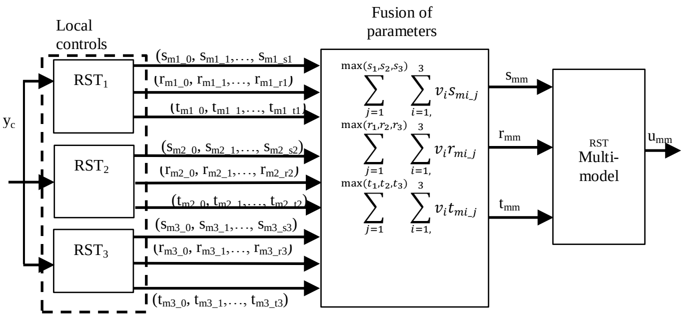

Fig.5: Scheme of control by fusion of parameters

We denote by:

- s_{mi_j}, r_{mi_j} and t_{mi_j}: the coefficients of respectively polynomial S, R and T of the local RST controller, i, j is the number of the coefficient of respectively polynomial S, R and T.
- s_i, r_i and t_i: the degrees of respectively polynomials S, R and T of the local RST controller i.
- S_{mm}, R_{mm}, T_{mm}: are, respectively, the polynomials S, R and T of the multimodel RST controller.
- u_{mm} : the control obtained from the RST multimodel controller.

In fig.5, we present the principle of control by fusion of parameters. The obtained control law u_{mm} will be applied directly to the real system.

In the objective of using RST controller to control system presented by multimodel, we are going to:

- ✓ present system with a set of local linear models
- ✓ design the local RST controller for each model
- ✓ calculate control law by fusion of local control laws
- ✓ Calculate control law by fusion of local RST controller's parameters'.
- ✓ Conclude the multimodel RST controller and enhance its performances by comparing the two type of multimodel control.

IV. Illustrative Example

The example is described by the following recurrent equation: [1]

$$y(k) = -a_1(k) * y(k-1) - a_2(k) * y(k-2) + b_0(k) * u(k-1) + b_1(k) * u(k-2) \qquad (25)$$

Where $b_0(k)$, $b_1(k)$, a_1 (k) and $a_2(k)$ are the time-variable parameters as indicated in fig.6.

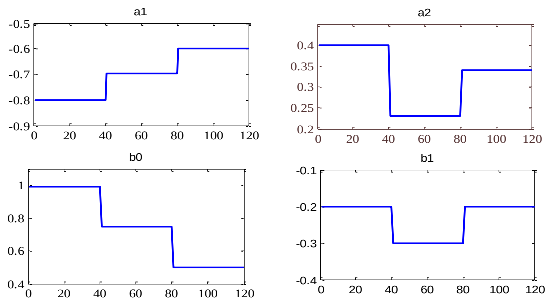

Fig.6: Parameters of non-linear system

A) Methodology and results

1) Basis of models

The basis of models is determined in [1]. We distinguish the following transfer functions of local models:

$$H_1(z^{-1}) = \frac{0.9999 - 0.1997 * z^{-1}}{1 - 0.7997 * z^{-1} + 0.399 * z^{-2}} \qquad (26)$$

$$H_2(z^{-1}) = \frac{0.7499 - 0.2987 * z^{-1}}{1 - 0.6982 * z^{-1} + 0.2296 * z^{-2}} \qquad (27)$$

$$H_3(z^{-1}) = \frac{0.4999 - 0.1999 * z^{-1}}{1 - 0.5998 * z^{-1} + 0.3399 * z^{-2}} \qquad (28)$$

Figure 7 shows step responses of local models y_1, y_2, y_3 and real system y. we remark a coincidence between:

- The response of local model n° 1 with the response of the real system in the time-range [0, 0.4].
- The response of local model n°2 with the response of the real system in the time-range [0.4, 0.8].
- The response of local model n°3 with the response of the real system in the time-range [0.8, 1.2].

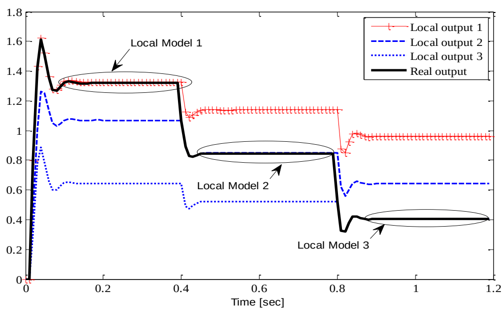

Fig.7: Coincidence between the local models and the real system

2) Validity computation

We apply the equations (18), (19), (20) and (21) to calculate the normalized strengthened validity.

In each moment, we calculate the validity for each local model in open-loop to determine the valid model.

Figure 8 shows the normalized strengthened validities of local models. This validity allows the design of multimodel RST controller from local controllers.

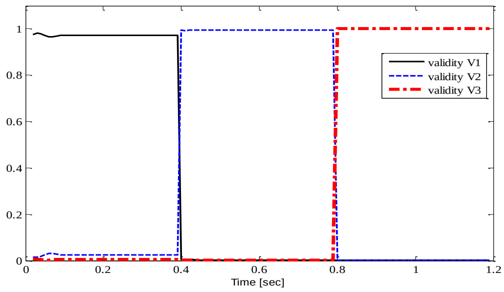

Fig. 8: The strengthened validities of local models

3) Calculation of multimodel control

For each local model, we synthesize an RST controller by determining the polynomials for each model using the method described in the section 2. The polynomial chosen with steady poles is $P(z^{-1}) = 1 - 0.5z^{-1} + 0.045z^{-2}$ (29)

We impose this polynomial for the three transfer functions (23), (24) and (25); we build a local controller for each transfer function. Polynomials of these controllers are determined in the following table I

TABLE I

Polynomials of local R.S.T controllers

Local models	**$R(z^{-1})$**	**$S(z^{-1})$**	**$T(z^{-1})$**
Local model 1	$1.492 - 1.236\,z^{-1} + 0.3812\,z^{-2}$	$1 - 1.191z^{-1} + 0.1908\,z^{-2}$	0.6368
Local model 2	$2.028 - 1.149\,z^{-1} + 0.2482\,z^{-2}$	$1 - 1.323\,z^{-1} + 0.3229\,z^{-2}$	1.1281
Local model 3	$3.01 - 1.882\,z^{-1} + 0.6886\,z^{-2}$	$1 - 1.405\,z^{-1} + 0.405z^{-2}$	1.8167

Let's consider y_c the set point, y_i the output of model i, and u_i the control of model i avec i=1, 2, 3

The control laws corresponding to local controllers are written:

- $u_1(i) = 1.191 * u_1(i-1) - 0.1908 * u_1(i-2) + 0.6368 * y_c(i) - 1.492 * y_1(i) + 1.236 * y_1(i-1) - 0.3812 * y_1(i-2)$ (30)
- $u_2(i) = 1.323 * u_2(i-1) - 0.3229 * u_2(i-2) + 1.2079 * y_c(i) - 2.028 * y_2(i) + 1.149 * y_2(i-1) - 0.2482 * y_1(i-2)$ (31)
- $u_3(i) = 1.405 * u_3(i-1) - 0.405 * u_3(i-2) + 1.8167 * y_c(i) - 3.01 * y_3(i) + 1.882 * y_3(i-1) - 0.6886 * y_3(i-2)$ (32)

These control laws are shown in figure 9.

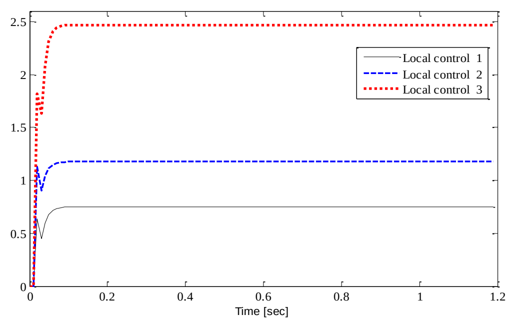

Fig. 9: control laws of local models controlled by RST controllers

a) Fusion of local controls

In this case, the evolution of multimodel control is shown in figure 10 and equal to:

$$u_{mm}(i) = v_1(i) * u_1(i) + v_2(i) * u_2(i) + v_3(i) * u_3(i) \quad (33)$$

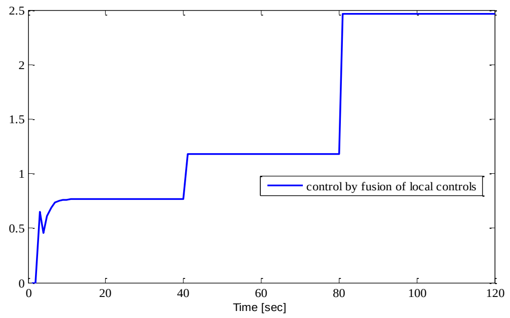

Fig.10: Fusion of local controls

b) Fusion of parameters

we merge the coefficients of polynomial R,S and T according to validities:

$$s_{0_{mm}}(i) = v_1(i) * s_{0_{m1}}(i) + v_2(i) * s_{0_{m2}}(i) + v_3(i) * s_{0\_m3}(i) \quad (34)$$

$$s_{1_{mm}}(i) = v_1(i) * s_{1_{m1}}(i) + v_2(i) * s_{1_{m2}}(i) + v_3(i) * s_{1\_m3}(i) \quad (35)$$

$$r_{0_{mm}}(i) = v_1(i) * r_{0_{m1}}(i) + v_2(i) * r_{0_{m2}}(i) + v_3(i) * r_{0\_m3}(i) \quad (36)$$

$$r_{1_{mm}}(i) = v_1(i) * r_{1_{m1}}(i) + v_2(i) * r_{1_{m2}}(i) + v_3(i) * r_{1\_m3}(i) \quad (37)$$

$$r_{2_{mm}}(i) = v_1(i) * r_{2_{m1}}(i) + v_2(i) * r_{2_{m2}}(i) + v_3(i) * r_{2\_m3}(i) \quad (38)$$

$$t_{0_{mm}}(i) = v_1(i) * t_{0_{m1}}(i) + v_2(i) * t_{0_{m2}}(i) + v_3(i) * t_{0\_m3}(i) \quad (39)$$

The equations (34) - (39) give the coefficients of a new controller called multimodel RST controller whose polynomials are:

$$R_{mm}(z^{-1}) = r_{0\_mm} + r_{1\_mm}z^{-1} + r_{2\_mm}z^{-2} \quad (40)$$

$$S_{mm}(z^{-1}) = s_{0\_mm} + (s_{1_{mm}} - s_{0_{mm}})z^{-1} - s_{1_{mm}}z^{-2} \quad (41)$$

$$T_{mm}(z^{-1}) = t_{0_{mm}} \quad (42)$$

The figure 12 illustrates the control law of multimodel RST controller whose polynomials are R_{mm}, S_{mm} and T_{mm}. this control law is calculated by applying the equation (14).

$$u_{m_{rst}}(i) = -(s_{1_{mm}} - s_{0_{mm}}) * u_{m_{rst}}(i-1) - s_{1_{mm}} * u_{m_{rst}}(i-2) + t_{0_{mm}} * y_c(i) - r_{0_{mm}} * y_1(i) - r_{1_{mm}} * y_m(i-1) - r_{2_{mm}} * y_m(i-2). \quad (43)$$

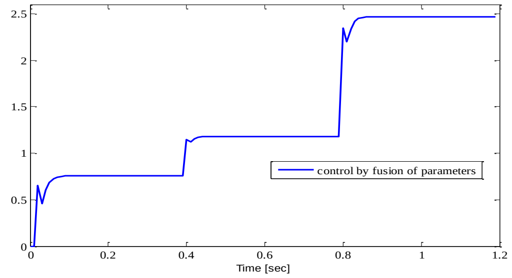

Fig.11: Control by fusion of parameters of local RST controllers

B) Interpretation and discussion

To compare the two types of control, we examine the response of system by applying the control obtained by fusion of local controls and the response of system by applying the control obtained by fusion of parameters. In figure 12, we superpose the two curves of outputs to well visualize the effect of the two types of controls on the output of system.

We verify that the control by fusion of parameters allows a better smoothing at the level of transitions zones between local models than the control by fusion of local controls.

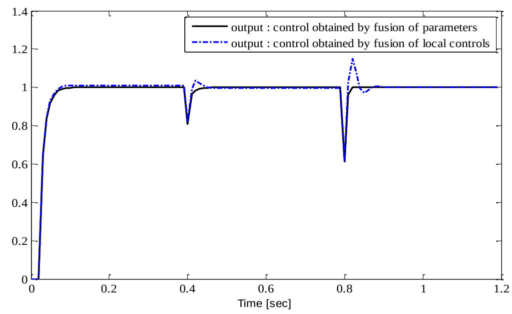

Fig. 12: system output by applying the control by fusion of local controls and fusion of parameters

The figure 13 shows static error of the system by applying the two types of controls.

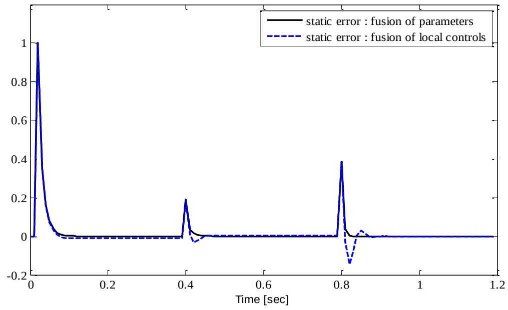

Fig. 13: static error by applying the two types of controls

We observe that the static error by applying the control obtained by fusion of parameters is inferior to that obtained by fusion of local controls. The difference between the two static errors appears exactly at the transition zones, between local models. Simulation results prove that control by fusion of parameters ensures a best static error compared with control by fusion of local controls.

To test the robustness of the considered controls, we add a step disturbance at the output of system.

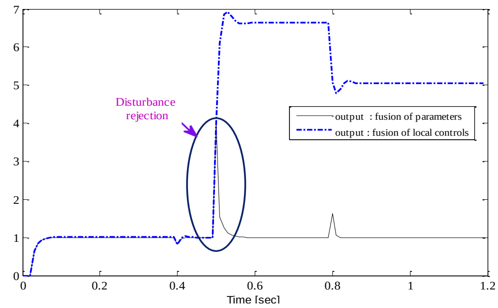

Fig.14: responses of system when applying the two type of controls with an output disturbance.

Figure 14 depict the influence of disturbance in the response of system with two types of controls. This figure shows that only the control by fusion of parameters ensures the disturbance rejection. However, the control by fusion of local controls does not ensure the disturbance rejection, although each local control ensures the disturbance rejection for the response of its corresponding local model.

Based on these results, we conclude that the fusion of parameters transfers the performances of local controllers to the RST multimodel controller. This controller ensures a good regulation and tracking. The obtained multimodel RST controller is a digital controller for complex system presented by multimodel with linear model basis.

V. CONCLUSIONS

This paper emphasizes the migration of control techniques of linear systems (regulation by RST) to nonlinear systems due to the multimodel approach. We have built an RST controller applicable to the nonlinear systems. Indeed, the study of academic example shows the accuracy and the robustness of multimodel RST controller obtained by parameters fusion of local RST controllers. This robustness is proved by testing the disturbance rejection and comparing it to the multimodel control obtained by fusion of local controls.

The implementation of control law of multimodel RST controller to control nonlinear system will be an easy mission at a programmable PLC, this is a conceivable prospect.

VI. References

[1] S. Talmoudi, *L'approche multimodèle et les réseaux de neurones artificiels pour l'identification des systèmes complexes,* Doctoral thesis, ENIT 2005.

[2] M. Ksouri-Lahmari, *Contribution à la commande multimodèle des processus complexes,* Doctoral thesis, UST of Lille, 1999.

[3] M.Elkhalil, *Modélisation, observation et commande une approche multimodèle*, Doctoral thesis, CAEN/BASSE-NORMANDIE University, 2011.

[4] N.Khezami, Commande multimodèle optimale des éoliennes : Application à la participation des éoliennes au réglage de la fréquence, Doctoral thesis, Lille Central School and Sciences and Technology High School of Tunis, 2011.

[5] L.Thiaw, *identification de systèmes dynamiques non linéaires par réseaux de neurones et multimodèle*, Doctoral thesis, Parix XII University, 2008.

[6] R.Murray-Smith &T.A.Johansen (Eds), *multiple model approaches to modelling and control*, Taylor and Francis, London, 1997.

[7] F.Delmotte, *Analyse multimodèle*, Doctoral thesis, UST of Lille, 1997.

[8] Y.Piguet, *Synthèse multimodèle d'un régulateur polynomial robuste*, Doctoral thesis, Federal Polytechnic School of Lausanne, 1997.

[9] I.D.Landau, *Identification et commande des systèmes (seconde édition)* Hermes, Paris 1993.

[10] M.Etique, *Régulation numérique*, Courses industrial technology for electrical engineering sector, HEIG-VD, Suisse, 2014.

[11] I.D.Landau, *The RST Digital Controller design and applications*, Control Engineering Practice 6, pp155-165, 1998.

[12] A.Akhnak, *conception d'observateurs non linéaires par approche multimodèle : application au diagnostic*, Doctoral thesis, National Polytechnic Institute of Lorraine ,2004.

[13] T.Zouari, *Diagnostic des systèmes dynamiques hybrides à modes non linéaires*, Doctoral thesis, UST of Lille, 2013.

[14] M. Chedli, *Stabilité et commande de systèmes décrits par des multimodèles*, Doctoral thesis, National Polytechnic Institute of Lorraine,2002.

[15] S.Lacroix, M.Hilairet et E.Laboure, *Design of battery-cherger controller of electric vehicle based on RST controller*, in proc. vehicle power and propulsion conference on IEEE (VPPC), 2011.

[16] C.Sandu, D.Popescu, C.Dimon, *Polynomial RST control for blood pressure regulation*, 20th international conference on control systems and science, 2015.

[17] I. D Landau, A Karimi , *Robust digital control using pole placement with sensitivity shaping method,* Int. J. Robust Nonlinear Control,4, pp 191-210 ,1998.

[18] R.Orjuela, B.Marx, J.Ragot, D.Maquin, *Diagnostic des systèmes non linéaires par une approche multimodèle,* 6th International Francophone Control Conference, CIFA 2010, jun2010, Nancy, France

[19] M.Rodrigues, *Diagnostic et commande active tolérants aux défaut appliqués aux systèmes décrites par des multimodèles linéaires*, Doctoral thesis, University Henri Poincaré Nancy I ,2005

[20] S.Ladaci, S.Cheniki, H.Bendjama, A.Charef, *Indirect Fractional Adaptative Pole Placement Control* , 3rd international Conference on Control, engineering and information technology (CEIT), 2015.

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