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Hybrid Control of a Station of Irrigation by Sprinkling

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Abstract— ***In the context of scarce water resources and the effects of climate change and the exponential increase in needs, the issue of saving water wastage becomes more important. The objective of this work is to improve the performance of a station of irrigation by sprinkling which we tried to incorporate a new control law guaranteeing a certain performance. Development is done on a real pumping station. The appearance of a temporal delay and the existence of unknown variables make the use of mathematical model founded very difficult. Identification of an approximate model was provided by the application of the algorithm identification N4SID subspaces. To get the best performance, we analyzed the control law PI planted in an educational station sprinkler, and then applied a fuzzy control law and we ended up with encouraging results. An idea of combining the two control laws through a fuzzy supervisor, has improved the results significantly.***

Index Terms— **Pressurized Irrigation, Identification Subspace Technique, Fuzzy Control, Hybrid Control.**

I. INTRODUCTION

From the beginning of civilization, man has sought to develop more agriculture which is the first business even today, but since a small percentage of our land is not ripe for agriculture, man has tried to find solutions to transport water, beyond the natural water resources can do. In future decades, humanity will lose one third of its fresh water reserves [1] [2] This is mainly due to the great climate change and irrigation which is the main activity of consuming water around the world since the consumer can reach more than 72% of fresh water available [1] [2]. However, much of the water used for irrigation is wasted; this is due to the poor management of irrigation systems. The water management has become a major preoccupation for man. Important steps were taken to modernize the methods of water management to conserve and make the best use of existing resources. In the light of this new social consciousness, automatic sciences must be put for the benefit of hydraulic systems to optimize the management of water resources. In this context, the French company LEROY SOMMER offers researchers a pumping station teaching (Fig 1), but with practical constraints existing in the real irrigation stations. In this article, we will try to develop a model of the station of irrigation where the synthesis of a control hybrid combines the PI set on the station with another fuzzy logic.

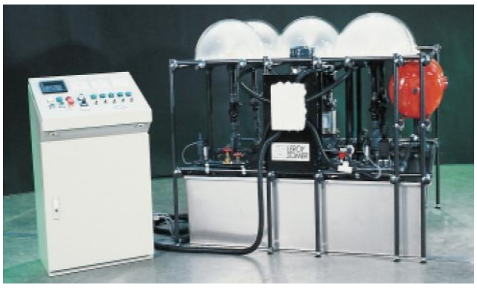

Fig 1: Overview of the Station Pressurized Irrigation by Sprinkler

II. MODELING THE STATION

The development of a mathematical model requires the studies of the water flow in the channels of the station. To achieve this, we will try to develop the calculations starting from the Saint-Venant equations [3] [4] [5] applied to the flow supported on an irrigation network under pressure.

A. *Extract the Naviers-stokes equations*

To describe the flow, we used the Naviers - Stokes equations that describe the hydraulic behavior of a Newtonian fluid.

$$V= V1 + V2(N) \qquad (1)$$

V1: flow velocity of water due to the growth of turbine fixed speed pump.

V2: flow velocity of water due to the growth of turbine variable speed pump "N".

V: total velocity of water flow in the pipe of the station.

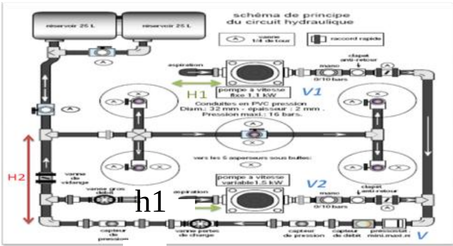

Fig 2: Pumping Station: Block diagram of the hydraulic element

The mass of water does not vary during its flow in the pipeline then:

$$\nabla.V = \frac{\partial Vx}{\partial x} + \frac{1}{r} \times \left(\frac{\partial (r \times Vr)}{\partial r}\right) + \frac{1}{r} \times \left(\frac{\partial V\theta}{\partial \theta}\right) = 0 \qquad (2)$$

(∇ : Operat nabla)

Assuming that the reference is of Galilee, where one can write the equation of conservation of momentum as follows:

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$$\frac{\partial \tau qm}{\partial t} = \sum \tau fext \quad (3)$$

τqm: momentum tensor.

τfext : tensor of the external forces.

Cauchy's equation is as follows:

$$\rho \times \gamma = \nabla.(\sigma) + f \quad (4)$$

It is assumed that water is under the sole action of gravity, so we will:

$$\rho \times \gamma = \nabla.(\sigma) + \rho \times g \quad (5)$$

Where σ: the tensor of the constraints for a viscous Newtonian fluid.
With

$$\sigma = -P.\ I + 2\mu\ D \quad (6)$$

μ: Coefficient of shearing.
D: Tensor speeds of deformation.
P: Pressure in Bar.
ρ Water density in Kg/l.
g : Gravity or acceleration of gravity in N/Kg
f : Force external in N

Applying the operator nabla in the tensor of the constraints we have:

$$\nabla.\sigma = -\nabla.P + \nabla.(2\mu D) \quad (7)$$

Really, the pipe is PVC so we can neglect the thermal effect in the station so we can consider that the viscosity coefficients as constants and therefore we have:

$$\nabla.D = 0.5\,\nabla.(\nabla V) \quad (8)$$

We integrate the equations (6), (7), (8) in equation (5), we arrive to find the Naviers-Stokes equations as follows:

$$\rho \times \left(\frac{\partial V}{\partial t} + V.\nabla V\right) = -\nabla.P + \mu \nabla^2 V + \rho g \quad (9)$$

B. *Simplification the Naviers-Stokes equations*

The pipe of the station is closed because it supposedly has a check valve so there is no air in the pipe and therefore no friction between water and air. Assuming that water flow is concentrated mainly in the centre with no leaks in the station so we can neglect the radial and tangential components of flow velocity. It is known that the study of this station requires consideration of the effect of long pipes, nodes and of course the rating of land so we can make all these charges, applied to the system, in a term called "hydraulic load H (t, x)."

The hydraulic load is modeled as follows:

$$H(t,x) = \frac{p(t)}{\rho \times g} + h(x) \quad (10)$$

According to Brenouillie, we can write the hydraulic load as follows:

$$H = \left(\frac{P}{\rho \times g}\right) + (h1 + h2 + hx) \quad (11)$$

h1 and h2 are the heights to the tank as shown in Fig 2. Finally, we can say that the system is described by the set of equations:

$$\left(\frac{\partial Vx}{\partial x}\right) = 0 \quad \text{: Law of continuity} \quad (12)$$

$$\left[\rho \times \left(\left(\frac{\partial Vx}{\partial t}\right) + Vx \times \left(\frac{\partial Vx}{\partial x}\right)\right) = -\left(\frac{\partial P}{\partial x}\right) + \mu\left(\frac{\partial^2 V}{\partial x^2}\right) + \rho\, g_x\right] \text{: Equation of Naviers-Stokes} \quad (13)$$

$$H(t,x) = \left(\frac{P}{\rho \times g}\right) + (h1 + h2 + hx) \text{ : Hydraulic load.} \quad (14)$$

To intervene in the variable flow in modeling we used the fundamental equation of Brenouillie as follows:

$$Q = S \times V_{moy} \quad (15)$$

S : The section of pipe in m².
Vmoy : The average speed in m/s

To simplify the calculations we will introduce the coefficient BOUSSISNEQ given by:

$$B = \left(\frac{1}{S} \times V^2 moy\right) \times \int_0^S Vx^2\, dS \quad (16)$$

After some mathematical transformations showing the flow, equations (12), (13), (14) can be put as follows:

$$\left\{\begin{array}{c} \frac{\partial Q(t,x)}{\partial x} = 0 \\ \rho \times \left[\frac{\partial(Q)}{\partial t} + \frac{1}{S} \times \left(\frac{\partial(Q^2 \times B)}{\partial x}\right)\right] + \rho \times g \times S \times \frac{\partial H}{\partial x} - \mu \times \frac{\partial^2(Q)}{\partial x^2} = 0 \\ H = \left(\frac{P}{\rho \times g}\right) + (h1 + h2 + hx) \end{array}\right\} \quad (17)$$

C. *Linearization of the equations of Saint-Venant*

After a thorough physical study of the flow of water into the pressurized irrigation station, we found the system of equations (17). We can write this system of equations as follows:

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$$\begin{cases} \frac{\partial Q(t,x)}{\partial x} = 0 \\ \rho \times \left[\frac{\partial (Q)}{\partial t} + \frac{1}{S} \times \left(\frac{\partial (Q^2 \times B)}{\partial x}\right)\right] + \rho \times g \times S \times \frac{\partial H}{\partial x} + J(Q(t,x)) = 0 \\ H = \left(\frac{P}{\rho \times g}\right) + (h1 + h2 + hx) \end{cases}$$

(18)

Where J (Q (t, x)) is the term of linear loss charges, by identifying

$$J(Q(t,x)) = -\mu \times \partial^2(Q)/\partial x^2 \qquad (19)$$

The hydraulic load and pressure are related by the relation of Brenouillie as follows:

$$H(t,x) = P(t,x)/[\rho g] + h(x) \qquad (20)$$

h (x): Height varies depending on the position x.
Assuming that the hydraulic load is invariant in terms of time 't', we can write the system of differential equations as follows:

$$\begin{cases} \frac{\partial P}{\partial t} = -g \times \left(\frac{\partial Q(t,x)}{\partial x}\right) \\ \frac{\partial (Q)}{\partial t} = -\frac{1}{S} \times \left(\frac{\partial (Q^2(t,x) \times B)}{\partial x}\right) - g \times S \times \frac{\partial H}{\partial x} - J(Q(t,x)) \end{cases}$$

(21)

The initial conditions specify the profiles of pressure and flow at the initial time can be written as follows:

P(x, 0) = P(0) (22)
Q(x, 0) = Q(0) (23)

Where x Є [0, Li] ; i =1 ,2 ,3 … n
Li : is the length of pipe at end of sprinkler « i ».
The two main outputs accepted by the operator are the following boundary conditions:

P(x=L, t) = Pc(t) (24)
Q(x=L, t) = Q1(t) (25)

Where Pc: pressure set point imposed by the manipulator and Q1: water flow at the end sprinklers.
Steady state is characterized by:

$$\frac{\partial P(t,x)}{\partial t} = 0 \qquad (26)$$

$$\frac{\partial (Q(t,x))}{\partial t} = 0 \qquad (27)$$

To lighten the writing, it is possible to set the model "(21)" as follows:

$$\frac{\partial}{\partial t}\binom{P}{Q} = \frac{\partial}{\partial x} f(P,Q) + g(P,Q) \qquad (28)$$

Where $:f(P,Q) = -\begin{pmatrix} \rho\, g\, Q(t,x) \\ \frac{B}{S} Q^2(t,x) + g\, S\, H(x) \end{pmatrix}$ (29)

And $g(P,Q) = \begin{pmatrix} 0 \\ -J(Q(t,x)) \end{pmatrix}$ (30)

It poses $X(t) = \binom{P}{Q}$ as a state vector and $Xe(t) = \binom{Pe}{Qe}$ the expression of the state vector around a uniform equilibrium profile.
Hence, the equation of state (28) around this equilibrium uniform:

$$\frac{\partial X}{\partial t} = \frac{\partial}{\partial x}\left[f(Xe) + \frac{\partial f(Xe)}{\partial x}(X - Xe) + O((X - Xe)^2)\right] + \left[g(Xe) + \frac{\partial g(Xe)}{\partial x}(X - Xe) + O((X - Xe)^2)\right]$$

(31)

Steady state must verify the following relation:

$$\frac{\partial Xe}{\partial t} = 0 = \frac{\partial f(Xe)}{\partial t} + g(Xe) \qquad (32)$$

Consequently the model (18), can be written as follows:

$$\begin{cases} \frac{\partial \tilde{P}}{\partial t} = -g \frac{\partial \tilde{Q}}{\partial x} \\ \frac{\partial \tilde{Q}}{\partial t} = a1 \frac{\partial \tilde{P}}{\partial x} + a2 \frac{\partial \tilde{Q}}{\partial x} + a3\, \tilde{P} + a4\, \tilde{Q} \end{cases}$$

(33)

Where $\tilde{P} = P - Pe$; $\tilde{Q} = Q - Qe$
(a1, a2, a3, a4) are unknown parameters to be identified.
Finally, a model in state space can be established as follows:

$$\begin{cases} \binom{\dot{\tilde{P}}}{\dot{\tilde{Q}}} = \begin{pmatrix} 0 & 0 \\ a3 & a4 \end{pmatrix}\binom{\tilde{P}}{\tilde{Q}} + N(t,x) \\ Y = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\binom{\tilde{P}}{\tilde{Q}} \end{cases}$$

(34)

Where $N(t,x) = \begin{pmatrix} -g\frac{\partial \tilde{Q}}{\partial x} \\ a1\frac{\partial \tilde{P}}{\partial x} + a2\frac{\partial \tilde{Q}}{\partial x} \end{pmatrix}$ (35)

By expanding *N (t, x)* to simplify the writing

$$N(t,x) = \begin{pmatrix} -g\frac{\partial \tilde{Q}}{\partial x} \\ a1\frac{\partial \tilde{P}}{\partial x} + a2\frac{\partial \tilde{Q}}{\partial x} \end{pmatrix} = \begin{pmatrix} -g\frac{\partial \tilde{Q}}{\partial t}\frac{\partial t}{\partial x} \\ a1\frac{\partial \tilde{P}}{\partial t}\frac{\partial t}{\partial x} + a2\frac{\partial \tilde{Q}}{\partial t}\frac{\partial t}{\partial x} \end{pmatrix}$$

(36)

$$N(t,x) = \begin{pmatrix} 0 & -\frac{g}{V(t)} \\ \frac{a1}{V(t)} & -\frac{a2}{V(t)} \end{pmatrix} * \binom{\dot{\tilde{P}}}{\dot{\tilde{Q}}}$$

(37) With

V (t): velocity of water in the pipes in m / s. After

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mathematical transformation we found the final state representation as follows:

$$\begin{cases} \begin{pmatrix} \dot{\tilde{P}}(t) \\ \dot{\tilde{Q}}(t) \end{pmatrix} = Z(p) \begin{pmatrix} \frac{a3\ g}{L\ p} & \frac{a4\ g}{L\ p} \\ -a3 & -a4 \end{pmatrix} \begin{pmatrix} \tilde{P} \\ \tilde{Q} \end{pmatrix} + \begin{pmatrix} 1 \\ 0 \end{pmatrix} u(t) \\ Y = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} \tilde{P} \\ \tilde{Q} \end{pmatrix} \end{cases} \quad (38)$$

With $Z(p) = \frac{1}{1+\frac{a2}{L\cdot p}+\frac{g\ a1}{L^2\cdot p^2}} = \frac{p^2}{\frac{a1\cdot g}{L^2}+\frac{a2\cdot p}{L}+p^2}$ (39)

Which L: the length of pipes that fixed by acting on the valve loss charges.

D. *Modeling of the system*

From the feedback signals to the control part of the station, we have taken the real dynamics of the pressure in the sprinkler station and even the flow which are represented in Figures (3) and (4).

To study the station we took a precise area of operation including:

- The station is operating in full capacity that is to say the five sprinklers are open simultaneously.
- Adjustment of the valve losses charges, which provides a load equivalent to a length of 1Km pipe (estimated experimentally).
- No leaks through the pipes.
- No failures at the level of the membranes of the reservoir of anti-pressure surge or the level of performance reliability of the two pumps.

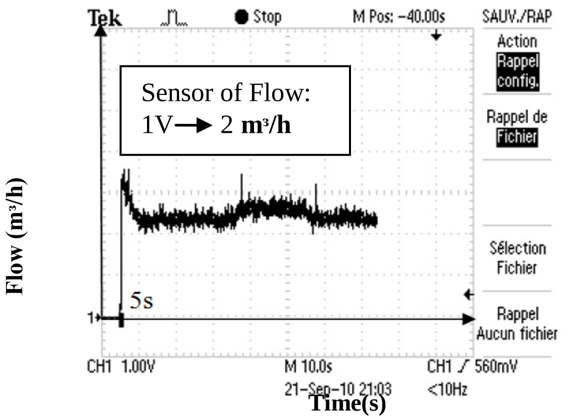

Fig 3: Evolution Of The Flow For A Pressure Set Point Equals 5 Bar.

The experimental study was made on the station and the measure taken has shown that the response of the process has a significant delay since its value exceeds the value of the time constant of the process.

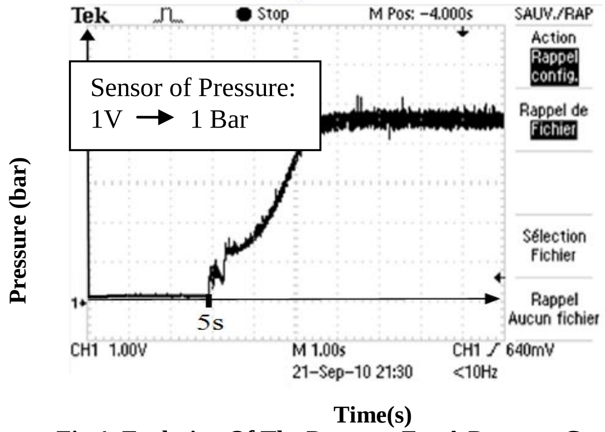

Fig 4: Evolution Of The Pressure For A Pressure Consign Equals 5 Bar.

Starting from equation (38), we can write our system in a delayed state representation as follows:

$$\begin{cases} \begin{pmatrix} \dot{\tilde{P}}(t) \\ \dot{\tilde{Q}}(t) \end{pmatrix} = \\ Z(p) \begin{pmatrix} \frac{a3\ g}{L\ p} & \frac{a4\ g}{L\ p} \\ -a3 & -a4 \end{pmatrix} \begin{pmatrix} \tilde{P} \\ \tilde{Q} \end{pmatrix} + \begin{pmatrix} -5 & 0 \\ 0 & -5 \end{pmatrix} \begin{pmatrix} \tilde{P}(t-5) \\ \tilde{Q}(t-5) \end{pmatrix} + \\ \begin{pmatrix} 1 \\ 0 \end{pmatrix} u(t) \\ Y = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} \tilde{P} \\ \tilde{Q} \end{pmatrix} \end{cases} \quad (40)$$

The state model (40) is non-linear delay and with terms that vary according to unknown laws and are even unobservable. This is in fact due to a complicated behavior of the flow of water into the station. To be able to use this model we will proceed in the following section of this paper with an identification of model from experimental tests.

V. STATION IDENTIFICATION

After the acquisition of system responses to a step input as a reference pressure, we tried to seek a second order model which can represent approximately the real dynamics of the wastewater spray irrigation. Based on simulation software, the program algorithm for identifying subspaces N4SID (Numerical algorithm for Subspace State Space System IDentification) [6] [7] [8]. The simulation of the identification algorithm which N4SID as input signals of the pressure (Fig 5), flow (Fig 6) and that of the reference (Fig 7) first requires a choice of an order desired for the estimated model.

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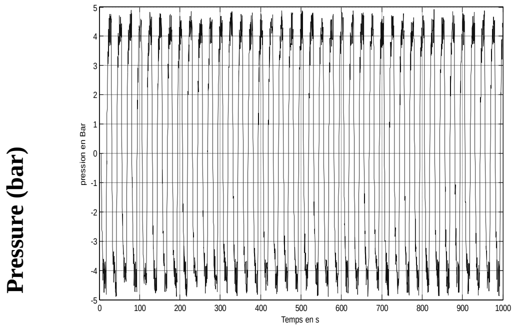

Fig 5: Signal of Pressure, Given For N4SID.

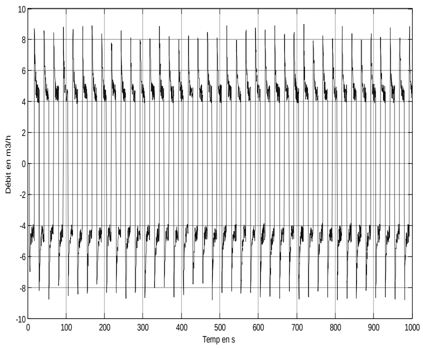

Fig 6: Signal flow, given for N4SID.

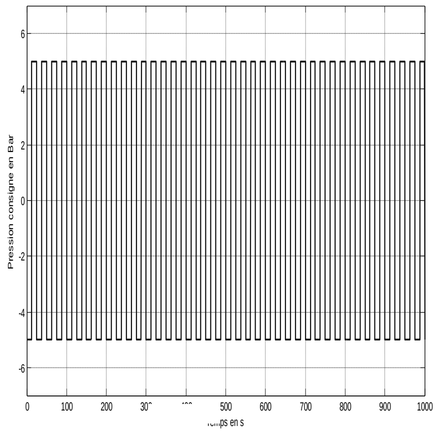

Fig 7: The reference signal is given for N4SID.

Since the system has a delay that has been identified mainly from the signals taken from the station of irrigation in Fig (3) and Fig (4) which we calculated the time delay between the action on the station and his reaction, because the delay can be incorporated in the representation of estimated state where we have the following form [9] [10]:

$$\begin{cases} \begin{pmatrix}\dot{\hat{P}}(t)\\ \dot{\hat{Q}}(t)\end{pmatrix} = \begin{pmatrix}-8.7295 & -4.8005\\ 1.0000 & 0\end{pmatrix}\begin{pmatrix}\hat{P}\\ \hat{Q}\end{pmatrix} + \begin{pmatrix}-5 & 0\\ 0 & -5\end{pmatrix}\begin{pmatrix}\hat{P}(t-5)\\ \hat{Q}(t-5)\end{pmatrix} + \begin{pmatrix}1\\ 0\end{pmatrix}u(t) \\ Y = \begin{pmatrix}0 & 4.7235\\ 14.7535 & 4.9165\end{pmatrix}\begin{pmatrix}\hat{P}\\ \hat{Q}\end{pmatrix}\end{cases} \qquad (41)$$

After a filtration operation made on the signals taken from the irrigation station, we had signals seen in Figures (8) and (9) that are comparable with those found by simulation.

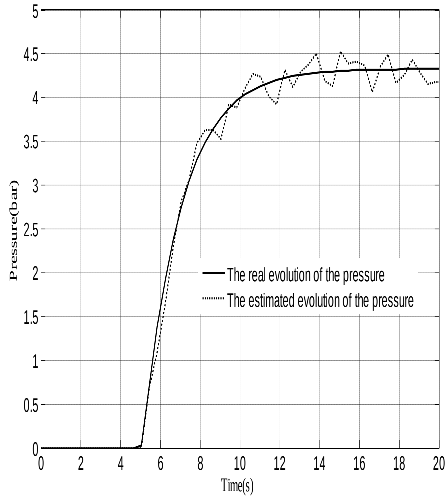

Fig 8: Comparison between the real evolution of the pressure and the estimated.

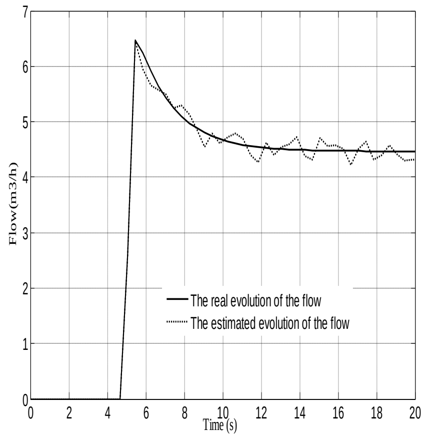

Fig 9: Comparison between the Real Evolution of Flow and the Estimated.

After the comparison between the actual and the estimated responses to a level which represents the pressure set point from potentiometer at desk, we can say that the model describes the dynamics found faithful to the actual evolution of the pressure and flow into the station so we can validate our estimated model.

IV. DEVELOPMENT OF LAW ORDER

In normal operation, the PI controller implemented in the control board of the station of irrigation appears very robust and efficient, but most real-world problems must take into account imprecise and uncertain information. The static PI controller shows the difficulty of adaptation. The development of fuzzy logic as a simple solution to this problem where imprecise and uncertain

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information can be reformulated in the form of fuzzy IF-THEN rules.

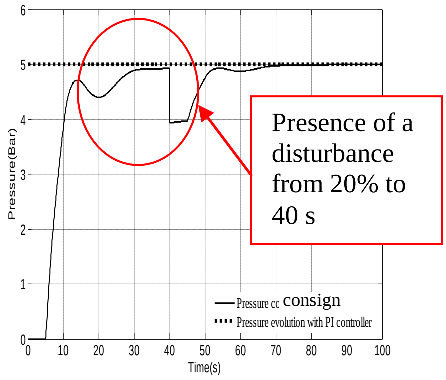

Fig 10: Evolution of the Pressure in the Wastewater Spray Irrigation Enslaved By a PI Controller.

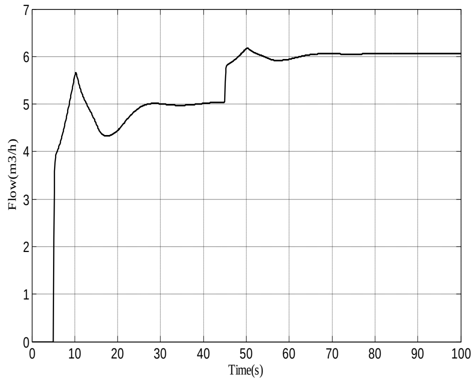

Fig 11: Evolution of the Flow in the Wastewater Spray Irrigation Enslaved By a PI Controller.

A. *Design of a fuzzy controller*

In the case of our system, the wastewater spray irrigation, the fuzzy controller has the error « e » and its derivative « $\dot{e}$ » as inputs and the command « C_{cf} » as output.

Thus the " i " fuzzy rule programmed is given by:

IF (e is A) AND ($\dot{e}$ is B) THEN $C_{cf} = S_i(e, \dot{e})$ (42)

A and B are fuzzy sets corresponding to « e » and « $\dot{e}$ ».

S_i : *is a singleton for the output* C_{cf} .

Using the product as inference engine and center of gravity for defuzzification.

The output of the proposed fuzzy controller can be written as follows:

$$C_{cf} = \sum_{i=1}^{N} S_i(e,\dot{e}) \times (\mu_A^i(e) \times \mu_B^i(\dot{e})) / \sum_{i=1}^{N} (\mu_A^i(e) \times \mu_B^i(\dot{e})) \quad (43)$$

N: Number of fuzzy rules; N=25.

μ_A: Degree of membership of « e » in A.

μ_B: Degree of membership of « $\dot{e}$ » in B.

To synthesize the fuzzy controller, we divided the universe of discourse for the error and its derivative into five groups: NG, NM, AZ, PM, and PG. Thus, using all possible combinations, 25 fuzzy rules were generated for nine singletons at the party accordingly as shown in Table 1:

Table 1: Matrix Inference of Fuzzy Controller.

e / $\dot{e}$	NG	NM	Z	PM	PG
NG	AP	AP	DM	DG	DTG
NM	AM	AM	DM	DM	DG
Z	AM	AP	VZ	DP	DM
PM	AG	AM	AM	AM	DM
PG	AG	AG	AG	AP	DP

Where the notation considered for the universe of discourse Output: A is the acceleration and deceleration D is the speed of the pump with variable speed.

From Table 1, there is symmetry in the state space that helps to reduce the computation time.

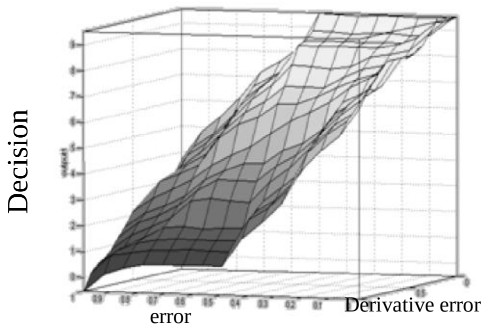

Fig 12: View of the Surface of Fuzzy Decision

Note that the decision surface reflects the smooth control law synthesized by the fuzzy controller which there are no acute forms thus resulting energy savings in order.

B. *Control station with fuzzy controller*

In order to control the irrigation station by a fuzzy controller is considered the functional diagram of the following command:

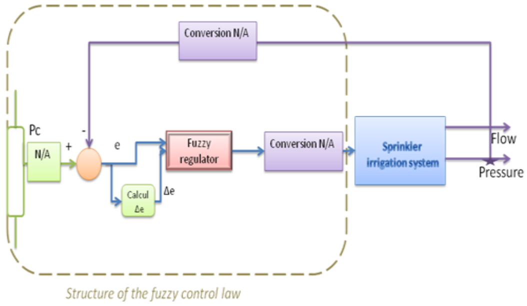

Fig 13: The Functional Diagram of the Command by a Fuzzy Controller.

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Using the model previously estimated (41) and applying the structure of the command shown in Fig (13), we found the following results:

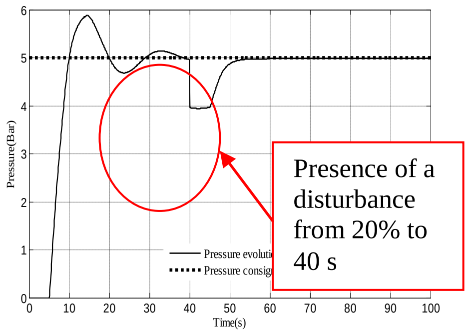

Fig 14: Evolution of the Pressure In The Presence Of a Fuzzy Controller.

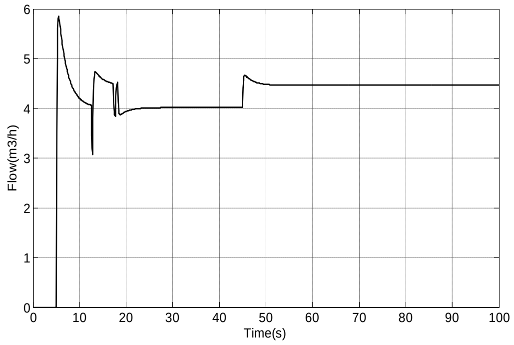

Fig 15: Evolution of the Flow In The Presence Of a Fuzzy Controller.

C. *Design of a hybrid regulator*

The fuzzy approach overcomes the problem of modeling and uncertain signals but we note that the optimal choice of the parameters of fuzzy controller is a very difficult task. Since we want to improve the behavior of the real system with minimal expense, we have proposed in this work to develop an advanced control law which is a good compromise between power management control and robustness against structural disturbances. We propose to use the combination of the two controllers defined above, the PI and the fuzzy.

To avoid a sudden switch from one controller to another, we will use a gradual switch as follows:

$$C = \beta \times C_{cf} + (1-\beta) \times C_{PI} \qquad (44)$$

C: control signal on the outlet side of the hybrid controller. Where β is a factor loading generated by a fuzzy supervisor having for entries the error of successive continuation and its derivative. The base of rules of this last is built so that the exit is worth " 1 " when the error of continuation and its derivative convergent towards zero and is worth " 0 " when the system is far from the trajectory of reference. The functional diagram of the hybrid command suggested is illustrated in the figure (16):

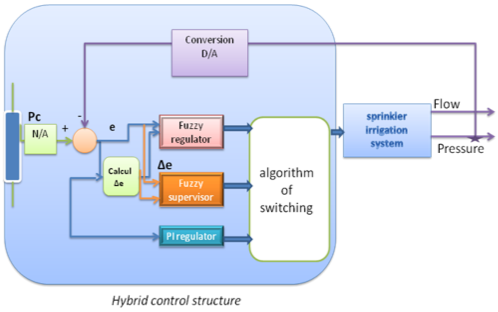

Fig 16: The Functional Diagram of the Command by a Hybrid Controller.

V. STUDY OF THE STABILITY OF HYBRID CONTROLLER

In this section, we propose to study the stability of the closed loop system using the hybrid control law expressed by (44):

Or

$$C_{cf} = \sum_{i=1}^{N} S_i(e,\dot{e}) \times (\mu_A^i(e) \times \mu_B^i(\dot{e})) / \sum_{i=1}^{N} (\mu_A^i(e) \times \mu_B^i(\dot{e})) \qquad (45)$$

To simplify the writing of the control law of fuzzy controller we have rephrased as follows:

$$C_{cf} = f_1(e,\dot{e}) \times e + f_2(e,\dot{e}) \times \dot{e} \qquad (46)$$

The control law provided by the PI controller installed on the machine can be written as follows:

$$C_{PI} = K_p(Pconsign - Poutput) + \frac{K_p}{T_i}\int(Pconsigne - Psortie)dt \qquad (47)$$

So if we integrate (46) and (47) in the analytical expression of the hybrid control law (44) becomes:

$$C = \beta \times [f_1(e,\dot{e}) \times e + f_2(e,\dot{e}) \times \dot{e}] + (1-\beta) \times [K_p \times e + \frac{K_p}{T_i}\int e\,dt] \qquad (48)$$

To study the stability of the control law developed, using the direct method of Lyapunov hence the stability of the control law ensures the stability behavior of the wastewater spray irrigation.

Consider the following Lyapunov function:

$$V = \frac{1}{2} P^2(e,\dot{e},t) \times |C| \qquad (49)$$

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P : is the pressure.

Using (48), the derivative of equation (49) is:

$$\dot{V} = \frac{\partial V}{\partial(e,\dot{e})} \times |C| \quad (50)$$

$$\dot{V} = P \times \dot{P} \times |C| < 0 \quad (51)$$

Referring to the theorem of Lyapunov [19] we can say that the developed control law is globally asymptotically stable with energy control system decreases caused with the convergence of the pressure evolution to 0.

VI. RESULTS OF SIMULATION

In this part we represent the results of simulation with a comparative study showing the differences between the three types of studied orders which we took the normal operating conditions previously presented.

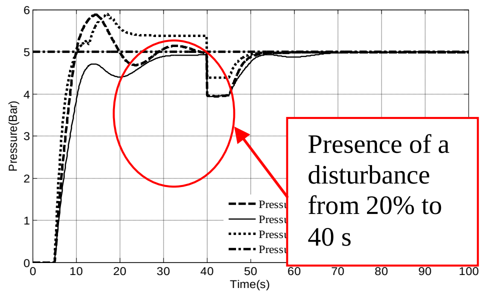

Fig 17: Evolution of the Pressure in the Pipes of the Station for Three Types of Regulators.

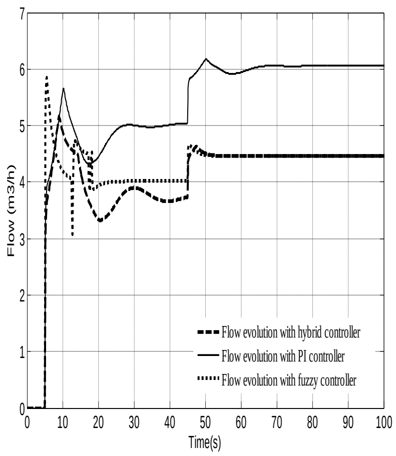

Fig 18: Evolution of the Flow in the Pipes of the Station for Three Types of Regulators.

Table 2: Comparison between PI techniques, Fuzzy and hybrid relative to the pressure.

	PI controller	Fuzzy controller	Hybrid controller
Response time to 80% of final value.	11.2 s	7.8s	9.5 s
Static error of position (Bar)	0.015	0.01	0.01

Table 3: Comparison between the Techniques of PI, Fuzzy and Hybrid Relative to the Flow.

	PI controller	Fuzzy controller	Hybrid controller
Response time to 80% of final value.	5.2 s	5.07s	5.12 s
Static error (m^3 /h)	1.4	0.3	0

Note: For the comparative study of evolution of the flow is considered the lowest rate as a benchmark for other approaches to regulation studied. Within sight of the results obtained, we note well that a hybrid order by the intermediary of a fuzzy supervisor makes it possible to ensure a gradual commutation between an order by regulator pi and a fuzzy controller. The purpose of this structure is to exploit the advantages of each approach of order where one exploits the precision of PI and the flexibility of the fuzzy regulator.

VII. CONCLUSION

In this work, we presented a new method to optimize the hydraulic state of a water supply network in order to reduce the losses. Initially, we worked out a model of networks of irrigation by holding account of all the existing physical phenomena during transmission of the water of irrigation. So, to develop a law of powerful order; it was very reasonable for us to find a model approached to carry out this task, we had to choose the method of identification by under spaces N4SID characterized by its flexibility and aptitude to handle systems MIMO. After, a validation of the approximate model found with its comparison with real signals taken recently, we analyzed the dynamic corresponding to the flow and the pressure in the loop of regulation proposed by the manufacturer of this didactic station ordered by a PI regulator. The possible structural changes in the station of irrigation by sprinkling require the application of a law of order which adapts with these changes. A fuzzy controller was proposed. After a comparative study between the two laws of order PI and Fuzzy, we proposed to develop a hybrid law of order which gathers the advantages of the two regulators.

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