RESEARCH ARTICLE OPEN ACCESS

Identification Method by Least Squares Applied On a Level Didactic Plant Viafoundation Fieldbus Protocol

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ABSTRACT
The industrial field is always considered a growing area, which leads some systems toimprove the techniques used on its manufacturing. By consequence of this concept, level systems became an important part of the whole system, showing that needs to be studied more specific to get the optimal controlled response. It's known that the good controlled response is gotten when the system is identified correctly. Then, the objective of this paper is to present a didactic project of modeling and identification method applied on a level system, which uses a didactic system with Foundation Fieldbus protocol developed by SMAR® enterprise, belonging to CEFET MG-Campus III –Leopoldina, Brazil. The experiments were implemented considering the least squares method to identify the system dynamic, which the results were obtained using the OPC toolbox from MATLAB/Simulink®to establish the communication between the computer and the system. The modeling and identification results were satisfactory, showing that the applied technic can be used to approximate the system's level dynamic to a second order transfer function.
Keywords – System Identification, System Modeling, Level Plant, Methodological Experimentation.

I. INTRODUCTION

Due to the globalized world, which every day new technologies arise, the industries seek to produce more and more, with enhanced quality and quickness, lower cost and faults. Then, it's required to train professionals which can provide a better control analysis of their processes, which are becoming increasingly complex.

To assist in the design and analysis of the control systems functioning, it's necessary to obtain the mathematical model that represents the actual physical process. This model is a mathematical equation used to answer questions about the system, such as the temporal variation and/or spatial variables of this, without conducting trials.

With a good mathematical model, it is possible to analyze and predict the behavior of a system under various operating conditions, and adjust the performance of the same, if he didn't show satisfactory. Thus, it permits to perform simulations of the system safely with low cost [1].
They are considered good models if theycan describe the phenomena of interest with considerable accuracy [2].

To determine the mathematical model of a system, it's made the system's modeling and identification which can represent its main features for diagnosis, monitoring, optimization and control.
Within the context of mathematical modeling, it arises two types, phenomenological modeling and modeling by identification. Phenomenological modeling is based on the physics of the process, in other words, it addresses the phenomena involved through differential equations[3].

Modeling by identification is based on techniques that seek to describe the relations of cause and effect between the input and output variables, as the resulting models and techniques used, associated with the different phenomenological modeling. Thus, the modeling by identification becomes a very useful tool, advised to obtain the approximate mathematical equation of any system's loop [4].

This paper is divided as it follows: The Section II shows the system used to explain the method; The Section III comments the OPC and Foundation Fieldbus protocols; The Section IV demonstrates the non-recursive least squares estimator; The Section V explains the procedure of algorithm'sexecution; The Section VI concludes the paper's results.

II. SMAR® DIDACTIC PLANT

The SMAR® Didactic Plants were developed to simulatefaithfully some industrial processes in smaller scale. Due to the system be a didactic plant, it performs multithreaded, allowing the simulation of various processes commonly found in the industry and using the same tools and their configurations used in real industrial processes. It is shown in Fig. (1).

Fig. 1. SMAR® Didactic Plant operated by Foundation Fieldbus Protocol.

It has sensors to measure variables such as flow, temperature and level. It offers the possibility to manipulate equipment such as PLC (Programmable Logic Controller), positioners to control valve, actuators, transmitters, static converter to control temperature through immersion resistance.

III. OPC AND FOUNDATION FIELDBUS PROTOCOL

The OPC ("OLE for Process Control", where OLE means to be "Object Linking and Embedding") is a standardized communication interface that was developed in order to solve problems of interoperability in industrial automation systems, integrating data between different levels of networks [5].

The OPC Interface establishes rules that are developed for systems with standardized interfaces for communication devices (PLCs, sensors, etc.), like monitoring, supervision and management of systems (for example: SCADA, PIMS, MES and ERP). The OPC is nothing more than a link between the supervisory and the communication drivers [6].

In respect to communication between the computer and the didactic plant, when the client want to accomplish access, either writing or reading of an instrument, it must first pass through the OPC Server, which interprets the request client access, links, TAG identifier (instrument) to its driver. Hence, the OPC Server realizes the access to the instrument and forwards the response to the client, as shown below in Fig.(2) [7].

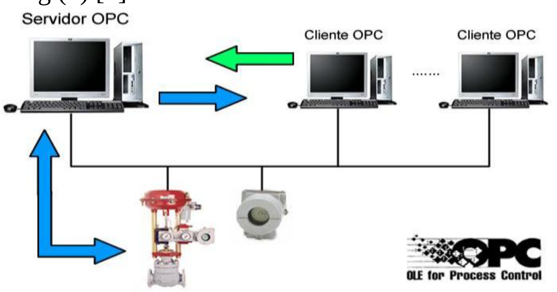

Fig. 2. Topology that illustrates the data traffic via OPC protocol.

The Foundation Fieldbus Protocol (FF) can be seen as a bi-directional serial communication system which is capable of distributing control functions over the devices on the factory floor. The term*bi* means to be the equipment connected to the network executes the role of sender and receiver. The devices are immune to failures that occur in the operating stations, since their control actions are local, processed in the equipment itself and not the stations [8].

One of network revolutions made by FF was the introduction of the distributed control concept[9]. In other technologies, such as the HART (Highway Addressable Remote Transducer), the control is performed using an external controller, and the FF control is done in the many instruments that have embedded technology. With that, it is not necessary to go up one level, in an external controller to perform the control action [10]. To be illustrated, the Fig. (3) showsa comparison between these two protocols.

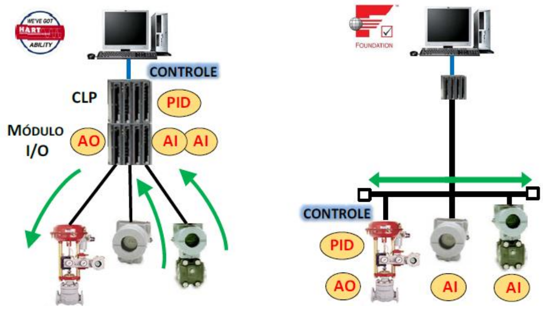

Fig. 3. Comparison between HART/4-20 mA Foundation Fieldbus Protocol.

IV. THE NON-RECURSIVE LEAST SQUARE ESTIMATOR

All physical process can be characterized by a differential equation derived from the phenomenological model by identification or modeling [11]. However, the most common way of representing a system is the use of representation by frequency, in other words, in the frequency domain. This representation is expressed as the ratio of output to input, which is called transfer function [12]. From the computational point of view, it is more important to represent a transfer function of a process in the frequency domain by a complex process in complex discrete frequency domain. To represent a discrete transfer function, consider a linear physical process characterized by input *u(z)*, output *y(z)* and disturbance *e(z)*, resulting the Eq. (1) represented below:

$$A(z^{-1})Y(z^{-1}) = z^{-d}B(z^{-1})U(z) + E(z) \quad (1)$$

Where:

$$A(z^{-1}) = 1 + a_1 z^{-1} + \cdots + a_{na} z^{-na} \quad (2)$$

$$B(z^{-1}) = b_0 + b_1 z^{-1} + \cdots + b_{na} z^{-nb} \quad (3)$$

The Eq. (1), (2) and (3) have to be represented in discrete transfer function, enabling the simulation on computer:

$$y(k) = -a_1 y(k-1) — a_2 y(k-2) - \cdots - a_{na} y(k-na) + \cdots + b_0 u(k-d) \; + \; b_1 u(k-d- 1+ \ldots +bnbuk-d-nb+ek \qquad (4)$$

From Eq. (4), it can be observed which there are $nb + na + 1$ parameters to estimate. To determine a_i and b_j, it's used the entry and exit of the process, which the term $e(k)$ represents the error of modeling, measurement error, noise in the output, stochastic or deterministic type.

The Eq. (4) can be rewritten by two vectors: one by measuring (φ(k)) and other by parameters (θ(k)):

$$y(k) = \varphi^T(k)\theta(k)e(k) \qquad (5)$$

Where:

$$\varphi^T(k) = [-y(k-1) - y(k-2) - \cdots - y(k-na)u(k-d) \ldots u(k-d-nb)] \qquad (6)$$

$$\varphi^T(k) = [a_1 a_2 a_3 \ldots a_{na}\, b_0 b_1 \ldots b_{nb}\,] \qquad (7)$$

As it's known, the process has N measurement, which are determined by a_i and b_j, Then, the Eq. (7) is represented in matrix form:

$$Y = \phi\theta + E \qquad (8)$$

Where:

$$Y^T = [y(0)y(1)y(2) \ldots y(N-1) \qquad (9)$$

The estimated parameter vector can be obtained by the least-squares procedure. The best prediction of the system's output is given by:

$$\hat{Y} = \phi\hat{\theta} \qquad (10)$$

The Markov estimator (also called weighted least squares estimator) is obtained by minimizing the following criterion:

$$J = \min_{\hat{\theta}} \left\| Y - \phi\hat{\theta} \right\|^2_{\omega} \qquad (11)$$

$$J = [Y - \phi\hat{\theta}]^T W [Y - \phi\hat{\theta}]^T \qquad (12)$$

The elements of W, W(i) are the weighting of the error in each component and depending on the measurement precision. Differentiating Eq. (12) and equating it to zero, it's got:

$$\frac{\partial J^2}{\partial \hat{\theta}^2} = -2(Y^T W \phi)^T + 2\phi^T W \phi\hat{\theta} \qquad (13)$$

$$\hat{\theta} = [\phi^T W \phi]^{-1} \phi^T W Y \qquad (14)$$

The non-recursive least squares estimator is obtained assuming that:

$$\hat{\theta} = \left[\frac{1}{\sigma^2}\right] [\phi^T \sigma]^{-1} \phi^T [\sigma^2] Y \qquad (15)$$

After estimate the discrete transfer function, its determination is obtained by continuous relations like backward, forward or trapezoidal. Basically, the procedure for the non-recursive estimated least squares (which is off-line) is inject into the plant a PRBS signal (Pseudo Random Binary Sequence) with amplitude ±1 [13] (it depends the situation, like this process, the amplitude is 100 due to valve opening). This condition is necessary in order to have an excited signal. The output values are stored in a vector to apply them in the next step.

V. PROCEDURE OF EXECUTION

To accomplish the identification, it was developed an application using the MATLAB/Simulink®, which through the OPC interface performs the communication between the PLC SMAR LC700 from the didactic plant and the software that performs the identification of the plant. In this case, the OPC client is the software MATLAB/Simulink®, who will write and read values directly from the output and input peripheral OPC server, provided by *TagList* SMAR.

The communication with the didactic plant's PLC is made up by using three blocks on the OPC toolbox. They are OPC Configuration, *OPCWrite* and *OPCRead*. The control loop is created in Simulink to simulate the pump drive plant, which works connected to a constant block (value 1 turns on the pump; values 0 turns it off).

The next step was to acquire the reaction curve for its level loop, which uses the OPC Configuration blocks, like OPC Write and OPC Read.

To apply the PRBS signal, it was used the following blocks in Simulink described below in Fig. (4), with the tags already previously configured from the OPC server:

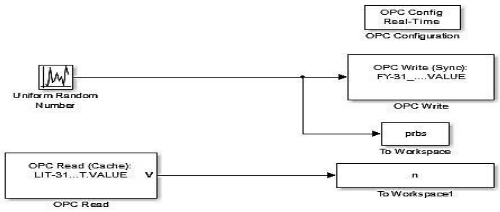

Fig. 4. Simulink block diagram for the application of PRBS signal and reading level variable.

Thus, when the method of identification is started, a PRBS signal is applied and two signals are got: the signal level of the system response and the PRBS applied to the control valve. Later, the method of non-recursive least squares is run to get the pattern.

To illustrate the level system, a flowchart is presented below in Fig. (5), showing all components included on it.

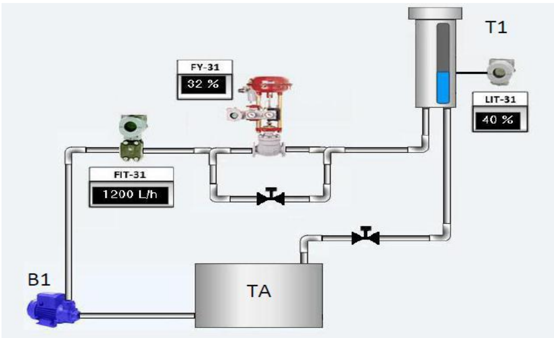

Fig. 5. Flowchart of the level system and its components included on it.

Through Fig. (5), it's possible to understand it by: B1 – Hydraulic Pump; ST – Storage tank; T1 – System's Tank; FIT-31 – Flowmeter Input of T1; FY-31 – Positioner of the Control Valve 31 and LIT-31 – Levelmeter 31.

The water from the tank ST is pumped by the pump B1 to tank T1. The water passes through the control valve FY-31, where the opening percentage of this valve is set. The flow can be measured through the transmitter FIT-31.

The opening in the bottom of the tank simulates the consumption of water and it's made through a manifold valve.

Initially, the flow rate should be greater than the outflow to the tank level increases. When there is an increase in the level of tank T1, there is an increase in the weight of the water due to gravity and this hinders the entrance of water hence the outflow of water from the tank increases.

To clear the signal forms, a PRBS signal and level system response are shown below in Fig. (6) and (7):

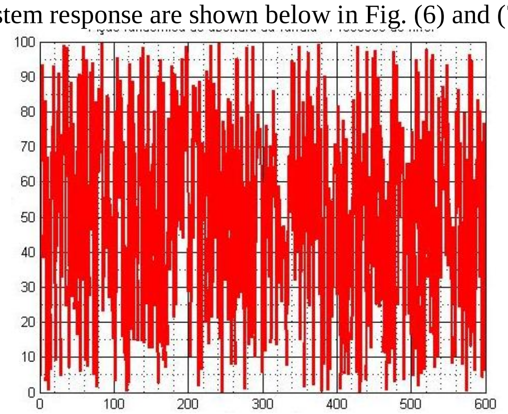

Fig. 6. PRBS signal applied to the level system.

Fig. 7.

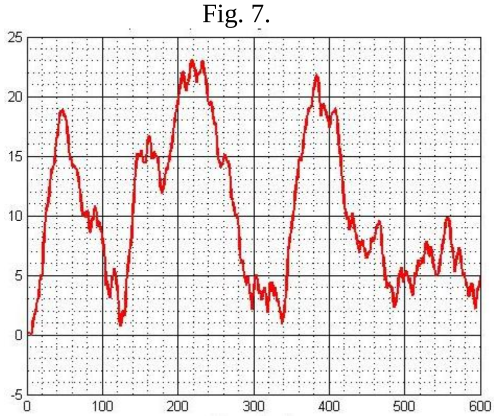

Fig. 8. Level response to the PRBS signal.

As it's presented in Fig. (7), the system response reacts slower than the PRBS signal applied to the control valve. It happens due to the "heavy dynamic" of level systems, which means that the system has to receive a long and constant signal to change its state. Another reason is about the non-linearity of level system, which influences the water flow from the tank T1.

VI. RESULTS OF THE EXPERIMENTS

Taking the related vector at PRBS signal as the starting, it's possible to apply the equations described in section IV, which leads to obtain a finite difference equation (FDE) as described by Eq. (4).

Reordering the FDE, writing in the Z domain and transforming it to the S domain by Tustin discretization method (sampling time of 0.1 seconds), the following equations were got:

$$G(z) = \frac{0.002063\,z + 0.0071}{z^2 - 1.489z + 0.4935} \quad (16)$$

$$G(s) = \frac{0.08183\,s^2 - 0.4614\,s + 0.5955}{s^2 + 0.6792\,s + 0.006256} \quad (17)$$

To exemplify the experiments, it's shown below in Fig. (8)some comparisons between level responses by different methods, for the purpose to evaluate the non-recursive estimated least squares technique.

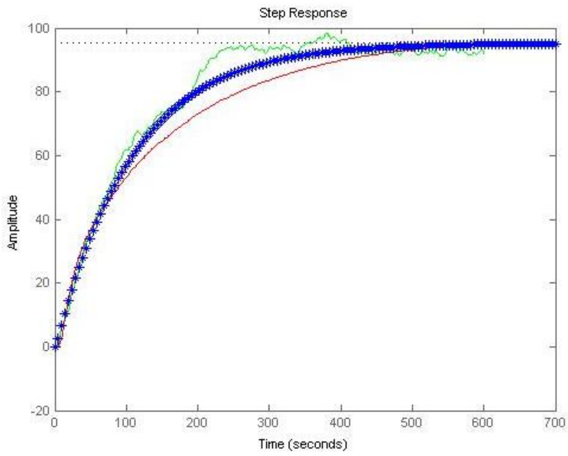

Fig. 9. Comparison between different methods of identification and real response.

All the responses presented above in Fig. (8)are based on the step response acording to an especific consumption of the oppening valve.

The red curve represents the real response, the green one accounts a second order identification already done in the same didact plant and the blue one shows the identification made by non-recursive estimated least squares technique.

VII. CONCLUSIONS

This paper presented the application of the method of identification model by non-recursive least squares estimator in a process level, whose dynamic characteristics changed according to the dynamics produced by an outlet valve.

As shown in the Fig. 8, the responses were reliable when compared to the real system, demonstrating the functionality of the implemented method. It remains to note, however, that it is necessary to verify that the transfer function is identified approachable to second order, enabling to project simpler controllers.

It's important to highlight that this method didn't need big efforts from the computer, being advantageous to its use in systems which require computational efforts for conclusion of other tasks.

ACKNOWLEDGMENT

The authors would like to thank MEC / SESu, ENDF, CAPES, FAPEMIG, CEFETMINAS Foundation and CEFET-MG by supporting the development of this work.

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