INTERNATIONAL JOURNAL OF COMPUTERS COMMUNICATIONS & CONTROL
ISSN 1841-9836, 10(2):165-173, April, 2015.

Control System Architecture for a Cement Mill Based on Fuzzy Logic

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Abstract: This paper describes a control system architecture for cement milling that uses a control strategy that controls the feed flow based on Fuzzy Logic for adjusting the fresh feed. Control system architecture (CSA) consists of: a fuzzy controller, Programmable Logic Controllers (PLCs) and an OPC (Object Linking Embedded for Process Control) server. The paper presents how a fuzzy controller for a cement mill is designed by defining its structure using Fuzzy Inference System Editor [1]. Also, the paper illustrates the structure of the implemented control system together with the developed PLC program and its simulation. Finally, the dynamic behavior of the cement mill is simulated using a MATLAB-Simulink scheme and some simulation results are presented.
Keywords: Control System Architecture (CSA), fuzzy controller, cement mill, fresh feed control, ball mill, feed change.

1 Introduction

The modern automation equipment is controlled by software running on Programmable Logic Controllers (PLCs). The classical closed loop control presents a long time until stable operation and slow reaction on interruption, but the modern fuzzy control presents a rapid stabilisation and a fast reaction on interruption. Process control is an essential part of the cement milling system. Development of an effective control strategy requires a good knowledge of the dynamics of the milling circuit. An effective process control system consists of: instrumentation, hardware peripherals and control strategy [4] . Ball mills rotate around a horizontal axis, partially filled with the material to be ground plus the grinding medium. In cement industry, stainless steel balls is used very often. An internal cascading effect reduces the material to a fine powder. Industrial ball mills can operate continuously, fed at one end and discharged at the other end [6]. Cement mill has two chambers, separated by a diaphragm. The purpose for using a diaphragm is because it divides mill into chambers or compartments. Also, allows operators to have different ball charges and liners in each and hence a different type of grinding action in each. Diaphragm controls the material flow from one compartment to the other, regulates partially the retention time and the degree of material filling in the grinding media voids. In the cement manufacturing process there are many equipments linked in the closed loop. The mill, that is a part of closed loop, has the longest delay. From the mill outlet, the product is transported by a bucket elevator to the air separator. Air separator is mainly used for raw materials and clinker classifying and setting up close-circuit grinding system with mill. The separator separates fine particles from coarse particles. The fine particles are collected as final product while the coarse particles are sent back for further grinding. In this section (mill and separator) large amounts of mass are being circulating: fresh feed flow, mill product, flow of rejected particles which is re-circulated to the mill inlet, final product (cement). Important values that present more attention are: bucket elevator power, re-circulated flow (coarse return), clinker level in the first chamber of mill, clinker level in the second chamber of mill. Figure 1 presents the closed loop for grinding circuit with main interest points.

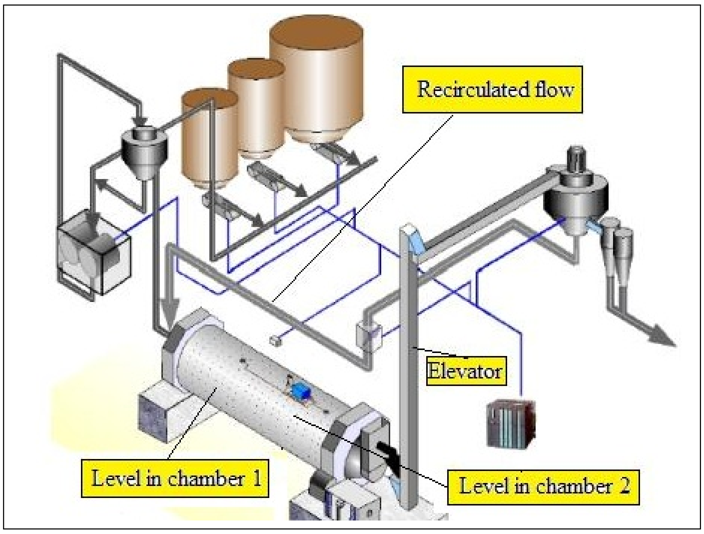

Figure 1: Closed loop for grinding circuit

The direct and precise measurement of levels inside the mill enables the fastest acquisition of any change in the grinding circuit and thus the fastest closed loop control imaginable.

2 The fuzzy system design

Taking into consideration the loop for grinding circuit of the cement mill, inputs and output of proposed fuzzy expert system used for grinding system control are presented in Figure 2 [1].

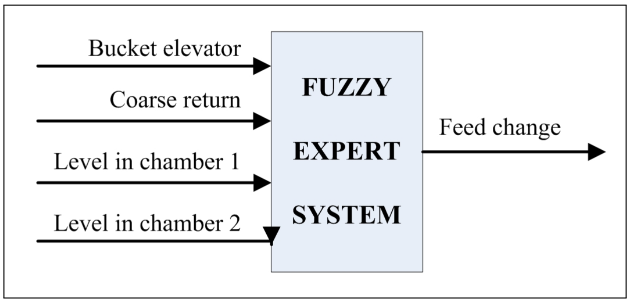

Figure 2: Inputs and output of fuzzy system

The output of the fuzzy controller is presumed to be described through singleton membership functions or by linear or nonlinear functions depending on the output process signal. The fuzzy structure consists on a fuzzy controller and a process [2, 3]. The structure presented in Figure 3 is being constructed by a number of r fuzzy blocks, connected in parallel FB1, FB2, ... FBr. The number r represents the number of the rules that define the fuzzy controller [2].

In Figure 3 the following notations are used: FC represent the fuzzy controller, FB is the fuzzy block, z is the controller input, u represent the command signal generated by the fuzzy controller, p is a vector that describes some possible external disturbances, x represents the state vector [1].

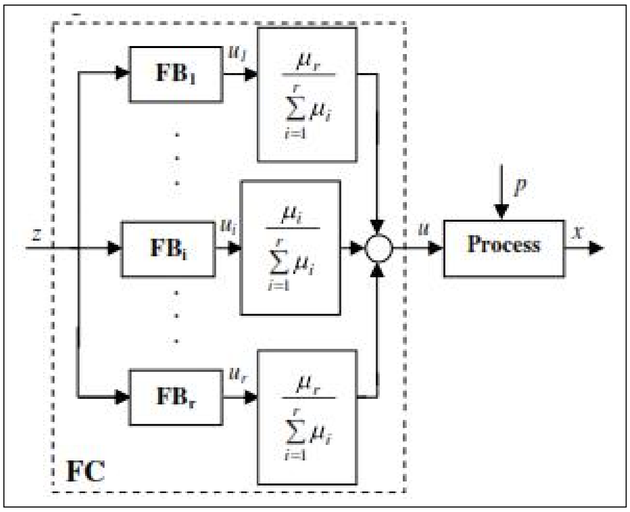

Figure 3: Fuzzy system structure with fuzzy controller decomposed by fuzzy rules

It was defined by the Wong team [7, 8] as a fuzzy subsystem associated to rule i, a system presumed to control the given process only by command ui. The command ui represents the output of fuzzy block associated to fuzzy rule i [2]. It was assumed that the fuzzy controller uses a rule basis consisting on r like rules. Each of these rules generates an output ui.

$$Rule\ i : IF premise\ i\ THEN u = ui, \tag{1}$$

with i = 1,2, ..., r.

Fuzzy systems are created based on three main steps. The first step is to define the input and output variables. The second step is to define the fuzzy subsets of each input and output variable and create membership functions. The third step is to define fuzzy rules that relate each input membership function to each output membership function [5]. Upon the completion of a fuzzy system, the fuzzy process will fuzzify an input, check each rule to find a degree of truth, and then defuzzify the result into an output value.

Using Fuzzy Inference System (FIS) Editor from MATLAB, the fuzzy system structure was defined by four inputs (bucket elevator power, coarse return, clinker level in the first chamber of mill, clinker level in the second chamber of mill) and one output (feed change). The fuzzy system structure, as it is defined by Fuzzy Inference System Editor, is presented in Figure 4.

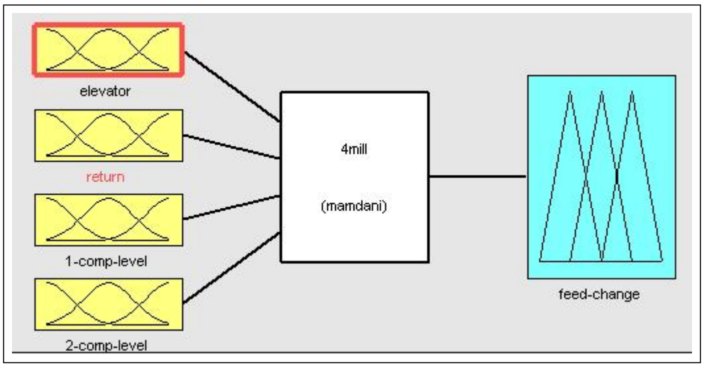

Figure 4: Fuzzy system structure using Fuzzy Editor

Each input linguistic variables has three membership functions: *low*, *ok* and *high*. Output linguistic variable has two membership functions: *add* and *sub*. The rule basis was implemented using Fuzzy Inference System Editor from MATLAB.

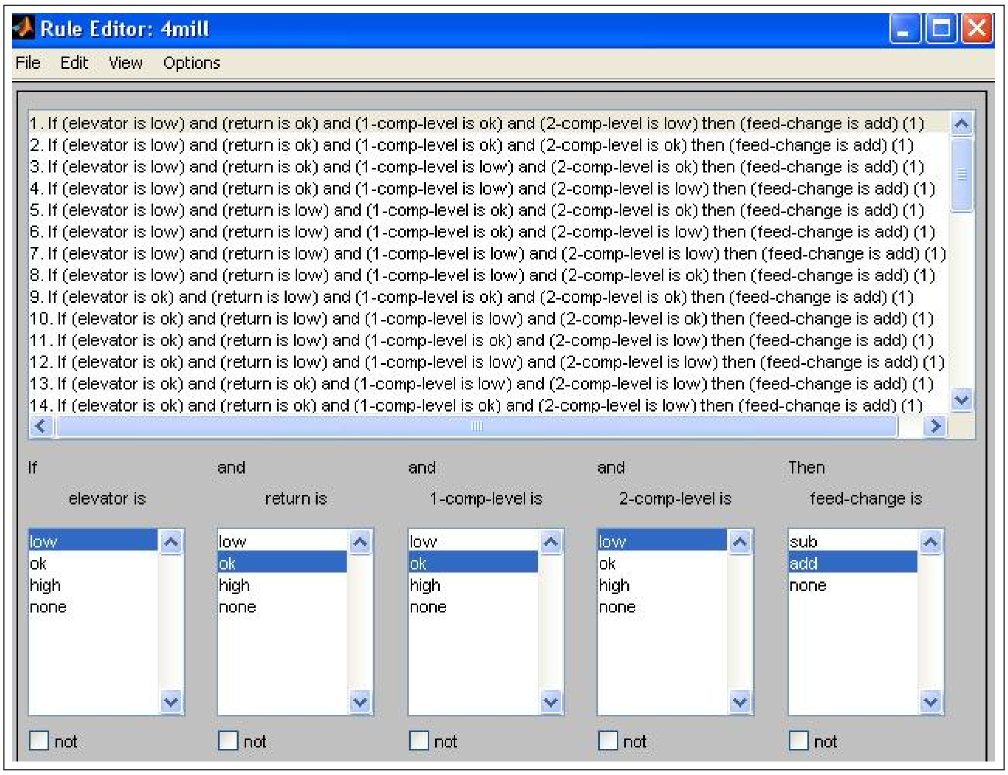

Figure 5: Rule editor

Optimal values for clinker level inside cement mill is 50% (30% are grinding media, for example steel balls and 20% are gas). Therefore, clinker level inside the mill is approximative 70% from mill capacity, excluding grinding media percentage. For coarse return a value of 20% can be considered optimal. This means that the final product is 80% and recirculated flow is 20% from mill product. The bucket elevator power is an important value because is necessary to avoid overfilling the buckets and therefore demaging the buckets [1]. Fuzzy sets have membership functions defined between 0 and 1. In this case, for a recirculated flow value of 20%, the membership function has a value of 0.2; for a clinker level value of 70%, the membership function has a value of 0.7. Figure 6 is a mesh plot of relationship between inputs and output (of fuzzy system). The plot results from a rule base and the surface is more or less bumpy.

The rule viewer depicts the fuzzy inference diagram for a Fuzzy Inference System stored in a file. The rule viewer is used to view the entire implication process from beginning to end. It is possible to move around the line indices that correspond to the inputs and then watch the system readjust and compute the new output. For the analyzed case, the rule viewer is shown in figure 7.

Figure 7 is a graphical construction of the algorithm, generated in the Fuzzy Inference System Editor from MATLAB. In Figure 7, each row refers to one rule. For example, the first row says that if the elevator power is low (row 1, column 1) and the return flow is ok (row 1, column 2) and the clinker level in the first chamber of mill is ok (row 1, column 3) and the clinker level in the second chamber of mill is low (row 1, column 4), then the output should be add (row 1, column 5).

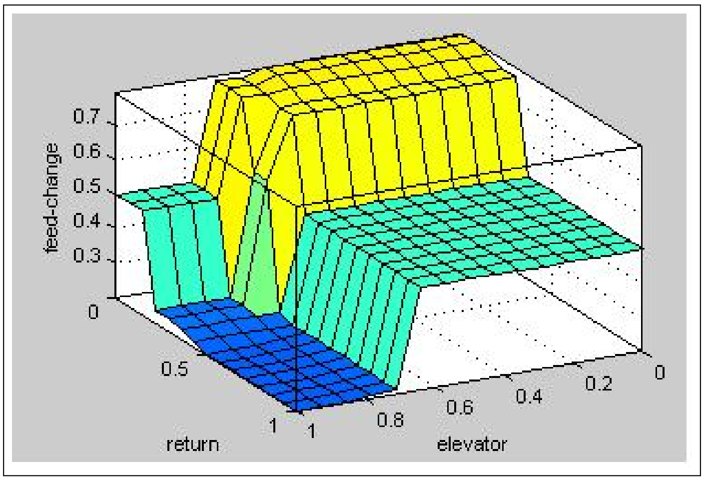

Figure 6: Control surface

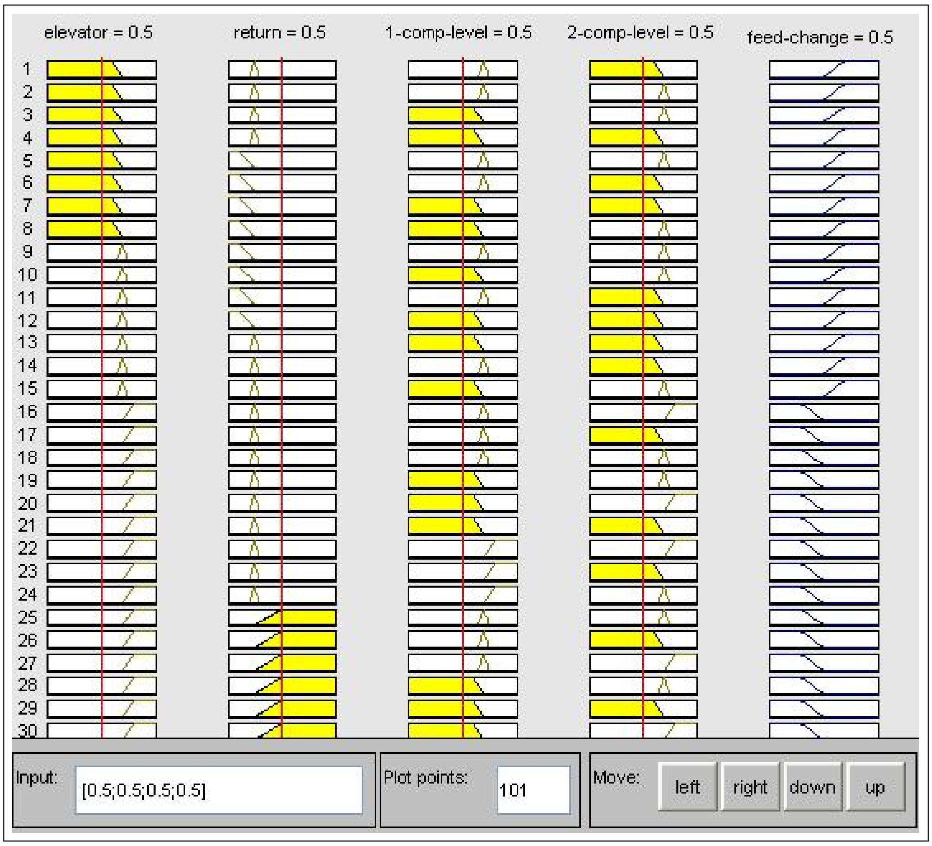

Figure 7: Graphical construction of the control signal in a fuzzy controller

3 The mill control system structure

A control system based on PLCs for clinker grinding circuit is developed. For cement mills, there are a few control loops that are considered; in this case, the control strategy is based on maintaining the total feed constant, by adjusting the fresh feed. The system has several options to enable application deployment:

- could be executed on systems from several suppliers;
- is able to work with other applications made on open systems;
- has a consistent style of interaction with the user.

The smart control system structure is illustrated in Figure 8.

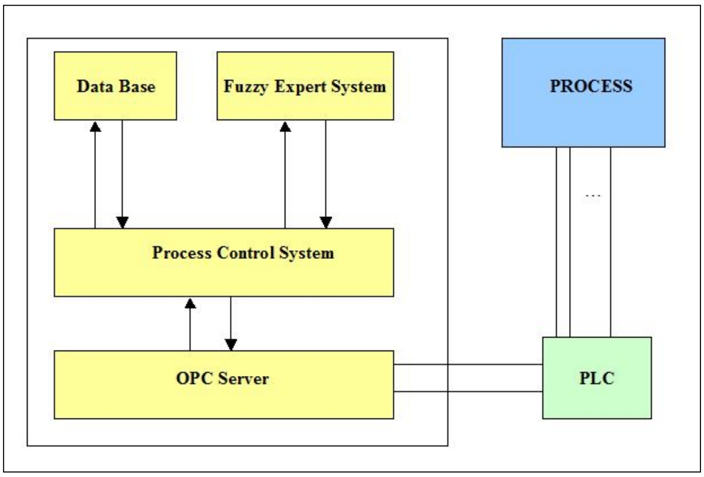

Figure 8: Smart control system structure

The process is controlled using an OPC server and this OPC server is connected to PLCs. In order to enable process monitoring, a graphical user interface was implemented by using WinCC Flexible environment for user interface development and configuration [9]. Thus the user is able to monitor the workload of the mill from the computer. The application is implemented using the SIMATIC STEP7 programming PLC [10] and SIMATIC WinCC Flexible implementation monitoring system [9].

As it is illustrated in Figure 9, the mill is load with throughput, from the feed bin. The ingredients fall down from feed bins to transporters. From the transporters, the ingredients fall down to another transporter. This transporter is feeding the mill. Material fed through the mill is grinding between the balls. From the mill outlet, the product is transported by a bucket elevator to the air separator. The air separator classify fine particles from coarse particles. The fine particles are collected as final product while the coarse particles are sent back for further grinding.

Ball mill control strategy proposal is: *total feed* = *constant*, by adjusting the fresh feed. At start, the ingredients quantities that fall down from feed bins to transporters are standard. The total feed is 100% fresh feed and 0% recirculated flow (coarse return). This fact can be seen in the Figure 9. After the materials are grinding, the particles pass out from mill and are send to the air separator. Here, the grinding particles are sorted in fine particles and coarse. From this moment, the coarse particles returns to the mill input. Because this reason, the fresh feed flow decreases (from 100% to 80%) and recirculated flow increases (from 0% to 20%). This fact can be seen in Figure 10.

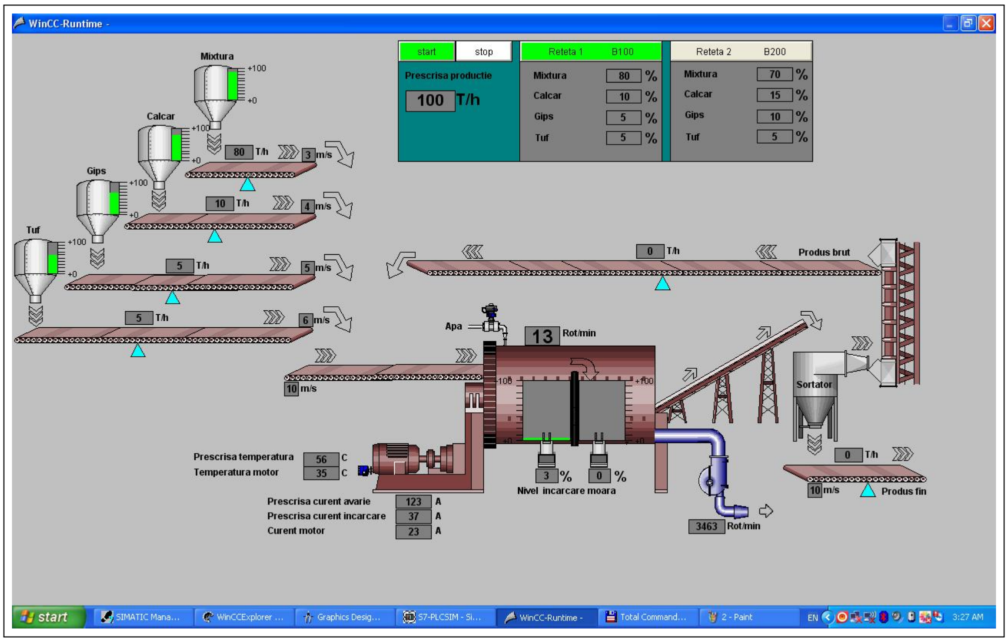

Figure 9: The process as viewed by WinCC Flexible

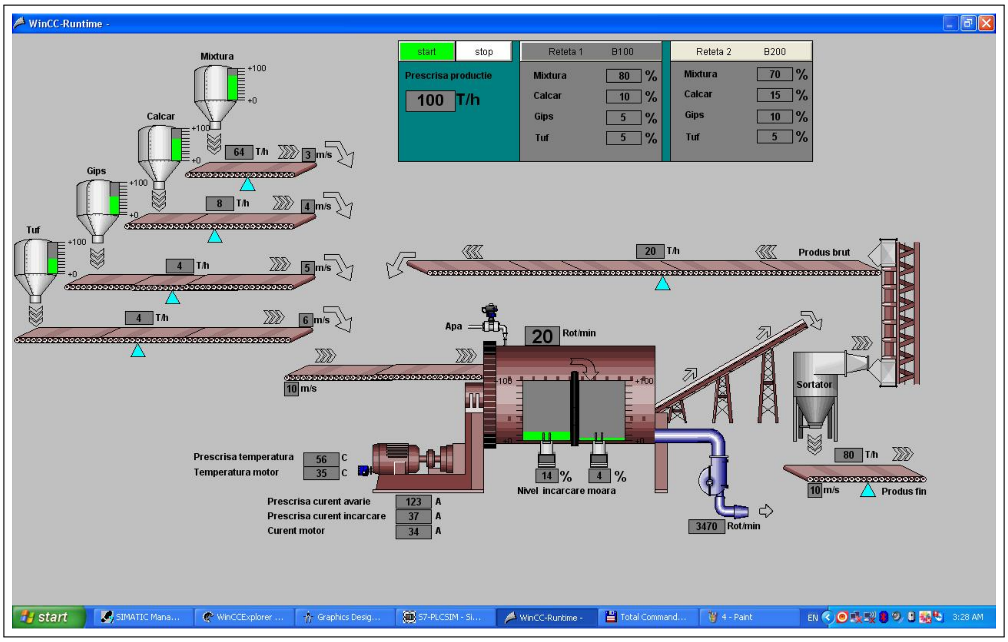

Figure 10: The process with total feed consisting of fresh feed plus recirculated flow

4 Simulation results

The dynamic behavior of a cement mill is simulated using a MATLAB-Simulink scheme. Simulation results that are presented in Figure 11 showing the value of the setpoint and the feed change. If it is used a signal generator to represent the setpoint, then the result are like in the Figure 11, where the setpoint has a square form. Figure 11 show that the feed is changing within range: 40%-60%.

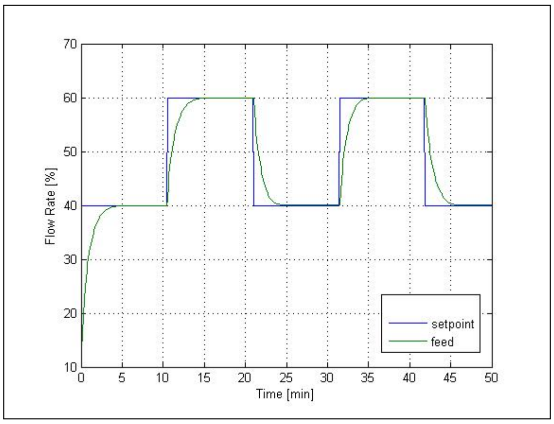

Figure 11: Feed Flow rate having a square form

But if is used a Step block instead signal generator, the results are better. Figure 12 is obtained for a setpoint that has a step signal form. The feed is constant, that mean the results will be better, because the flow rate hasn't oscillations. Figure 12 show that the feed has the optimal value (as is describe by membership function of fuzzy set) which remaind constant. Level signals simulated show a very fast reaction on material flow.

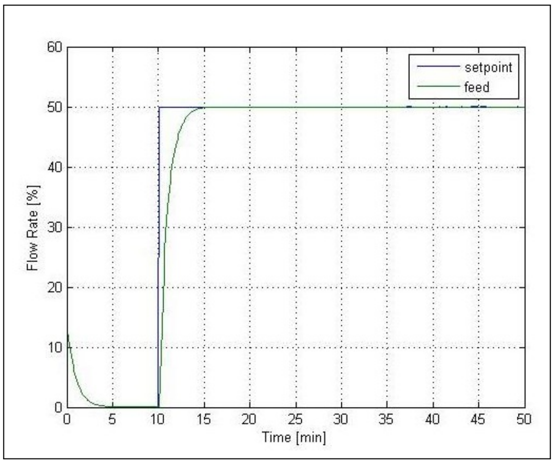

Figure 12: Feed flow rate having a step form

5 Conclusions and future works

A good control of the milling circuit contributes greatly to the stability of the process to increase grinding capacity and thus increase the amount of cement produced. This paper presents a strategy for process control in a cement miling circuit. The strategy proposed is based on keeping the *total feed constant*, by adjusting the fresh feed. The first part of the paper describes how the structure of the fuzzy controller for a cement mill, an important part of the closed loop of the cement grinding circuit, is designed [1]. The second part presents the design of a control system by using PLC for clinker grinding circuit together with the application of a PLC program and its simulation. Automation problem presented in the paper is complex, but the proposed solution leads to the development of a modern and efficient control system.

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