AUTOMATED SOLUTION FOR CONTROLLING THE OPERATION OF A FRANCIS MICRO HYDROPOWER PLANT

A. Bostan, *Babeș Bolyai University, Reșița, ROMANIA*
M.D. Stroia*, *Babeș Bolyai University, Reșița, ROMANIA, corresponding author*

ABSTRACT: Present paper describes a solution regarding automatic optimized functioning of hydraulic turbine used at a micro hydropower plant, with maintaining on the upstream of a prescribed water level. The solution, implemented in specific Ladder Logic software, proposes a stable control system through the oscillations of the water level in the surge tank, which can be adjusted for any type of micro hydropower plant. The results of the tests, performed for different variations of the stream flow, confirmed a stable functioning of the control system for water level fluctuations of ± 5 cm, under normal operating conditions. The proposed method was implemented and tested for a horizontal Francis turbine, with a power of 250 kW, connected to a current power supply. A practical example illustrates the application of this type of control system solution.

KEY WORDS: water-level, hydro power plant, wicked gate, flow.

1. INTRODUCTION

The Francis turbine is a type of reaction turbine, a category of turbine in which the working fluid comes to the turbine under immense pressure and the energy is extracted by the turbine blades from the working fluid [4-6].

In general, small rivers are characterized by a stream flow with significant debit variation. Due to these flow variations, the solutions usually adopted in terms of reinstallment of the MHCs were to replace them with ones of lower powers, respectively with a lower nominal stream flow [2,7].

Low power hydropower plants do not have significant water accumulations. Therefore, they are provided with compensating basins that are dimensioned to a capacity which allows a turbine to extend its functioning for a period of 0.5 - 2 hours, while allowing the turbine to stop when the water level in the tank decreases below the established minimum level [7].

The power that a hydropower plant can produce depends on the water fall (the height from which the water comes), H [m], respectively on the turbine water flow, Q [m^3 / s]. River flow represents the volume of water in [m^3] that passes through a cross section of the river in one second. The available theoretical power P [kW] can then be determined using a simplified relation:

$$P = \rho \times g \times Q \times H [kW] \quad (1)$$

where: δ – water density; g – gravity acceleration; Q – turbine water flow; H – height of water fall .

A water-level controller is often used in a run-of-river hydroelectric power plant to match the plant and river flows. This controller opens or closes the turbine wicket gates in order to ensure a constant water level in the upstream. Similarly, a water-level controller can be used between two hydroelectric power stations having a serial connection along a waterway in order to match flows between the two plants [3-9].

An optimal continuous operation involves observing the functioning behavior of a micro hydropower plant (MHC) in order to establish safety parameters which allow us to achieve a good correlation between the availability of the MHC and the number of start-stop cycles considered for a certain period of time [7-15].

The large number of starts-stops per day produces stresses with serious effects upon

the components from turbine structure, such as the rotor, bearings, etc.
In order to avoid these situations and to obtain an optimal operation and a high efficiency in energy production of the micro hydropower plant, an automatic system for monitoring and controlling the water level in the compensatory basin is imposed.
The solution proposed in this paper, for optimizing the functioning of horizontal Francis-type micro-hydropower plant (FO), is to embed an automated system for maintaining a prescribed water level upstream, having the result of reducing the number of start-stop cycles per day [4-8].

2. THE PRINCIPLE OF THE SOLUTION USED FOR AUTOMATIC OPERATION OF THE HORIZONTAL FRANCIS TYPE TURBINE

An important requirement of any control system is stability. In the case of MHC Francis operation, the control is obtained by checking the water level, which must be within the prescribed limits, depending on the type of turbine.
In order to optimize the control of the FO functioning by operating according to a prescribed level, the following characteristics were considered:
normal turbine operating mode: power between 80kW and 250kW
- 110 m water fall
- flow rate 0.3 m^3/s
- prescribed water level 2.4 m
- minimum water level 1.1 m
- maximum water level 2.8 m.

The algorithm of automatic functioning of the turbine is presented in the logic diagram from figure 1, for the particular case considered. A Twido PLC was used for the automation part. The PLC counter was set to 70 s. At the initial and final value of the counter, the values of the water level in the compensatory basin are read and the variation of the water level in the preset time period is determined, after this step the counter is reset and the process continues.
We set the condition that the variation of the level, z, falls within the prescribed limits, ± 5 cm in this study, limits between which the MHC continues its normal functioning. If, however, z exceeds the upper limit +5, then the value of the variable "increasing basin" changes and it is verified if the active power, P, exceeds the maximum turbine power of 250 kW, situation in which the wicked gate is closed. If the active power, P, has not yet reached the maximum value of the turbine power, it is checked if the current water level, L, has exceeded the prescribed water level, 2.4 m, and if the wicked gate can still be opened, it is operated in this sense.
In a similar manner, the automation process is performed in case z falls below the prescribed lower limit. In this case the value of the variable "decreasing basin" changes and is checked if the active power, P, is below the minimum turbine power of 80 kW, in which case the wicked gate opens. If the active power, P, has not yet decreased below the minimum value of the turbine power, is checked if the current water level, L, is below the prescribed level day [14-17]. Depending on the current value of the water level relative to the minimum water level, it is decided whether to close the wicked gate, if it is not already closed, or whether to stop the operation of the turbine until the water level in the compensatory basin exceeds the prescribed limit.

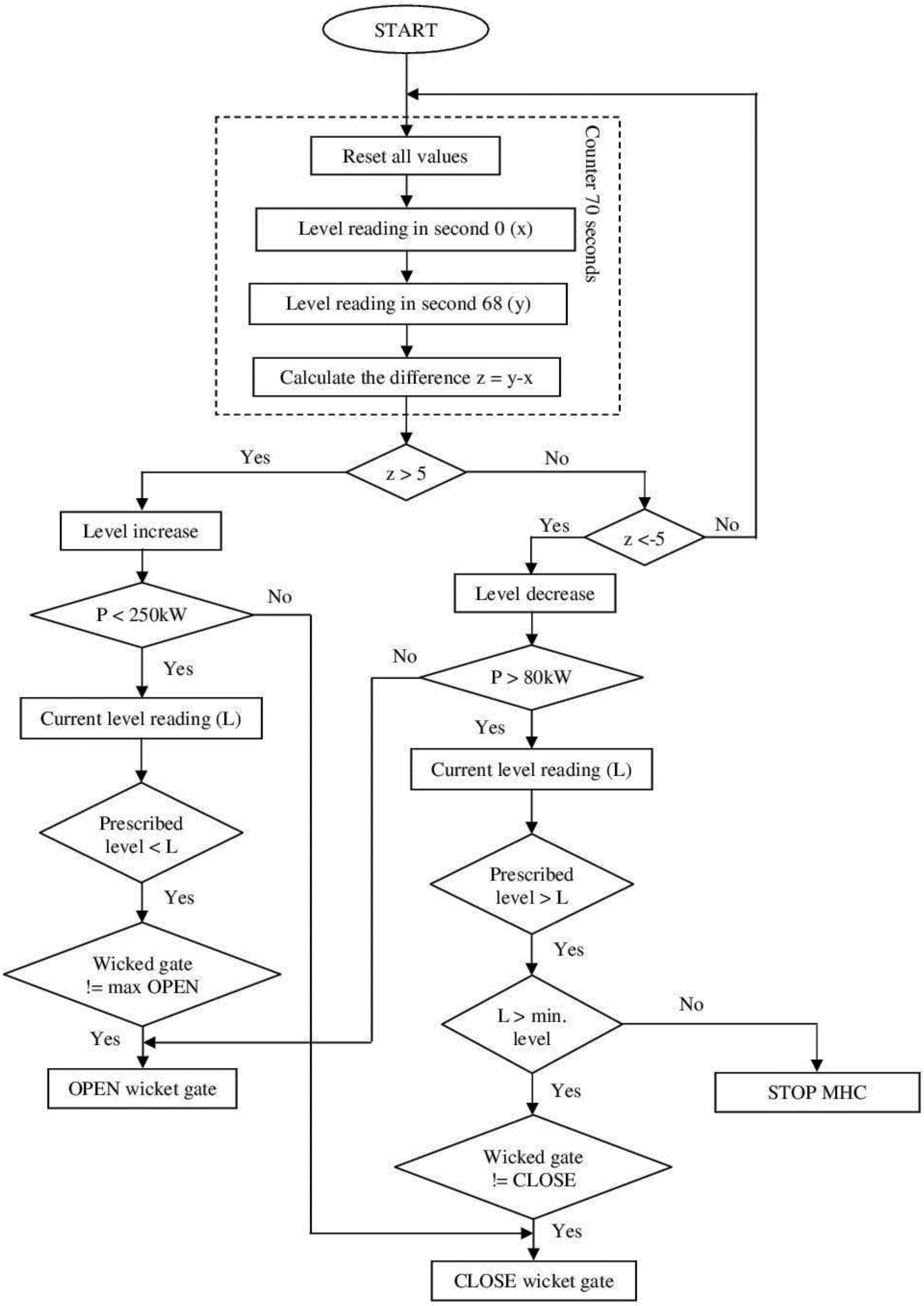

Figure 1. Flowchart of automatic functioning algorithm

3. IMPLEMENTING THE SOLUTION FOR AUTOMATIC FUNCTIONING OF FRANCIS TURBINE

For designing the hardware part of the automated system, as mentioned above, a Twido PLC was used, its structure and connections being depicted in figure 2.

On the RS485 communication port (1) the communication with the operator panel (4) is made through the Modbus 19200 bus. The PLC is programmed on the same port. The PLC module contains 12 digital inputs (3), 16 digital outputs (2) and an expansion module that has 4 analog inputs (5) in 4-20 mA unified signal. On the digital inputs module (3) we take from the MHC status signals such as: closed / open control unit, closed / open

generator switch, closed / open inlet valve and others.
The digital outputs (2) are used for the control by means of commands for opening / closing the steering device, opening / closing the valve, opening / closing the generator switch, opening / closing the inlet valve and others. On the extension module are used the analog inputs for the position of the steering unit on the range 0-100%, the input for the water level in the pool, the active power of the turbine generator.

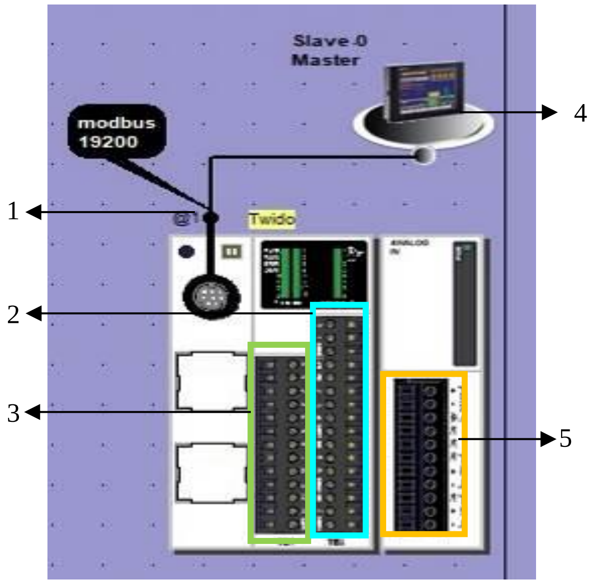

Figure 2. PLC Twido and connections

TwidoSuite software, version 2.20, was used for the program part of the application.
The program sequence in which the input data is read, the water level in the basin at time 0 (variable x in the logic diagram) and at time 68 (variable y in the logic diagram) of the counter, is presented in figure 3. Depending on the value of the difference, z, decisions are made to open or close the wicked gate.

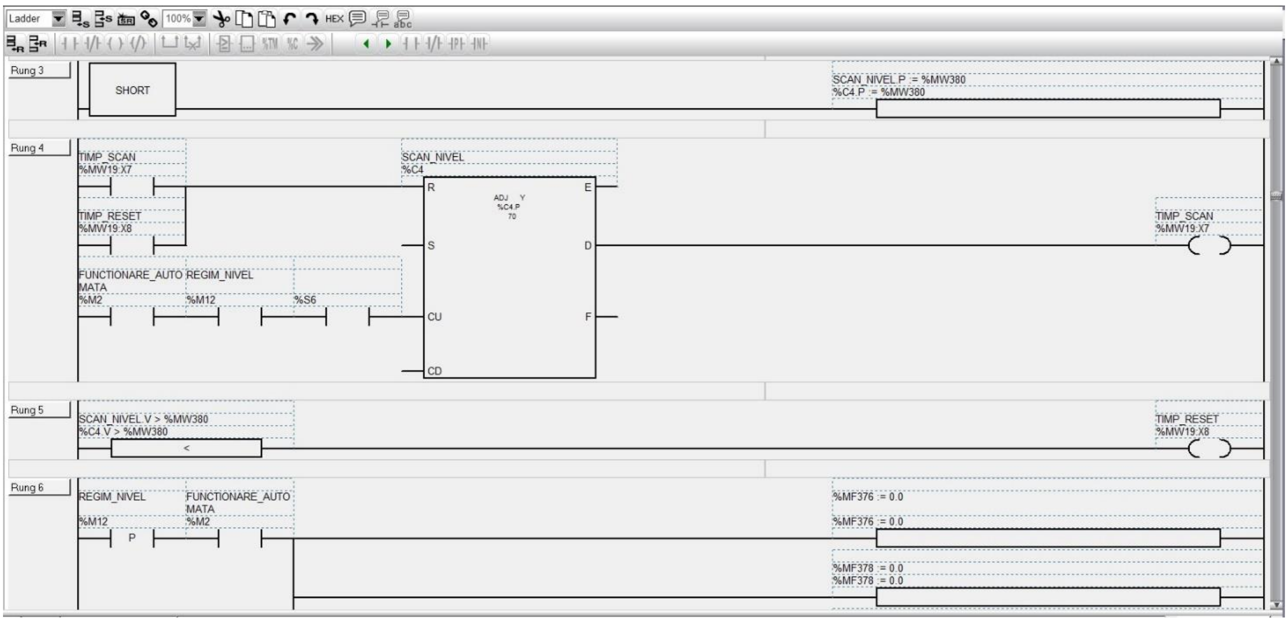

Figure 3. Program sequence – reading and analyzing data

Figure 4 shows the Ladder Logic program sequence which has the purpose of controlling the opening (Rung 20), respectively the closing (Rung 21) of the wicked gate, as it

was structured in the block diagram of the automatic operation algorithm from figure 1.
From the graphical representation shown in figure 5 it can be seen the variation of the turbine generator power, depending on the water level in the basin, monitoring performed over a period of 8 hours. The water level respects the imposed interval, noticing a recovery of it in case of reaching the prescribed limits. Also, as shown in Figure 5, the active power of the turbine generator varies in proportion to the water level in the basin.

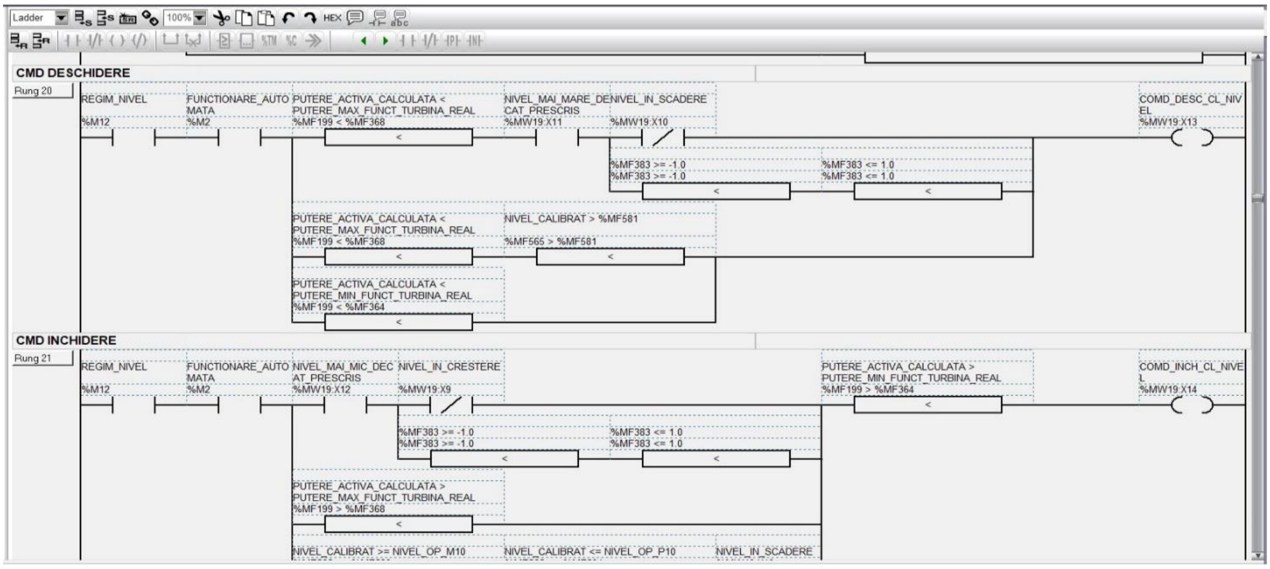

Figure 4. Program sequence – controlling wicked gates

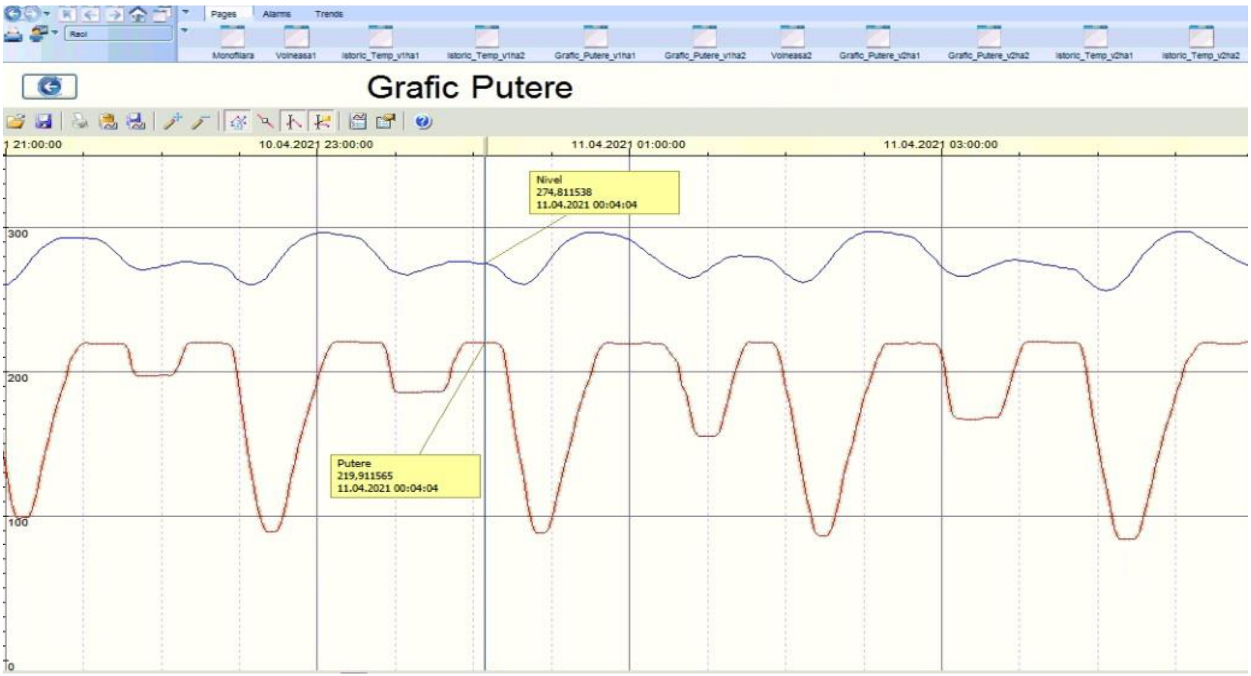

Figure 5. Power variation for an 8-hour period of functioning

4. CONCLUSION

The adopted solution for automatic turbine operation is functional and has applicability through increasing the reliability of turbine components. The values used in described application can be adjusted, depending on the structure and capabilities of the MHC system. These values can be changed from the operator panel.

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