

DESIGN OF PID CONTROLLER FOR PLC

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Abstract

This paper deals with PID algorithm for the Modicon Premium platform from Schneider Electric. Based on real time samples measured by the PLC a model of the process was created in Matlab and then PID controller parameters were designed. The verification of algorithms on a real system (container with an unobstructed drain) and the evaluation of control capabilities of the tested controller are introduced. Paper deals with theoretical and practical methodology, offering approach for control design and its successful application.

1 Introduction

Programmable Logic Controller (PLC) devices have various advantages, such as high computing performance or the ability to communicate using different ports for different protocols (RS232, Ethernet) [2]. Relative complex and difficult ways of control and technical diagnostics can also be handled by a compact PLC. Another positive feature, also from the PLC design perspective, is a simple combination of two basic types of control systems: distributed systems and integrated systems. Thus, the advantages of both systems can be combined. An essential element of these systems is PLC. Components such as sensors, actuators, visualization features, etc. are connected via (digital/analogue) input and output modules or through communication channels. The above mentioned facts confirm that the PLC is suitable for complex solutions in the field of measurement and control.

The ability of proportional integral (PI) and proportional integral derivative (PID) controllers to compensate many practical industrial processes has led to their wide acceptance in industrial applications. The easiest way for choice of either two or three controller parameters is perhaps by making use of tuning rules. Various surveys show that the use of PID algorithm is estimated somewhere between 90 and 95% in practice.

This paper deals with design of PID algorithm and parameters for Modicon PLC TSX Premium using Matlab [5]. The PID controller has been designed for a real laboratory hydraulic system.

2 Software – Unity Pro XL

Schneider-Electric Unity Pro XL is a software environment for designing and programming of Schneider-Electric PLCs. It is an unique and high performance multitask software, offered for the Modicon M340, Premium, Quantum PLC's and Safety family. Unity Pro makes the best use of the graphic and context-sensitive interfaces of Windows operating systems. It offers five IEC61131-3 languages as standard. Each section of code can be programmed in the language of user's choice, best adapted to each processing operation. All of the edit, debugging and operation tools are accessible whatever language is used. The main benefit is in a complete set of functions and tools enabling modelling of application structure on any machine or process structure. The program is split into organised function blocks by grouping: program sections, animation tables, operator screens and hyperlinks. Repetitive used basic functions are encapsulated in user function blocks DFB (Derived Function Block) in IEC61131-3 language. In addition, with the Unity EFB (Elementary Function Blocks) Toolkit, user know-how can be standardised by developing their own basic functions in C language to supplement the Unity Pro library. An integrated library of application diagnostic is provided by DFBs depending on function monitor permanent safety conditions and the evolution of the process over time. With the UDE, Unity is enhanced by specialised software for IT (Information Technology) developers in VBA (Visual Basic for Applications), VB (Visual Basic) or C++. It offers access to all Unity Pro software server objects for development of tailor-made solutions such as

creation of interfaces with an electrical CAD (Computer-Aided Design) or application automatic generator. Example of Unity Pro application is in Fig. 1.

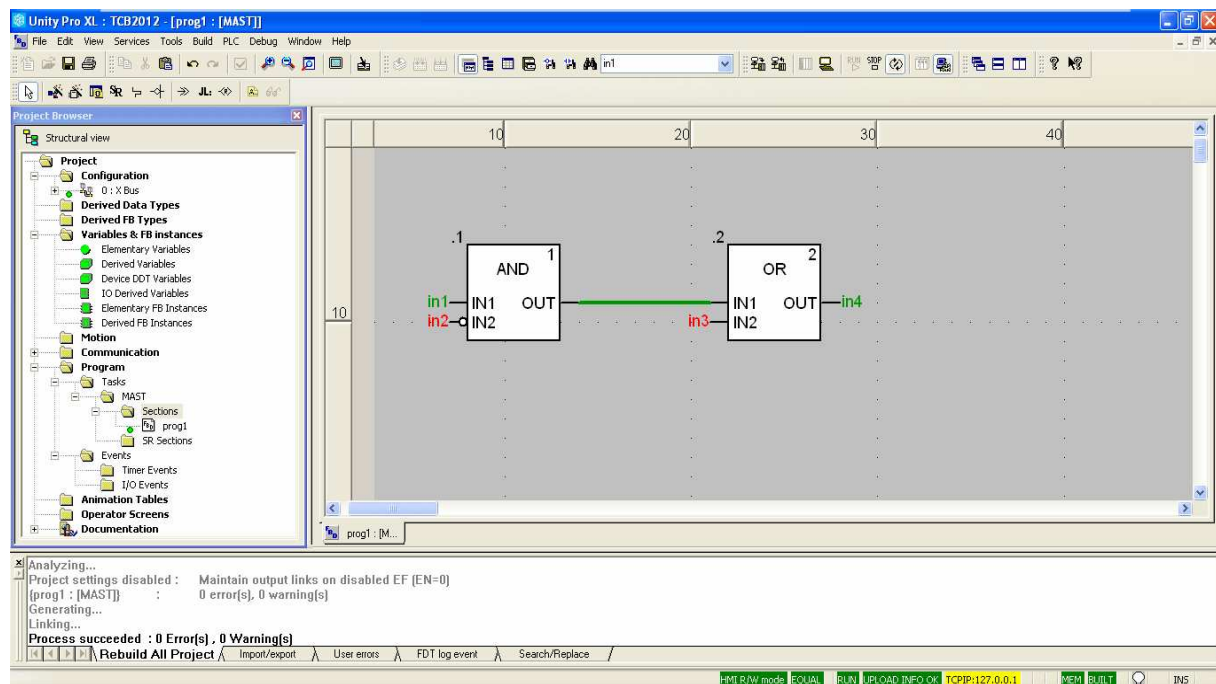


Figure 1: An example of Unity Pro application

3 PID controller design

PID control is a fundamental feedback control mechanism for various systems. It attempts to correct the difference between the measured and desired value – control error – using manipulated variable to suppress this difference to zero. The controller is represented by three components: proportional – represents the controller gain, depending on the error determines the actual response; integral – performs the sum of past deviations and derivative component – works with the rate of change of the error.

Different PID function blocks are used in Unity Pro. These function blocks perform initialization in the first program cycle of the PLC program. Therefore they must be called in the main program task, otherwise the initialization fails and outputs can have bad values [1].

These function blocks have the following properties:

- calculating the proportional, integral and differential component in its incremental form,
- anti-windup reset,
- direct or inverse action,
- differential component to process value or deviation,
- parameterization of the differential component transfer gain,
- weight of the setpoint in the proportional component (reducing the overrun),
- feed forward component for disturbance compensation,
- dead zone on deviation,
- incremental value and absolute value output,
- upper and lower limit on the output signal (according to operating mode),
- gradient limitation of the output signal,
- output offset,
- selecting manual/automatic mode,
- tracking mode - bump less changeover between manual and automatic,
- upper and lower setpoint limit.

General block diagram of the PID function is shown in Fig. 2.

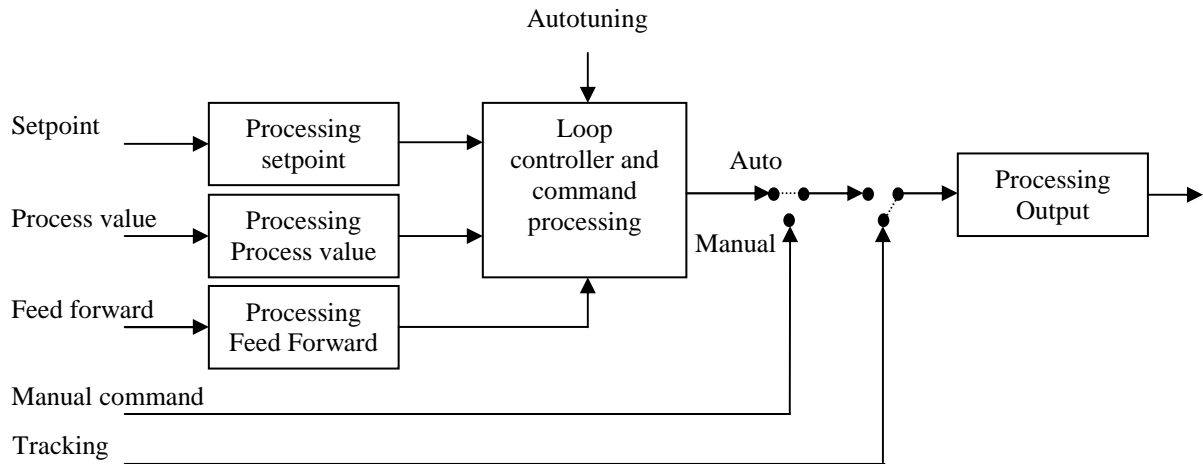


Figure 2: PID function block diagram

Representation of the PID function block (in Function Block Diagram - FBD language) with inputs and outputs is shown in Fig. 3. The illustration shows, that it is possible to assign SP, PV, MODE PARA FEED_FWD a YMAN tags (variables). Variables are explained in detail in Table 1.

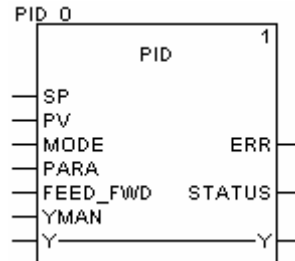


Figure 3: PID Function block

Possibility to create controllers with different combinations of P , I and D components is provided by Boolean internal variables of the functional block en_p , en_i and en_d by setting their values to 0 or 1.

Table 1: LIST AND DESCRIPTION OF PID CONTROLLER VARIABLES

I/O parameters	Parameter	Data type	Description
Inputs	SP	REAL	Reference value
	PV	REAL	Process value
	MODE	Mode_PID	Operating mode
	PARA	Para_PID	Parameters
	FEED_FWD	REAL	Feed forward
	YMAN	REAL	Controller output value in manual mode
Inputs-Outputs	Y	REAL	Manipulated variable
Outputs	ERR	REAL	Control deviation
	STATUS	Stat_MAXMIN	State of manipulated variable

The structure and description of the data types of variables Mode_PID, Para_PID and Stat_MAXMIN are in Tab. 2.

Table 2: LIST AND DESCRIPTION OF DATA STRUCTURES PID CONTROLLER

Structure	Parameter	Data type	Description
Mode_PID	man	BOOL	"1": Manual mode
	halt	BOOL	"1": Halt mode
	en_p	BOOL	"1": P enabled
	en_i	BOOL	"1": I enabled
	en_d	BOOL	"1": D enabled
	d_on_pv	BOOL	"1": D processing deviation, "0": D processing process value
Para_PID	gain	REAL	Gain
	ti	TIME	Integral time
	td	TIME	Derivation time
	td_lag	TIME	Delay of D
	ymax	REAL	Upper limit of manipulated variable
	ymin	REAL	Lower limit of manipulated variable
Stat_MAXMIN	qmax	BOOL	Upper limit of manipulated variable reached
	qmin	BOOL	Lower limit of manipulated variable reached

4 Case study

Hydraulic system (Fig. 4) consists of water tank with water reservoir, PLC, pressure transmitter, frequency inverter and a pump [3].

Honeywell ST 3000 S900 pressure transmitter was used to measure the water level in the tank. It is a reliable and intelligent transmitter [4]. It offers the possibility of measuring pressure, absolute pressure, differential pressure and level. The signal from the transmitter is connected to the PLC analogue input card.

The transfer of water from the water reservoir into the water tank was making use of a monoblock centrifugal pump with threaded neck from CALPEDA manufacturer. The pump type is CALPEDA NM 2/AE.

The pump is controlled by a compact inverter PowerFlex 40 from Allen-Bradley, which is connected to the PLC analogue output card.

PowerFlex 40 has a standard control panel display, touch keypad and potentiometer. The inverter also includes LEDs to indicate the current status of the inverter.

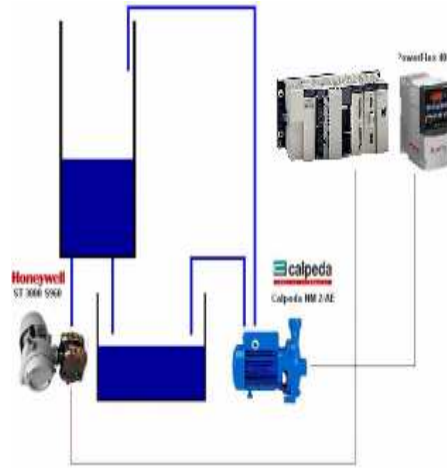


Figure 4: Block diagram of the hydraulic system (PLC, inverter, pump, pressure transmitter, tank and reservoir)

5 Simulation Results

The K_p , T_i and T_d parameters has been obtained by Ziegler-Nichols method [6].

Transfer function of PID controller is:

$$G_R(s) = \frac{U(s)}{E(s)} = P + \frac{I}{s} + Ds = K_p \left(1 + \frac{1}{T_i s} + T_d s \right) \quad (1)$$

The procedure is as follows:

- 1) Turn off the I -term and the D -term in the controller.
- 2) Turn P to zero, and then increase it slowly, while looking at time responses of the output variable (y) or - some times better - the output of the controller, u . Increase P until the output exhibits sustained oscillations (see Fig. 5 - violet, $P=6.5$)
- 3) At this "quasi steady-state" point we have reached the critical gain, called $P=P_K$, and period of oscillations, $T_K=5.34$ s.
- 4) Then the T_i and T_d should be turned on with the following configuration values (see the Tab. 3).

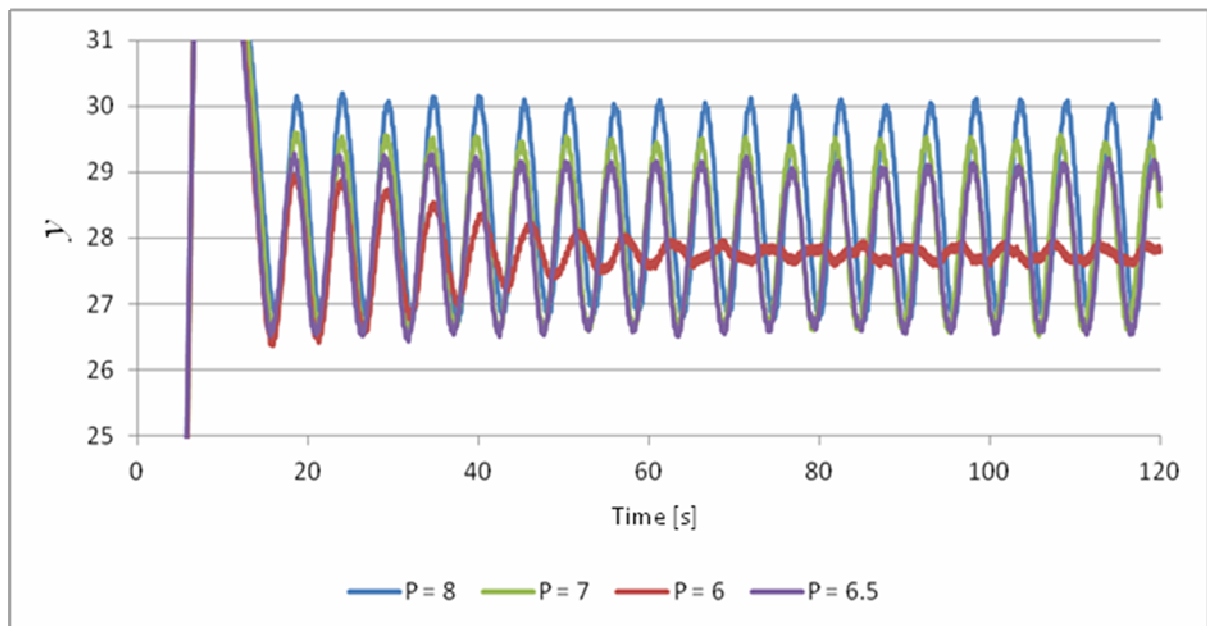


Figure 5: Time responses of the output variable by different parameter P ($I=0$, $D=0$)

Table 3: CLOSED-LOOP CALCULATIONS OF PID PARAMETERS

	K_p	T_i	T_d
P controller	$P_K / 2$	-	-
PI controller	$P_K / 2.2$	$T_K / 1.2$	-
PID controller	$P_K / 2.7$	$T_K / 2$	$T_K / 8$

From Tab. 3, K_p , T_i , and T_d can be calculated for all three types of controllers. The results are shown in (Tab. 4 and Tab. 5).

Table 4: PARAMETERS OF PID CONTROLLER (SEE EQ. 1)

	K_p	T_i	T_d
P controller	3.25	-	-
PI controller	2.95	4.45	-
PID controller	3.82	2.67	0.67

TABLE 5: PARAMETERS OF PID CONTROLLER (SEE EQ. 1)

	P	I	D
P controller	3.25	-	-
PI controller	2.95	0.66	-
PID controller	3.82	1.43	2.55

At first glance, we can see from the table that the PI controller has T_i greater than K_p , and in theory we know that for the most applications it is the opposite.

Also T_d is high value in comparison with the other parameters and such tuned PID controller can create oscillations of the output variable around the desired variable.

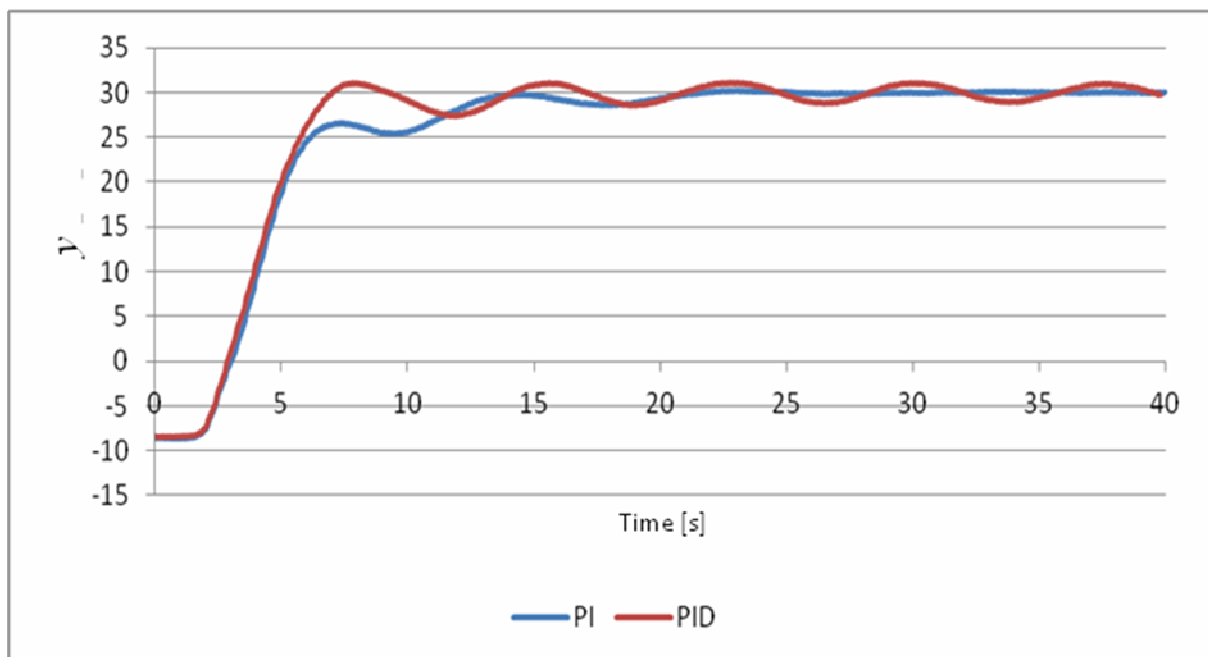


Figure 6: Time responses of the output variable under PID controller (Ziegler-Nichols method)

Time responses of the output variable under Ziegler-Nichols controller are shown in Fig. 6.

Designed PI controller (Ziegler-Nichols) is compared with PI controller, whose parameters were designed by experimental methods ($P=2.6$, $I=3.6$). Time responses of the output variable under both controllers are shown in Fig. 7.

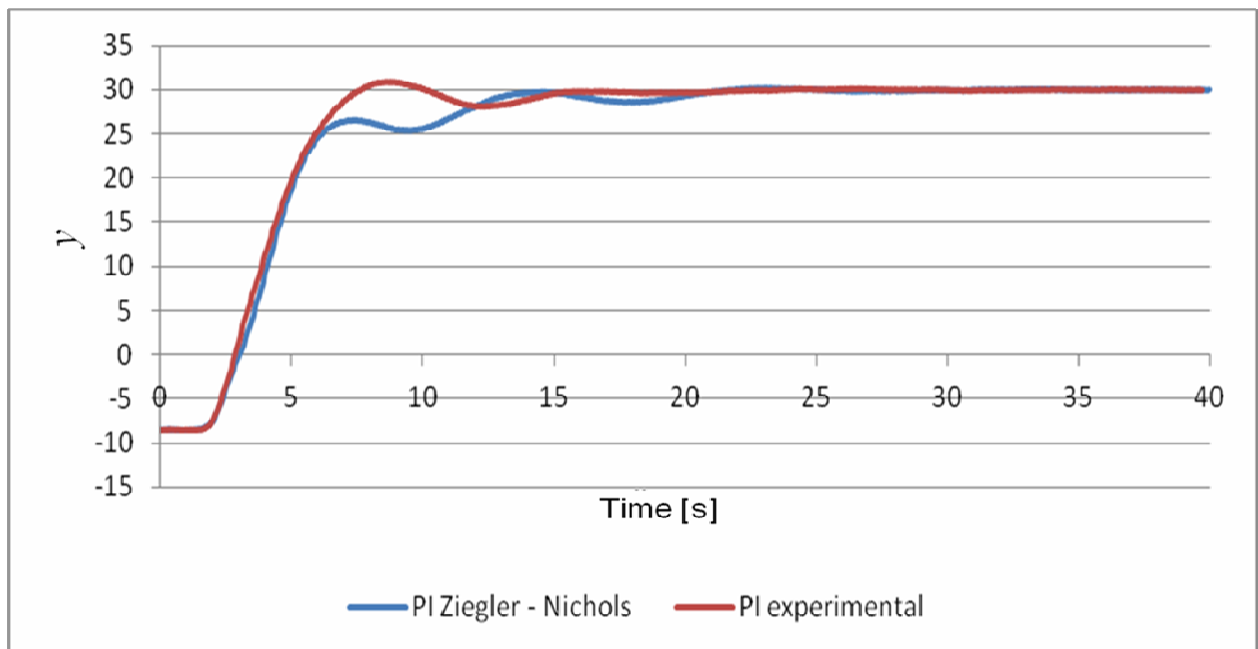


Figure 7: Comparison of time responses of the output variable under PI controller (Ziegler-Nichols method and experimental method)

6 Conclusion

This paper deals with control of a real system – a container with an unobstructed drain. PID controller for control of hydraulic system was designed by Ziegler-Nichols method and experimental method. Each of the designed control loops were verified by a simulation model in Matlab-Simulink before a test on the real system.

ACKNOWLEDGMENT

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References

- [1] A. Pulen. *Implementation of automatic design of PID controller in the PLC*. Master Thesis, FEI STU, Slovak Republic, May 2009.
- [2] L. Mrafko, M. Mrosko, L. Körösi: PLC a ich programovanie. Available on internet: <http://www.posterus.sk/?p=6903>
- [3] Frekvenční měnič PowerFlex 40. Available on internet: <http://www.controltech.sk/products/fmpf40.php?pid=2>
- [4] Inteligentný vysielač pretlaku, absolútného tlaku, tlakovej diferencie a hladiny ST 3000. Available on internet: <http://www.honeywell.sk/?com=documents&node=341&id=672>
- [5] Modicon TSX Premium PLCs. Available on internet: <http://detector-cooling.web.cern.ch/Detector-Cooling/coolingsystems/CoolingSystemWeb/ATLASphII/Materials/PLCProces.pdf>

[6] Štruktúry a formy spojitéch PID regulátorov. Available on internet:
<<http://www.kasr.elf.stuba.sk/predmety/ls/prednasky/Linearne%20systemy%202005/ls1-prednaska.pdf>>

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