Comparison Between Mostly-Used Old-Fashion Method and New PITOPS Simulator for PID Controller Tuning Method

Lalit Kumar[1]

[1]Aditya Birla Science and Technology Co Ltd

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Abstract

Since the 1980's the field of process control has become increasingly important in chemical and petrochemical plants, oil refineries and other manufacturing units. They are widely used are & still a very powerful tool in process control domain is the PID controller. To get optimal performance of any PID controller and to extract the full economic and safety benefits of it, appropriate PID tuning is required. This paper examines and compares industrial mostly-used old-fashion PID controller tuning method with the better PITOPS simulator. Old-fashion PID controller tuning method use Trail-and-Error approach or Empirical sets of rules, whereas the PITOPS technology uses powerful mathematical NC-GRG (Nonlinear Constrained General Reduced Gradient) optimization approach developed by International automation and process control company PiControl Solutions. The main goal of the paper is to highlight the benefits of PITOPS over the mostly-used old-fashion methods for industrial PID controller tuning, over several typical examples.

Introduction:

Need for automation and process control was felt back in early 1900's, old factory mills, distilleries, breweries, mechanical transmission, and in many other examples. Since the 1960's the field of process control has generated numerous money-saving ideas. Therefore, has become increasingly important in chemical and petrochemical plants, oil refineries and in other manufacturing units in order to improve and keep stable their entire operation and production. Process control continues to be one of the most fascinating and growing areas with tremendous future prospects related to economy, safety and process stability. Optimal process control strategy can help by:

- Improving product quality
- Increasing production rates of desired products
- Reduction in unwanted by-products
- Optimization of utilities
- Reducing environmental pollution
- More stable plant and equipment operation
- Increasing automation and modernization

The primary control layer is the backbone of process control hierarchy and it supports all advanced control and complex optimization applications. Study of the chemical and other manufacturing plants reveals that often the modern, complex advanced control applications receive primary focus and often the underlying bottom-layer, primary control, issues are somewhat neglected because of lesser emphasis.

The heart and soul of a primary control layer is an PID controller. The PID control algorithm is the oldest, yet most popular and widely used control method. Amazingly, the PID control algorithm is unclear and misunderstood by many. If understood clearly, the PID control algorithm can provide, tremendous benefits, control improvements in a simple and robust manner.

The PID controller is basically a Proportional, Integral & Derivative algorithm-based controller which works on the output sum of these three terms. Each of these terms in most of the times depends on the error (**e**). Error is the calculation value between the desired process output i.e. Set Point (SP), set by the operator or some advanced process control logic and the actual measurement signal i.e. Process Value (PV), coming from the field measurement sensor. According to the present and past error values the controller Output (OP) is generated by the algorithm, which moves final control element (*valves, motors, etc.*), in order to minimize the error. In the PID control algorithm PID parameters play a key role, where the most effective control action depends on their optimal values, as shown in Figure 1.

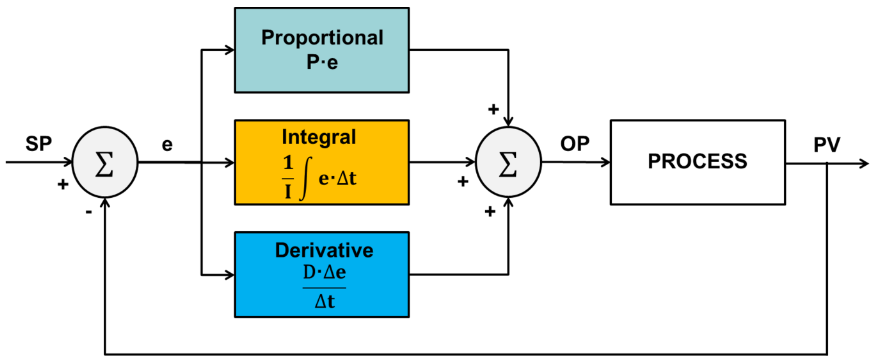

Figure 1 – *PID control algorithm structure*

In algorithm, all three have different significance like Proportional gain is directly linked with present error; more the error more the MV output to reduce the error, Integral is linked with the past values which were over the time & behaves accordingly and Derivative is a best estimate of the future trend of the error, based on its current rate of effect. The effect of PID controller parameters can be seen in Table 1.

Table 1: Effect of increase in PID controller parameters **Table 1: Effect of increase in PID controller para**

Parameters	**Rise time**
P	Decrease
I	Decrease
D	Small Change

Proportional gain (P) represents the level of aggressiveness in the PID controller. The P parameter is like a gain multiplier. High P value means more aggressive PID controller action, called proportional contribution. Integral tuning parameter (I) represents the level of impatience in the PID controller. Most of the times the "I" parameter is in the denominator. Derivative parameter (D) shows the level of anticipation based on past history of PV movement (*PV trajectory*). When dead time is long, adding derivative is like being able to increase the proportional gain without causing oscillations. Derivative action is lead response of the PID controller which compensates the process lag. The complete and detail behavior of a fully blown PID algorithm can be nicely seen in Figure 2.

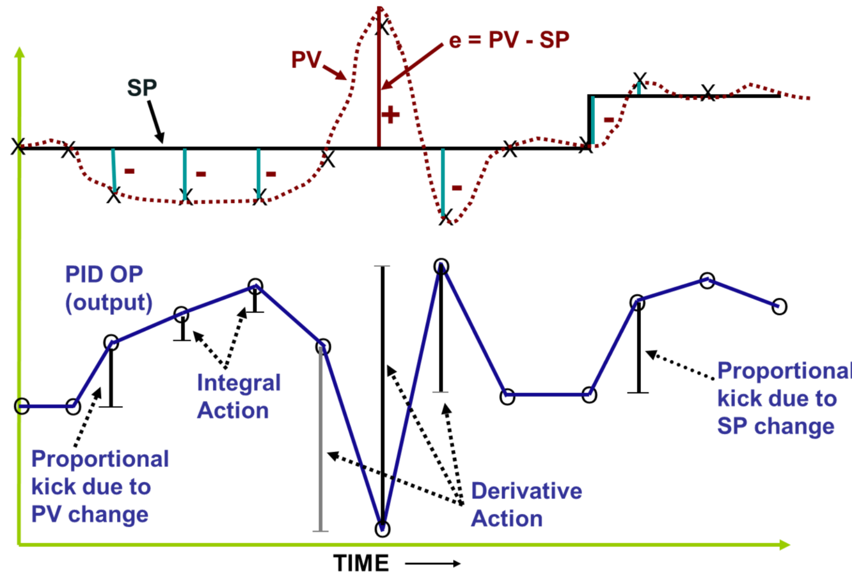

Figure 2 – *PID control algorithm behavior*

With changes in process conditions, hardware and equipment; there is a need for PID tuning according to the modified conditions, which are rarely made, often due to lack of available tools or the required skill set. On the other hand, many control loops are not fully optimized due to lack of awareness of the potential and the resulting benefits.

Often the old-age Trial-and-Error, Ziegler Nichols (ZN) and similar empirical PID tuning methods are used with little chance of correctness and weak control quality performance. Inappropriate tuning of PID controller results in poor control quality, often oscillations or sluggish control followed by the control room operator turning off the advanced process control schemes or putting the PID controllers in manual mode. If PID controllers tuning parameters are not adjusted, then the controller could run in this mode for years and even decades. Therefore, proper PID tuning is increasingly important for many chemical plants in present scenario.

For the best performance of the PID controller the values of P, I and D parameters have to be at their optimum. If PID tuning parameters are not optimal, control action will be sluggish or oscillatory. Bad PID control action can reduce product quality, make products sub-prime, off-spec, prevent production rate maximization and distract the operators/engineers focusing on the other important tasks in the plant.

The procedure opted to find the optimum values of PID tuning parameters is known as controller PID tuning or optimization. There are plenty of methods, tools & theories which are available for tuning of PID controllers, however finding the best parameters for the dedicated PID controller is still a tricky task. Mostly used industrial PID tuning methods are old fashion. In 90% of the cases they are: Trial-and-Error, Ziegler Nichols, Cohen Coon (CC), IMC (*Internal Model Control*) and Lambda methods. Against all of them, this paper introduces brand new and more powerful PITOPS PID tuning technology. It uses sophisticated mathematical optimization algorithm NC-GRG (*Nonlinear Constrained General Reduced Gradient*) developed by PiControl Solutions and it will be compared with previously mentioned old-fashion methods.

Mostly-Used Old-Fashion PID Tuning Methods:

For tuning of PID controllers, industries still use methods like Trial-and-Error, Ziegler Nichols, Cohen Coon, IMC and Lambda which are quite obsolete in today's world. These methods mostly rely on trial and error steps for questing PID tuning parameters or on some old-fashion empirical rules and equations set back around 1940's when processes were simple, production grades & rates were not as changing as it is today, product and environmental specifications were not so tight as today. To cope up with these problems PID tuning should be appropriate to achieve the specification, production rate which is required. All these old-fashion PID tuning methods rely on time consuming and large step-test changes by forcing the PID controller to manual mode and producing either too aggressive or sluggish PID control action. Many times, their performance and success rely on the experience of a process control engineer whose knowledge is based on many years of PID tuning and process understanding. Therefore, all these methods will never produce optimal PID tuning parameter values which are required for good PID control in auto or in cascade mode when typical and frequent SP changes and the effect of process disturbances are present. The procedure followed during the old-fashion technique is described below:

- A typical PID tuning session begins when a plant operator requests help from a process control engineer to tackle with an oscillatory or sluggish response of PID controller to achieve its SP after a condition change or a load upset.
- Based on past experience; he starts to work on the PID tuning parameters using one of several old-fashion PID tuning methods. To tune a PID controller often process control engineer first needs to put the PID controller in manual mode.
- In manual mode, for finding the process dynamics parameters for PID tuning parameters, he will do some step-tests. Many times, due to presence of process disturbances and noise these step-tests need to be large enough for distinguishing the real process dynamics from typical process upsets which is not recommended in steady state.
- Once the PID parameters are calculated, after putting them in PID controller they need to be tested by online changing a PID controller SP. If new PID tuning parameters are not performing well the job of process control engineer is to fine tune them. Fine tuning method is purely based on his experience and trial-and-error procedure. As seen from all above steps tuning of a PID controller by old-fashion approach require an experience process control engineer, uses a lot of time, produces high uncertainty of results and upsets the plant seriously due to needful step-tests.

A large number of manufacturing plants still use these methods. The reasons which account for usage of these methods are absence of engineering knowledge and understanding, unavailability of robust process control software tools for closed-loop system identification, PID tuning and optimization, and PID tuning parameters simulation and testing without conducting serious plant step-tests due to fear of causing shutdowns and plant problems.

PITOPS Technology:

PITOPS is basically short form of "**Process Identification, Controller Tuning and Optimization Simulator** ". PITOPS works solely in time domain and that makes PITOPS different from the other market simulators which work in Laplace domain. It also has the ability to identify multivariable process models based on the closed or open-loop history or live data. It can also simulate the behavior of new vs. old PID tuning parameters based on the SP change, existing disturbances and signal noise, valve stiction or some other real-life and frequently seen process constrains. It does not require new, time consuming and large plant step-tests. The working of PITOPS is described below:

- A typical PID tuning session begins when a plant operator requests help from a process control engineer to tackle with an oscillatory or sluggish response of PID controller to achieve its SP after a condition change or a load upset.
- Process control engineer will gather past data of closed-loop or open-loop PID controller from the DCS or a PLC containing just PV and PID OP.
- Collected data in excel workbook will be imported to PITOPS and based on the data true process dynamics will be identified. This feature of PITOPS eliminates the step in which we force PID controller in manual, producing oscillatory control action or making damaging step-tests for finding the process dynamics.
- Identification of process dynamics will be done by PITOPS itself in just 3-5 minutes.

- The next step would be to use identified process dynamics and based on it to tune the PID controller. In PITOPS the user can choose one of the following goals for PID tuning:

- PID tuning based on the SP change
- PID tuning based on the PID OP rate of change
- PID tuning based on pulse/step/ramp/sine disturbance
- PID tuning based on the noise
- PID tuning based on the most aggressive but still stable PID tuning parameters
- PID tuning based on no PV overshoot
- PID tuning based on the sluggish PID tuning parameters
- PID tuning based on the control valves stiction
- PID tuning based on several combined above goals

Once the PID tuning and optimization has been finished, the produced new PID tuning parameters can be easily tested using robustness algorithm. Robustness algorithm allows user to test new PID tuning parameters upon the SP and dynamics change on simulator and see how process will behave in real. When the process control engineer is satisfied with new PID tuning parameters he just needs to enter them back to DCS or a PLC system and they will work properly. The usage of PITOPS is quite simple and easy to understand. Apart from simplicity, the time taken in PITOPS for tuning any controller is also less than using standard methods.

PITOPS vs. Old-Fashion PID Tuning Methods:

Table 2 shows complete list of practical process control functionalities which can be performed by old-fashion and PITOPS technologies.

Table 2 : The list of functionalities used in old-fashion and PITOPS technology

Table 2 : The list of funct

Functionality	**Old-Fashion**
Applicable to ramp/self-regulating/runaway process	**NO**
Model identification based on OP changes	**YES**
Model identification based on SP changes	**NO**
Model identification using non steady-state data	**NO**
Multivariable model identification	**NO**
Model identification based ultra-short duration data	**NO**
Control valve stiction identification	**NO**
Unmeasured disturbance identification	**NO**
Data preconditioning required	**YES**
Cascade PID tuning	**NO**
Calculation of feedforward parameters	**NO**
Inferential controller design	**NO**
Smith predictor design	**NO**
PID tuning based on the SP change	**YES**
PID tuning based on different disturbances	**NO**
PID tuning based on the valve stiction	**NO**
PID tuning based on the OP rate of change	**NO**
Robustness analysis of PID parameters	**NO**

Case Study:

For better understanding of both methods used for PID tuning and optimization, we will use the example of industrial batch reactor, as illustrated in Figure 3. In this example the temperature inside the reactor volume is measured and controlled by a temperature controller (TC) manipulating the steam control valve which enters the jacket of a batch reactor. The purpose of this TC is to have stable and tight control of a reactor temperature. The temperature inside the reactor can vary due to different operating SPs, steam pressure and temperature fluctuations (*disturbances*). Therefore, the goal is to tune this TC based on different SP and disturbances changes.

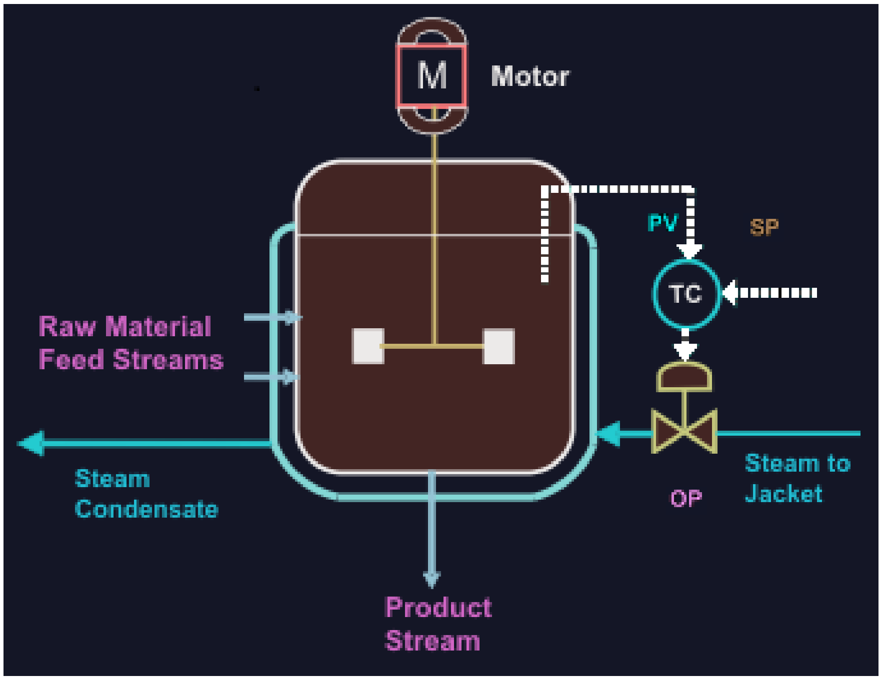

Figure 3 – *Industrial batch reactor P&I diagram*

Most of old-fashion PID tuning methods require PID data from which clear step change of PID OP in manual mode is visible or data showing oscillatory PID controller behavior, as shown in Figure 4. All these tests are time consuming, especially in the case of a slow TC, and they can seriously harm the process and produce off-spec product. Based on the conducted step-tests in manual mode the user will often need to calculate (*visually*) several parameters from the trends, depending on the used old-fashion PID tuning method.

Trial-and-Error method will require to know time-to-steady-state (TTSS) based on which the process time constant (*parameter which explains the speed of the response*) can be calculated. This parameter can be correlated with integral tuning parameter, but P&D parameters will be set just as a guess value based on the user past experience, as shown by Table 1. For using closed-loop Ziegler Nichols PID tuning method user needs to mark ultimate proportional gain and ultimate oscillation period. For open-loop Ziegler Nichols PID tuning method the user needs to calculate process reaction curve and its parameters. Relay method needs high and low peak values of PID OP which made PID controller to oscillate in manual mode. Lambda method requires to know closed-loop dead time and closed-loop time constant. IMC method needs to have open-loop dead-time, gain and time constant, based on visual trend analysis. Some other methods require the calculation of decay ratio (*typically set as 1:4*).

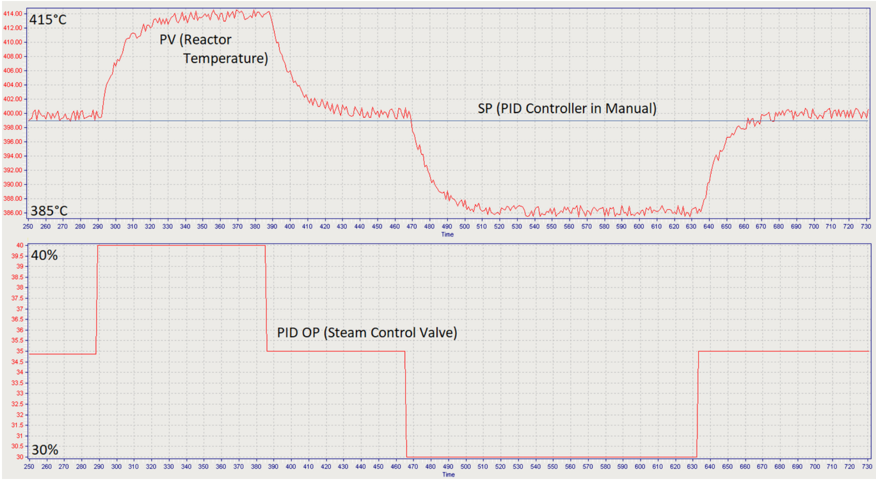

Figure 4 – *Needful data for old-fashion PID tuning methods*

Knowing all these parameters will help user to calculate PID tuning parameters purely based on the old set of rules, as shown in Table 3.

Table 3 – Example of ZN set of PID tuning rules	**Table 3 – Example of ZN set of PID tuning rules**	**Tabl**
PID Parameters	**P controller**	**PI c**
P	P = 0.5 * $P_{\mathbf{cu}}$	P = (
I	-	I = P
D	-	-

In the other hand, the PITOPS system identification is different from the other old-fashion techniques. PITOPS allows you to use typical past data from plant normal operation when either operator changed the SP in a step or a ramped manner in Auto Mode, when operator bumped a valve in Manual Mode or even when the PID controller was completely unstable in Cascade Mode, as shown in Figure 5.

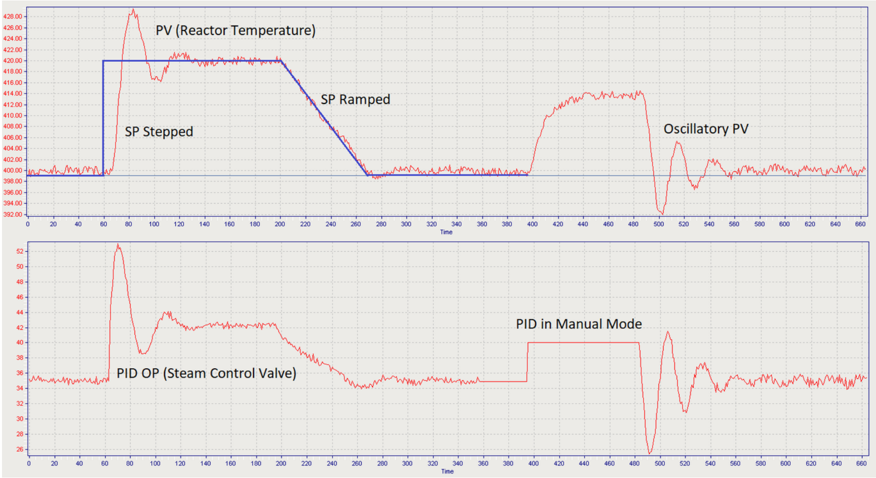

Figure 5 – "*Information rich*" *data for PITOPS PID tuning method*

PITOPS identification method is not sensitive to oscillatory data containing PV overshoots or undershoots (*as observed on the left side of Figure 5*). PITOPS identification doesn't require any data conditioning, which mostly refers to: removing outliers from data, data filtering, generating more data due to data missing points, data resampling methods and others which are typically needful when using old-fashion approaches. For better understanding which kind of data behavior PITOPS can easily handle, the PID was deliberately moved several times with a different behavior (*SP step change, SP ramp change, OP step change and oscillatory cascade mode*).

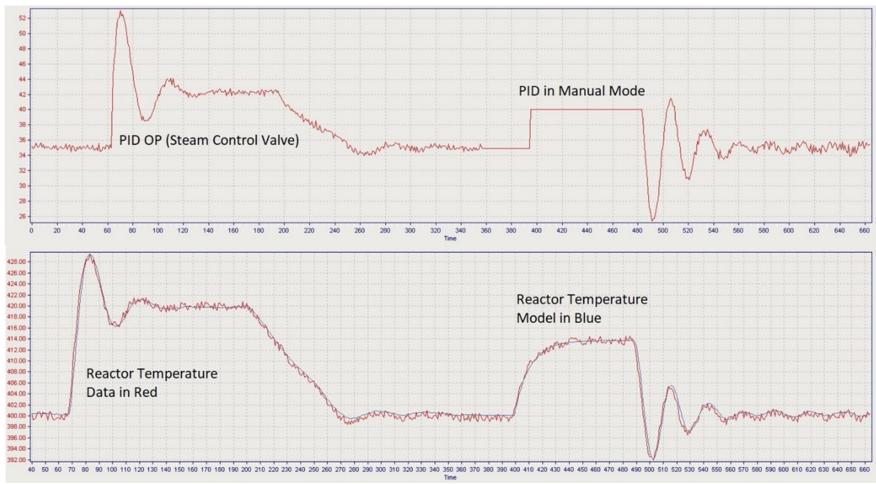

Figure 6 – *PITOPS process dynamics identification*

As it can be seen from Figure 6, identified process model (*shown with blue curve*) in PITOPS shows accurate model behavior which perfectly follows the raw reactor temperature data (*shown in red*) containing slow dynamics with a dead time of 4.5 minutes, process gain of 2.5 and a process time constant of 25.7 minutes. Considering the slow process dynamics if this process had to be identified using old-fashion methods, it would take much time of process engineer compare to PITOPS.

After process identification, the next step would be to find optimum PID tuning parameters. PITOPS uses precise and accurate algorithm for identifying process model and based on the process needs it tunes PID tuning parameters, as described earlier.

In this example, PID values computed from old-fashion PID tuning methods will be compared with PITOPS for a SP change and PV overshoot. Since this is a temperature controller, it needs to have very tight and stable control action without and oscillations and PV overshoot. To easily compare the PID tuning parameters computed from both methods, trends of both methods will be shown one after another. IMC and Lambda PID tuning standard will produce similar behavior where calculated PID tuning parameters gives very slow and sluggish control action without PV overshoot, as shown in Figure 7. ZN and CC PID tuning standard will produce somehow satisfactory control yet it will be very aggressive, oscillatory and with PV overshoot, as shown in Figure 8. Last shown PID tuning method is PITOPS. In house PID tuning standard will produce tight, stable and fast control action behavior without PV overshoot, as shown in Figure 9.

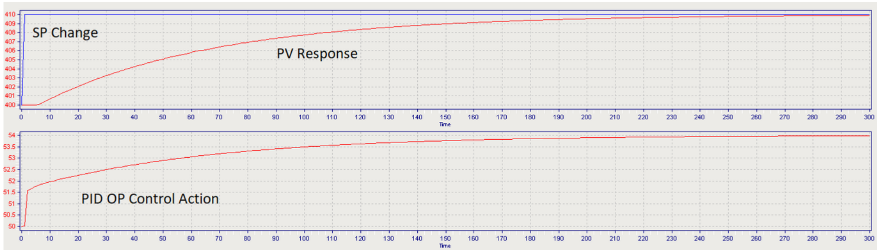

Figure 7 – *Lambda and IMC control action with new PID tuning parameters upon a SP change*

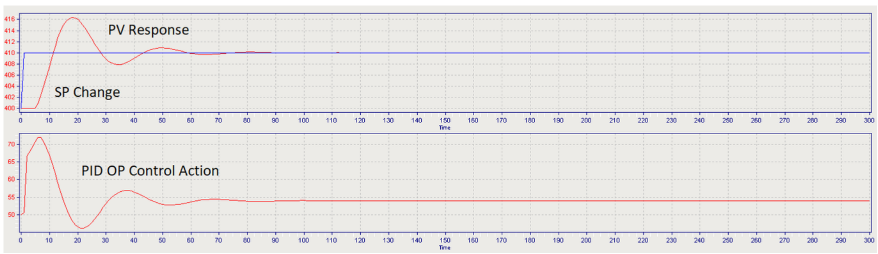

Figure 8 – *CC and ZN control action with new PID tuning parameters upon a SP change*

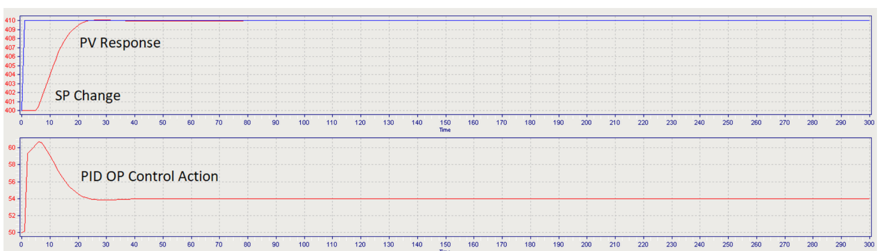

Figure 9 – *PITOPS control action with new PID tuning parameters upon a SP change*

All new calculated PID tuning parameters using above PID tuning methods are shown in Table 4.

Table 4 – Comparison of new calculated PID tuning parameters **Table 4 – Comparison of new calculated**

PID Parameters	**P**
IMC / Lambda	0.9
ZN / CC	8.8
PITOPS	5.3

In the example PID values computed using old-fashion PID tuning parameters will be compared with PITOPS for the same disturbance (DV) change. Since this is a temperature controller, it needs to have very tight and stable control action without and oscillations after disturbance appearance. Due to comparison simplicity PID tuning method trends will be shown one after another. IMC and Lambda PID tuning methods produce similar behavior where calculated PID tuning parameters gives very slow and sluggish control action which cannot reject typical process disturbances, as shown in Figure 10. ZN and CC PID tuning methods also give similar but too aggressive behavior where oscillations are visible after each disturbance, as shown in Figure 11. PITOPS PID tuning method provides optimal PID tuning parameters which produces tight, stable and fast disturbance rejection control action behavior as required for the process and shown in Figure 12.

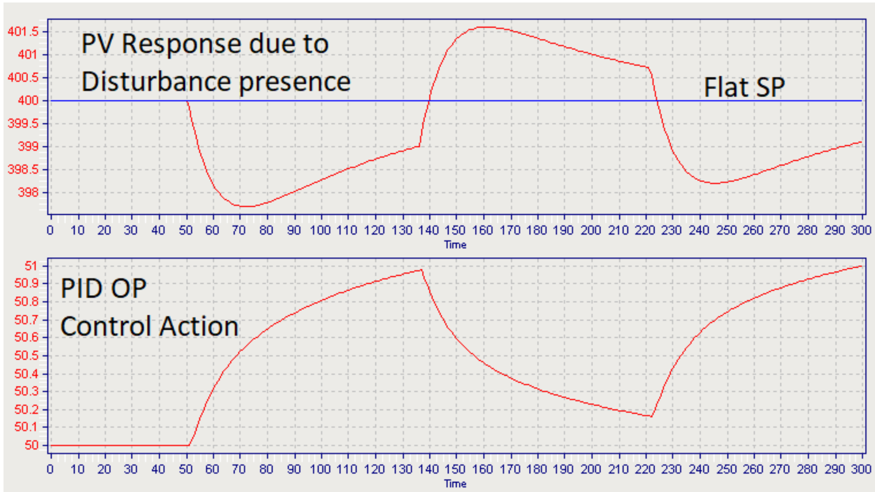

Figure 10 – *Lambda and IMC control action with new PID tuning parameters upon DV change*

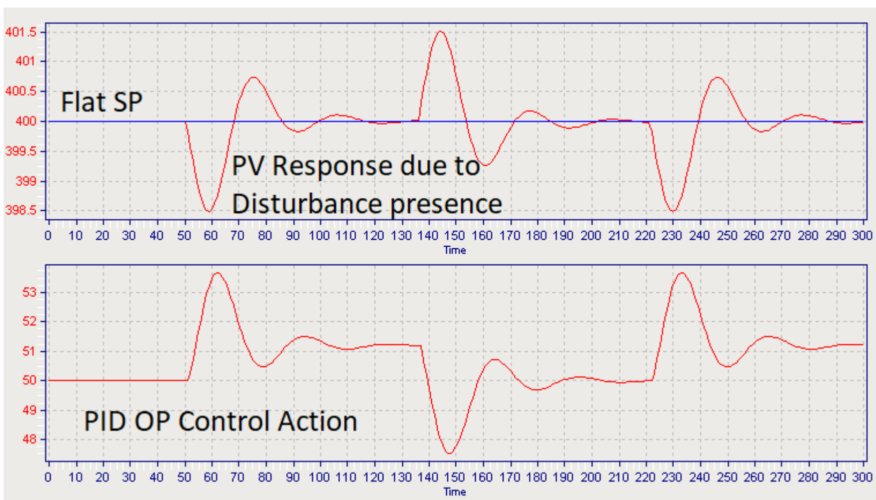

Figure 11 – *CC and ZN control action with new PID tuning parameters upon DV change*

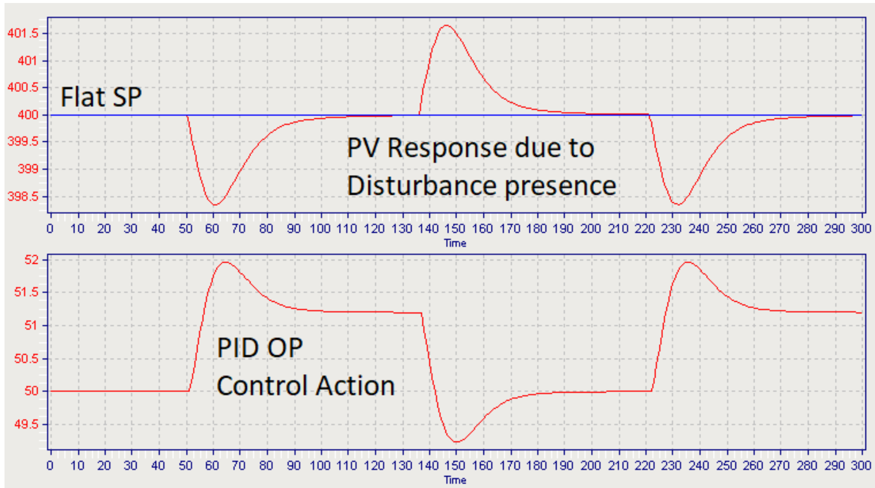

Figure 12 – *PITOPS control action with new PID tuning parameters upon DV change*

Conclusion:

PID controllers tuning is a very important aspect in today's process industries. Having poorly tuned controllers will result for manufacturing plants to miss the opportunity of achieving additional 2 - 7 % capacity enhancement. Most control engineers and operators still use the old-fashion methods for PID tuning. These methods are slow, imprecise and never allows the plant to run with maximum possible efficiency. Only few people use PID tuning software because most of them are expensive, complex and limited for practical use. Therefore, unfortunately only fewer than 20 % of all plants worldwide are precisely tuned. Keeping the limitations in mind, appropriate methods must be used to identify the optimum PID tuning parameters. Market studies show that properly designed and optimally tuned process control strategies can increase a plant's throughput anywhere by 2-10 %, equivalent to few hundreds of thousands of dollars to several millions. PITOPS is a practical and a low-cost comprehensive system identification and process control software which enables the control engineer to identify the optimal PID tuning parameters without any hiccup to the plant operations. It allows process units to be run closer to their hard limits without risking their safety which raises the production average of the plant.

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Conflict of Interest:

The author of this manuscript certify that he has No affiliations with or involvement in any organization or entity with any financial interest (such as honoraria, educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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