Real-time dynamic process control loop identification, tuning and optimization software

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Abstract: In today's globally competitive marketplace, industrial plants are looking at new ways to increase plant efficiency, production rates, safety and reliability. Engineer education, training and plant optimization play a key role in satisfying technological, economical and environmental constraints. Furthermore, control system optimization is the basis for system improvement and advanced process control (APC) implementation.

Only a small minority of plants use modern software for controller tuning, simulation, APC or optimization. The reasons are absence of engineering knowledge, unavailability of practical and robust process control software tools for system identification, simulation and parameter optimization and running plants conservatively due to fear of causing shutdowns and plant problems.

This paper presents a process control simulator and loop optimizer applied to a temperature control application. This paper also illustrates the application of software for quick and easy multivariable closed-loop system identification using data from a plant's historian. Such software can tremendously help to improve control education of students and plant personnel.

Keywords: process control simulator, system identification, controller tuning, process control optimization education

1. INTRODUCTION

With relentlessly increasing pressures on profitability, survivability in a competitive global environment, premier oil-and-gas, chemical and other manufacturing companies are resorting to improved process control as one of the powerful methods to maximize their profits, minimize their utilities and remain competitive. Some of the established and accepted process control concepts include:

- Equipping all chemical plants with modern DCS (distributed control system) and PLCs (programmable logic controller), as described in Schuppen et al. 2011, Bolton, 2009, Cauffriez et al. 2004 and Rullán, 1997.

- Control primary process variables with PID (proportional, integral and derivative) controller.

- Apply multivariable and APC (advanced process control) strategies, as described in Guidorz *et al*. 2003.

The popular PID control algorithm performs over 95% of primary control in today's chemical and manufacturing industry. Despite being branded sometimes as "archaic" and "too-simple", the PID's existence provides simplicity, reliability and robustness, as described in Chen, 1989, Ljung, 1999, Reznik et al. 2000, Panda 2009 and Escobar et al. 2013.

Unfortunately, industry studies show that many plants continually suffer with less than optimal control performance of the primary control PIDs. Oscillatory ripples caused by inappropriate PID tuning, control valve problems and avoidable interactive disturbances continue to plague the primary control performance. Poor primary control performance can cost a plant anywhere from several hundred thousand dollars to several millions due to lost production capacity, poor product quality control and needlessly high utility usage. Furthermore, poor primary control performance will cripple higher level advanced control and optimization systems and severely reduce their potential monetary benefits.

Also, industry study shows that controller tuning, maintenance and control quality monitoring surprisingly remain grossly neglected and severely under-emphasized. In an era of modern high-tech tools, computers and engineering specialists, one can ask why the PID and primary control negligence is so commonplace. The reasons are many and diverse:

Poorly tuned controllers can still easily allow the plant to operate at nameplate or higher capacities. What is a missed opportunity is that an optimally tuned plant can make much more - as much as 2-7 % extra capacity.

While a failed instrument or a failed pump must be repaired to allow the plant to run, a badly tuned primary controller appears harmless - the oscillations and poor control response does not intuitively or obviously seem to be costing money or causing any harm. In reality, the impact on the overall plant performance because of a few poorly performing controllers can be shocking high.

College and university professors do an excellent job in covering academic primary process control concepts and controller tuning methods, but practical hands-on process control exposure is very hard to get. When new engineers and technicians come to the control room and start tuning control loops, their prior experience and skill level is rather low and they are often afraid of making tuning changes.

DCS-PLC technicians well trained on the basics of how the controller works have little opportunity for mastering tuning skills because of unavailability of simulators for tuning training practice.

The plant's operating performance can be impacted significantly and noticeably by the choice of tuning parameters. Control engineers and DCS-PLC technicians need to be formally trained on practical process control catering to the control room needs and environment. They should be provided with a real-time simulator on which they can practice tuning in a very real plant-like environment. They should have the freedom and ability on a control simulator to fearlessly drive loops unstable, study sluggish control, valve problems and the effect of external unmeasured disturbances on control quality.

Authorized persons bestowed with control room tuning privileges ought to be trained, qualified and certified based on testing on a simulator. Simulator-based training, practice time and then testing not only improves tuning skills but also helps the engineer or technician to identify control and instrumentation problems that earlier seemed too subtle and elusive. To address this current gap and facilitate training and certification of control engineers and technicians, new modern real-time dynamic simulator software (Simcet) and system identification, PID/APC tuning optimizer software Pitops have been developed.

2. PROCESS CONTROL SIMULATOR

Simcet is a real-time, online simulator for controller tuning practice and testing of tuning skills which provides the hands-on experience necessary to understand and tune control loops in the practical control room environment, Fig 1.

Typical examples, under the tuning practice window, which can be seen in Simcet are related to chemical, air separation, compressor, turbine, polyethylene, laboratory and other plants and processes. Under the new simulation in Simcet any other custom simulation can be also easily configured to mimic a specific plant or process by using typical scheme of desired process in the JPEG format, controller manual and Excel file containing controller PV and OP data.

The uniqueness of Simcet is that it also provides testing and grading features, under the tuning tests window, to test controller tuning skills of engineers and technicians. After playing and practicing with various pre-configured process simulations, the user can take up-to 36 randomly generated real-time tuning tests. Controller parameters optimised by the user are compared to the optimum controller parameters. A grade sheet is generated to show the user tuning skills. This report can be used as a certification and qualification record and to allow student, engineer or technician to be skilled enough for tuning real loops in the control room.

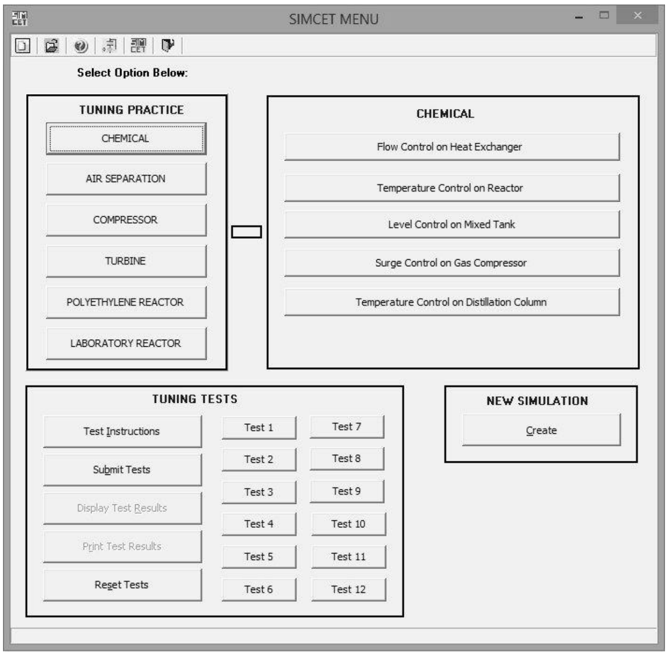

Fig. 1 Main Simcet tuning practice window

In each Simcet example the user can, Fig. 2:

See the process and process control scheme and highlighted process control trends showing process variable, setpoint and controller output movement in time domain.

Add typical signal noise and disturbances as in the real industry environment.

Change controller parameters and filter the noisy signal in order to improve the process control performance.

Switch the controller from manual to auto mode and vice versa and change the set-point or controller output.

Specify the controller algorithm and controlled and manipulated value range.

Activate the gap control.

Extend or reduce the simulation time and speed.

Collect and save the example data and changes in Excel for further analysis and trending.

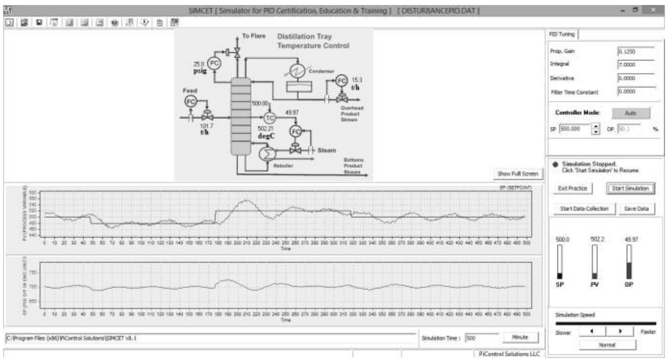

Fig. 2 Simcet simulation window for temperature control in distillation column

Simcet provides a lot of other features which can be seen on the real DCS or PLC system in the control room.

Table 1 shows functionality and advantages of Simcet compared to other currently available process control simulation software.

Table 1 Simcet functionality and advantages

Functionality	Simcet	Others
Ability to work as a real-time simulator?	Yes	No
Ability to work in a time domain?	Yes	No
Ability to test your PID loop based on setpoint and disturbance changes?	Yes	No
Ability to simulate the process noise?	Yes	No
Ability to filter the signal?	Yes	No
Ability to change all process model parameters?	Yes	No
Ability to simulate discrete data?	Yes	No
Ability to change the speed of simulation?	Yes	No
Ability to take process control tests?	Yes	No
Ability to be graded and certified after taking tests?	Yes	No
Ability to extract all data and parameters to excel or PDF?	Yes	No
Ability to add real process graphics?	Yes	No
Ability to simulate any DCS or PLC control system?	Yes	No
Ability to build custom simulation?	Yes	No
Complex and time consuming installation?	No	Yes
Long time to learn and use?	No	Yes

3. CONTROL LOOP OPTIMIZER

Even in current times, control loop tuning and optimisation engineers typically use the trial-error approach, which is time-consuming and not effective. This leads to longer commissioning time and loss of potential plant benefits.

Furthermore, many valuable DCS and PLC features are underutilized in today's plants. Often engineers use auto-tuning functions. While auto-tuning does work on simple PID loops with fast dynamics, it can generate uncertain or even wrong PID tuning parameters on slow or complex loops and is not advisable for critical or money-making loops. In some cases auto-tuning function could lead to a potentially dangerous situation if process conditions change significantly. Fast loops have almost no process dead time and fast dynamics and tuning is relatively simple. However, for slow loops careful custom tuning is beneficial, reliable and safe. For the purpose of improving PID control loop quality, a closed-loop multi-input system identifier and PID/APC tuning optimizer Pitops was developed.

Pitops is the acronym for process identification and controller tuning optimizer and simulator. It is aimed to developing and commissioning supervisory and advanced control strategies in the DCS or PLC. It can be used for tuning any PID or APC control loop from any vendor worldwide.

A unique feature of Pitops is analysing either closed-loop or open-loop data. It does not need crisp step tests conducted in a special manner but can use historical closed-loop oscillatory data or data heavily impacted with disturbance. Another unique feature is that identification of SISO (single-input and single-output) and MISO (multiple-inputs and single-output) process models is all in time-domain. The system identification works even with high amount of noise and large unmeasured disturbances and process drifts. The system identification is also possible with ultra-short data window using the NC-GRG (nonlinear constrained general reduced gradient optimization) method as described in Sharmaa and Glemmestadb. Much less data are required compared to ARMAX, DMI, step response coefficient methods and impulse response methods as described in Peng et al. 2004. The system identification algorithm does not need data conditioning, data normalization and step tests. System identification is possible even on multiple chain PID cascade loops with model-based control and feed-forward control loops, Fig. 3.

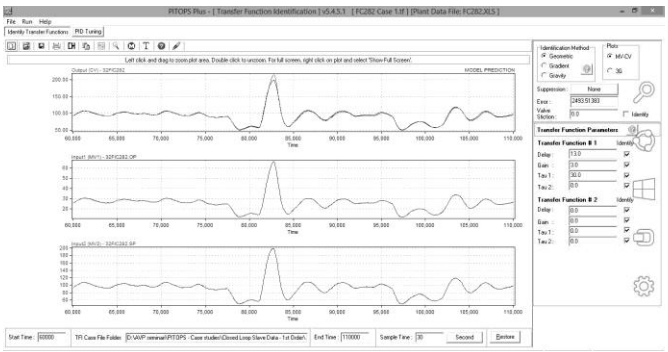

Fig. 3 Pitops process model identification window

Once process models have been identified, it is possible to design and tune primary, feed-forward and cascade control strategies as well as other popular supervisory and advanced control strategies. Pitops optimizes controller parameters based on the custom simulation, taking into account the control needs of the loop which include the following, Fig 5:

- typical set-point changes,

- typical disturbances,

- output rate of change consideration,

- process variable overshoot or undershoot after a set-point change,

- optimize PID tuning to handle control valve stiction or deadband,

- any other custom needs specific to the PID loop.

Also several others PID tuning methods such as Ziegler Nichols, Cohen-Coon, IMC (Internal model control) and Lambda methods are available.

Powerful model-based control schemes can be built in the DCS using suite of model-based controller design. Using regressed, empirical, semi-empirical or rigorous fundamental first principle models effective model-based dynamic controllers can be easily implemented. Pitops can also be used to improve step response models used in MPC (model predictive control) systems such as DMC, RMPCT, Star and others.

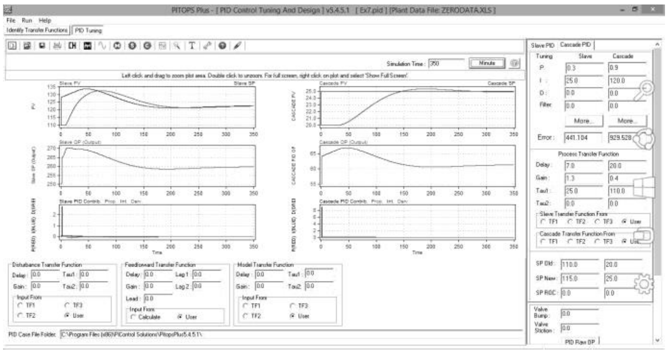

Fig. 4 Pitops PID/APC tuning and optimization window

Table 2 shows Pitops functionality and advantages compared to other available process control identification, simulation and tuning software.

Table 2 Pitops functionality and advantages

Functionality	Pitops	Others
Ability to analyse data without conducting plant step tests?	Yes	No
Data pre-processing and preconditioning required?	No	Yes
Ability to identify data containing high-frequency noise?	Yes	No
Ability to identify data containing SP ramp or even data coming from APC?	Yes	No
Required long data time period for analysis?	No	Yes
Ability to mathematically optimize feedforward control?	Yes	No
Ability to design special control?	Yes	No
Ability to design model-based control?	Yes	No
Ability to design dead-time compensation control?	Yes	No
Ability to simulate discrete signal (analyzer) behaviour?	Yes	No
Ability to identify all dynamic model parameters?	Yes	No
Ability to identify dynamic process model amidst strong unmeasured disturbances and drifts?	Yes	No
Ability to test optimal PID parameters based on set-point, noise and disturbance changes?	Yes	No
Ability to identify nonlinear systems?	Yes	No
Ability to design adaptive control?	Yes	No
Complex and time consuming installation?	No	Yes
Hard to understand and long manual?	No	Yes

4. CASE STUDY

Following case study shows bottom temperature control simulation of a distillation column shown on Figure 5. The main task is to strictly control the temperature in the distillation column. This is performed using a cascade control strategy. In cascade configuration temperature controller acts as master and reboiler steam flow controller as slave.

Trends on the Figure 5 show bottom temperature (PV), its set-point (SP) and reboiler steam flow set-point (SP) which is actually master controller output (OP). The bottom distillation temperature is oscillating almost ± 10°C due improperly tuned parameters

- Proportional gain = 0.1550
- Integral time = 5.00 *min*

and the presence of typical column disturbances - feed and reflux flow/temperature fluctuations.

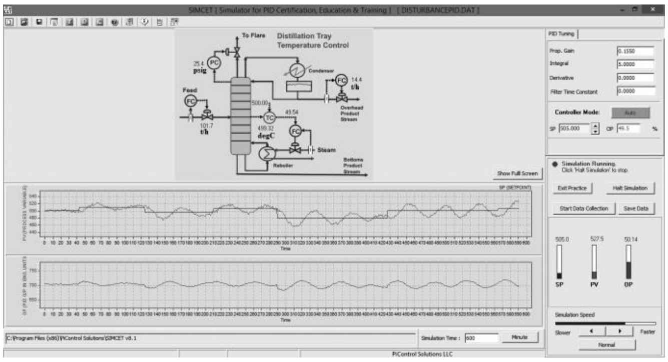

Fig. 5 Poor performing temperature controller

Process model identification is unavoidable and first step in control loop optimization. After the process parameter identification control loop simulation can be simple established in Pitops environment. Real plant control loop behaviour identified in Simcet is furthermore imported to Pitops identification interface. Pitops upper window shows the temperature measured data and model generated data comparison, whereas the bottom window shows the reboiler steam trend (master controller output as slave controller set-point). Identified first order dynamic model gave the following process parameters:

- dead time = 5 *min*
- process gain = 7.713 *°C/m³/h*
- time constant = 40.48 *min*

The identified model shows very good matching with the real temperature data as shown on Figure 6. The deviation between the model and temperature trends indicates the occurrence of the disturbance in the process.

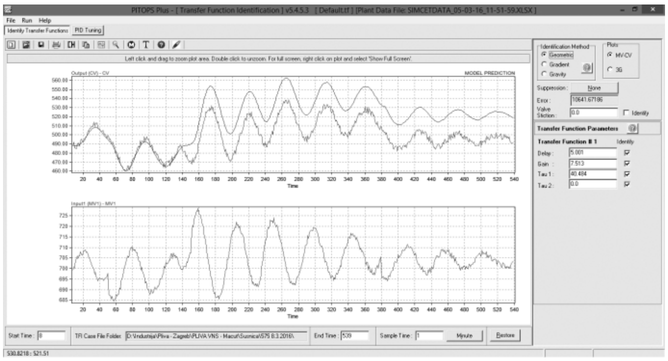

Fig. 6 Process model identification

Based on the identified process model new PID tuning parameters were calculated using Pitops reduced overshoot optimization criterion:

- Proportional gain = 0.1600
- Integral time = 35.00 *min*

Trends on the Figure 7 show optimized controller performance based on the set-point change and disturbance affect.

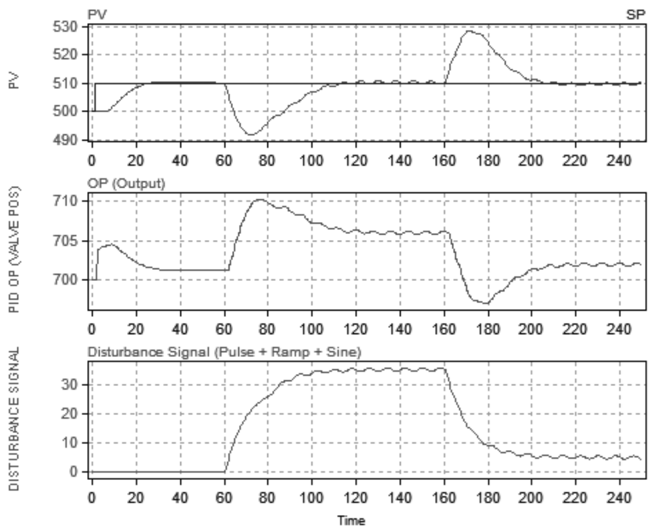

Fig. 7 Controller parameters optimization

Temperature control loop shows very stable and non-oscillatory behaviour providing a noticeably crisp and smooth response without overshoot.

5. CONCLUSION

Demonstrated process control software package for quick and easy process and control loop identification using available data from the real plant historian can be implemented for improve control performance as well as for education of plant personal and students.

Simcet allows tuning practice on variety of control loops which truly simulate the real plant control system. The uniqueness of Simcet is in providing features for testing and grading engineer and student tuning skills.

Pitops is a comprehensive system identification and process control simulator and optimiser. The software enables closed-loop multivariable system identification in the presence of interactions. Also, it enables the analysis of complex, non-linear and sluggish processes typical for chemical and other process industries.

Free trial software can be downloaded at the web site: http://picontrolsolutions.com/products

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