

Modern PID Tuning and Advanced Control Implementation

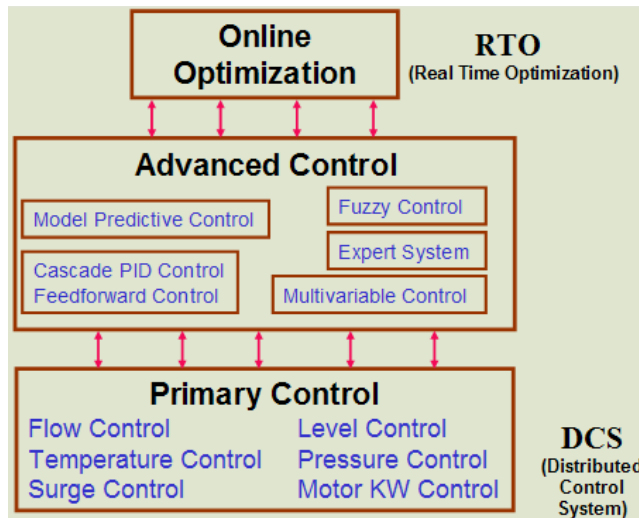
Introduction

Application of closed-loop advanced control has rapidly increased since the 1990s in the chemical, petrochemical and oil refining industry. The terms “DCS”, “PLC”, “PID”, “APC”, “Computer Control”, “Process Optimization”, “MPC”, “Model-Based Control” etc. are ubiquitous in chemical process control literature. Increasing application of advanced control schemes places higher demands on the skills and experience level of process control engineers and technicians in the control rooms. This paper describes some powerful process control software tools developed specifically for process control engineers and technicians in the chemical plant control room environment.

Process Control Application Hierarchy

Figure 1 shows common industrial process control software applications split into three major categories. At the lowest level, are the *Primary Control* loops – mostly PID controllers for controlling flows, pressures, levels, temperatures and other variables in the plant. To handle slow process dynamics, multivariable interactions, long dead times and complex control loops, pure PIDs alone cannot effectively provide the best control quality and *Advanced Control* applications are necessary. And to incorporate market, economic conditions, process and equipment constraints and nonlinearities, a third application level – *Online Optimization* can further provide monetary benefits.

Figure 1 - Process Control Application Hierarchy



Primary control and DCS-based Advanced Control, if correctly implemented can significantly increase the plant’s profit margins. Optimized primary and advanced control stabilizes process operation and pushes the operation closer to process, equipment and economic constraints. This increases production rates, minimizes operating costs and improves product quality.

Challenges facing Modern Control Rooms

The increasing use of primary and advanced control poses the following challenges in the control rooms:

1. New control engineers and DCS/PLC technicians come into the plant on regular basis. They need to be trained on practical process control.
2. Many primary and DCS-based advanced control concepts cannot be taught easily at schools and colleges. Learning practical process control skills quickly is not easy.
3. Changes in process or operating conditions, nonlinearities, external unmeasured disturbances can impact closed-loop control quality resulting in inefficient operation including lost production and could even cause equipment shutdowns and safety/reliability incidents.
4. Constant software and hardware upgrades add to the maintenance challenges in the control room.

Attractive Opportunities to Increase Profits using DCS Advanced Control

Using modern DCS and PLCs, various powerful, robust money-making control schemes can be implemented. This paper describes several powerful techniques for designing and implementing DCS/PLC-resident advanced control schemes. These include:

1. Process Dynamics Identification
2. Primary and Advanced Control PID Tuning Optimization
3. Online Adaptive Control
4. Model-Based Control for Product Quality
5. Production Rate Maximization
6. Engineer, Technician and Operator Practical Process Control Training

Process Control Tools for Control Rooms

PiControl Solutions Company has developed several powerful tools designed specially for use by control engineers and technicians in the plant control room environment. One of the uniqueness of the tools is that they can be easily and successfully used by both engineers and technicians. Most other currently available process control software tools are too expensive, too complicated, too academic or impractical or are just not readily available easily in the control room. The modern simple tools with relevant examples from control rooms are described below.

Process Dynamics Identification

Chemical processes range process dynamics from as fast as milliseconds on compressor surge control and motor control to as low as many hours in tall super-fractionator distillation columns. In modern control rooms, there are plenty of data sets available containing the controller OP (output), PV (process variable) and SP (setpoint). Data may contain OP step changes with the controller in manual mode, or may contain SP changes in auto mode. There are many opportunities in the plant where the operator may have made changes to the SP or OP. All these data sets are abundantly available from the plants data historians that continuously archive the data. The problem has been that no easy tool was available to quickly and easily use the data and extract information out of it.

With PiControl's Pitops-TFI identification software tool, dynamics identification takes just a few minutes. See Figure 2 showing pressure control (PC) data. The PC's output (valve position) was moved a few times (bottom window) which causes the pressure PV to respond (red trend in top window). Pitops TFI identifies the transfer function parameters as shown on the right side of the figure: Time Delay = 1.3 minutes, Process Gain = -1.01 psi / %valve position and Time Constant = 5.4 minutes. The blue trend in the top window shows the transfer function model prediction. The transfer function parameters are very useful. They can be used to optimally tune the PC, or to implement adaptive control, or to implement an optimal feedforward controller depending on the loop characteristics and process needs.

Figure 2 – Pressure Control Transfer Function Dynamics Identification

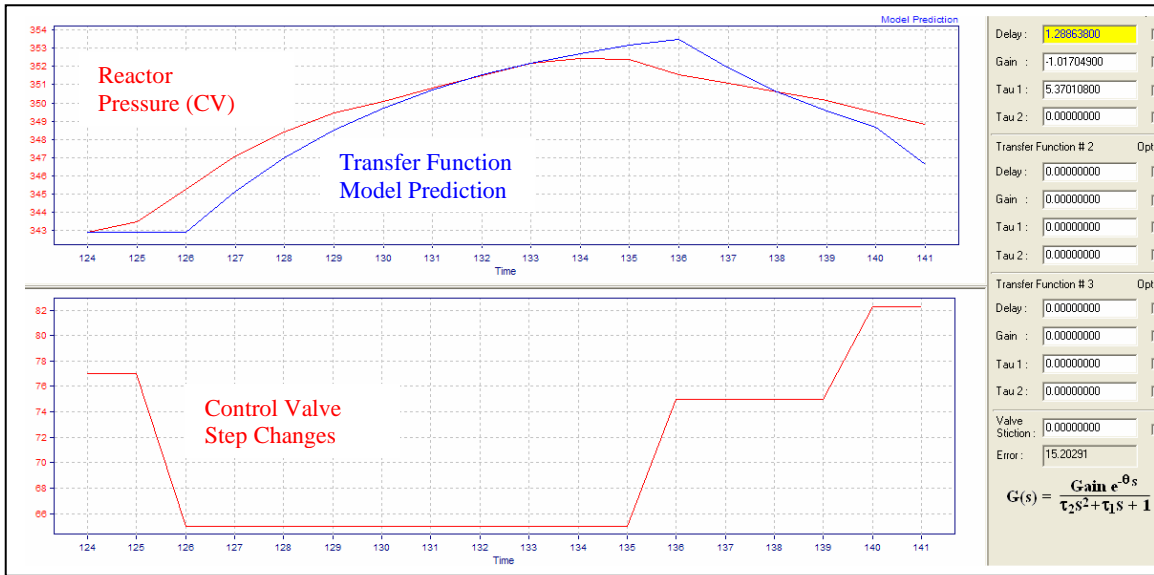


Figure 3 shows data on a tank level controller (LC). The LC's output (valve position) was moved a few times (bottom window) which causes the level PV to respond (red trend in top window). Pitops TFI identifies the zero order (ramp or integrating type) transfer function parameters as shown on the right side of the figure: Time Delay = 9.0 minutes, Process Gain = -0.091 % level / % valve position / minute. Note that this is a zero order transfer function (has ramp rate and dead time only but no time constants).

Notice the simplicity of the software; we just read in the PV and OP data and the tool determines the transfer function parameter all in the time domain which is easy to understand and use by everyone. The tool does not use the Z (discrete domain) which is harder to understand and apply.

Figure 3 – Level Control Transfer Function Dynamics Identification

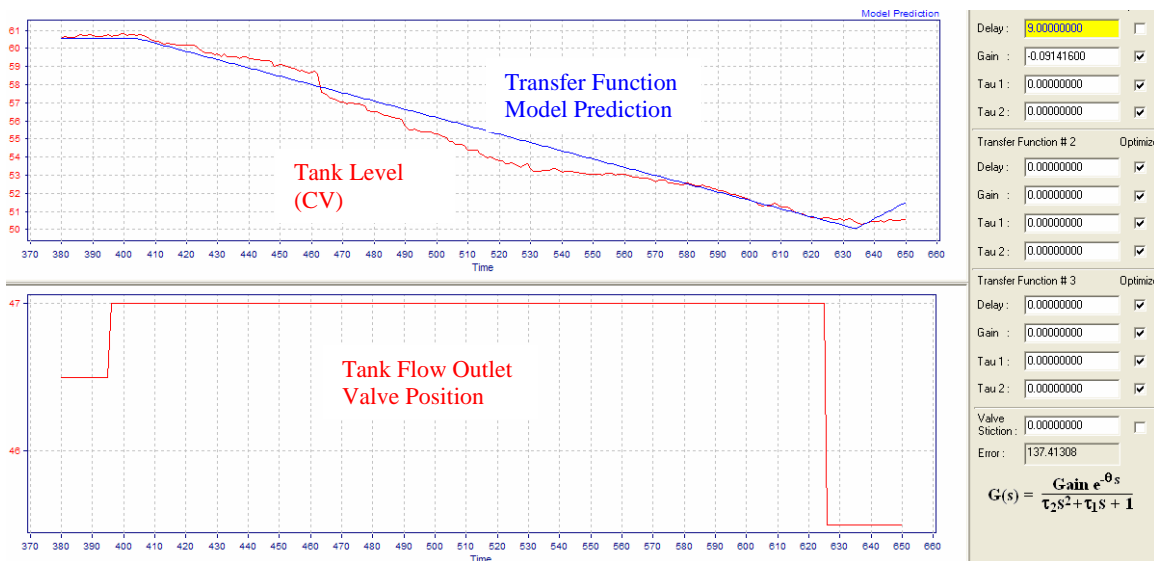
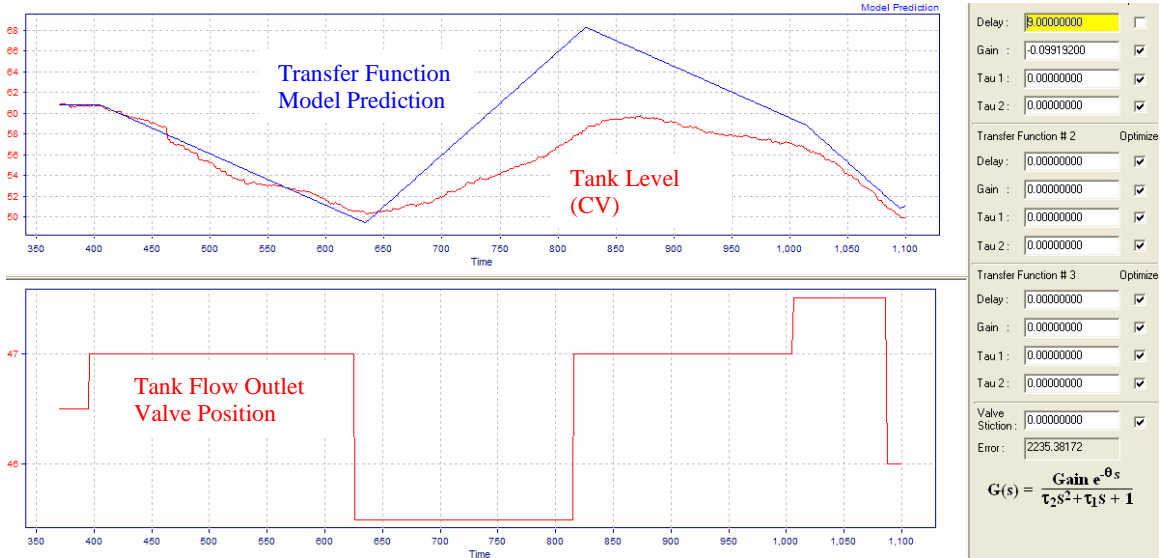


Figure 4 shows more step test data on the same level control example. With more step tests on this control loop, some nonlinearity is visible; this can be because of valve stiction, flowmeter problems or unmeasured disturbances that could mask the effect of the control valve step tests. The Pitops TFI tool determines control valve stiction also based on the OP and PV data.

Figure 4 – Level Control Transfer Function Dynamics Identification – Multiple Steps



The above example used open-loop data (with controller in manual mode). Figure 5 shows transfer function parameter identification using closed-loop data (with controller in auto mode). This example is a temperature controller manipulating a steam flow controller in a batch process. The TC output is often zero (no steam flow), but gets used as needed by the batch control sequence. Optimal tuning of the TC was hard before use of Pitops TFI because the TC is not always in control during the day shift. Using closed-loop control data on temperature and steam flow setpoint, the transfer function was identified by Pitops TFI. The transfer function delay time = 1 minute, process gain = 1.234 °C / (kg/h) and Time Constant = 23.7 minutes. Notice the simplicity of this closed-loop identification, all in the time domain.

Figure 5 – Temperature Control Transfer Function Dynamics Identification – Closed Loop Mode

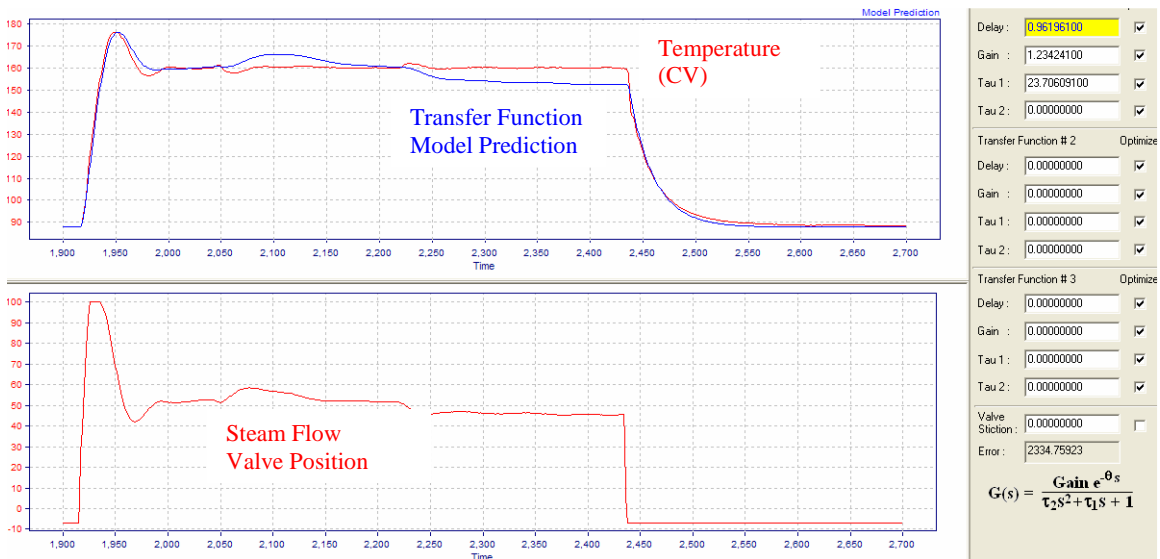
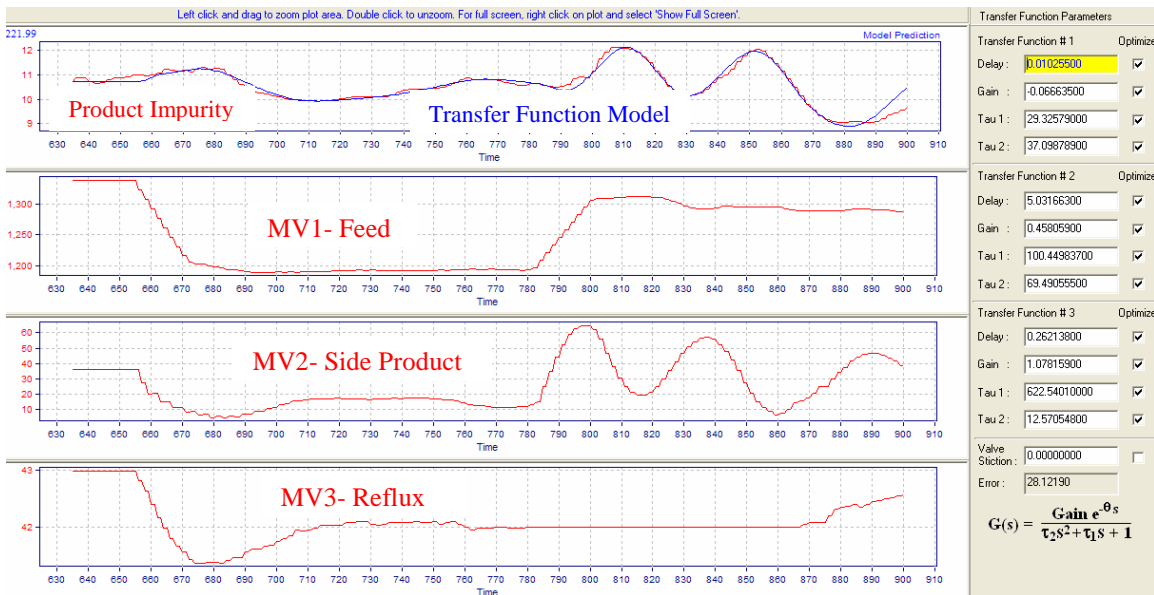


Figure 6 shows a Multivariable Model-Predictive Controller in closed-loop mode simultaneously manipulating three MVs (Distillation Column Feed, Side Product Flow and Reflux Flow). The product impurity is impacted by all three MVs (red trend in the top trend). Pitops TFI identifies all three second order transfer functions with dead time simultaneously using the closed-loop data.

This identification can be used to improve the step response coefficient models or transfer function models used in any of the commercially used multivariable model-predictive controllers to improve the controller performance.

Figure 6 – Multivariable Distillation Transfer Function Dynamics Identification – Closed Loop Mode



PID Tuning Optimization

Knowing the process transfer function helps to optimally tune base-level and cascade/advanced control type PIDs. Figure 7 shows an industrial pressure control example. The bottom window shows the PC's output. The top window shows the SP (blue trend) and PV (red trend).

The PC's objective is to not only provide crisp SP control but also to respond aggressively when hit by a disturbance. Disturbances can come and go anytime and it is important for the PC to respond quickly by closing or opening the valve immediately. The key is that such aggressive control action needed during disturbance rejection should not result in sustained oscillations at steady state.

Pitops PID tuning optimization software generates such tuning parameters that give crisp, non-oscillatory SP control while responding quickly during fast and large disturbances. Use of Pitops PID on this example resulted in increasing the controller proportional gain from 2 to 11 in one step and the integral from 8 to 3 minutes.

Without a tool like Pitops PID, control engineers confronted with tuning such a PC would not have the confidence to increase the controller gain that drastically from 2 to 11 in one step. They would have crept up the gain from 2 to 2.5 and 3 etc. over a much longer time period. And since the disturbance does not come all the time, it is hard to manually tune the loop for optimal control without the help of Pitops PID software tool.

Figure 7 – PID Tuning Optimization in presence of SP change and typical disturbance

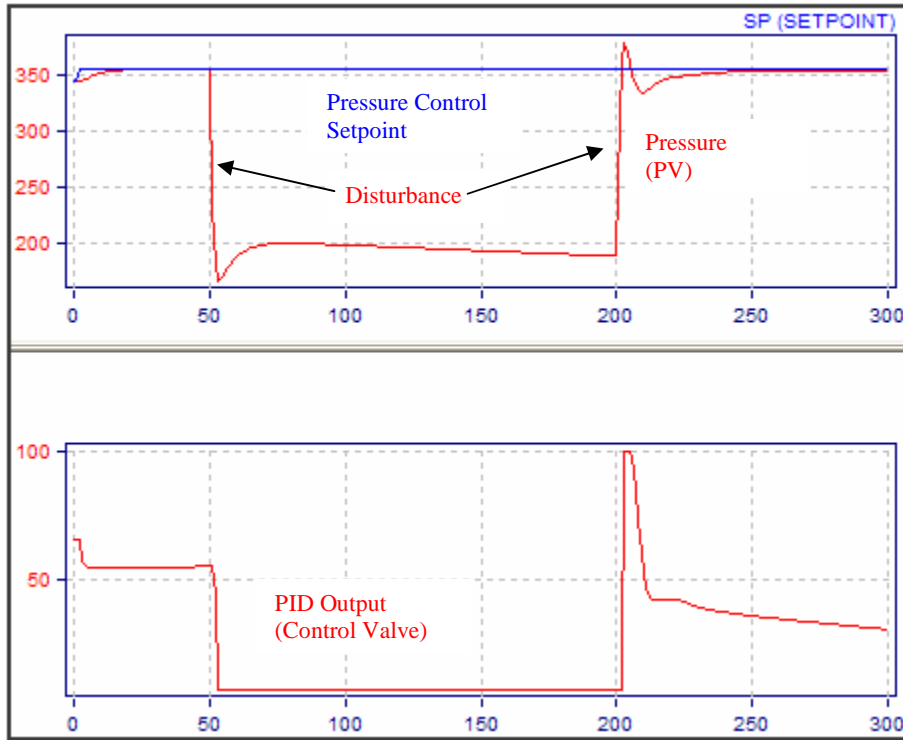
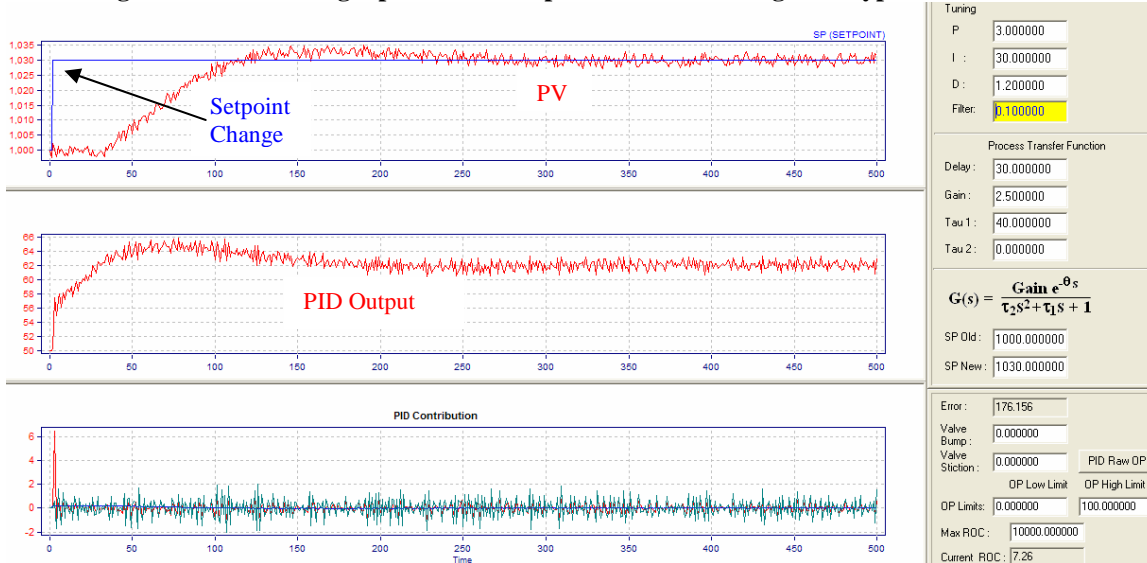


Figure 8 shows how Pitops PID optimizes PID tuning in the presence of signal noise. It mimics the real process by simulating the same level and frequency of white signal noise seen in the real process. In just a few minutes, Pitops PID converts the real process signal characteristics into a custom simulation comprising typical setpoint changes, signal noise and disturbances followed by PID tuning optimization.

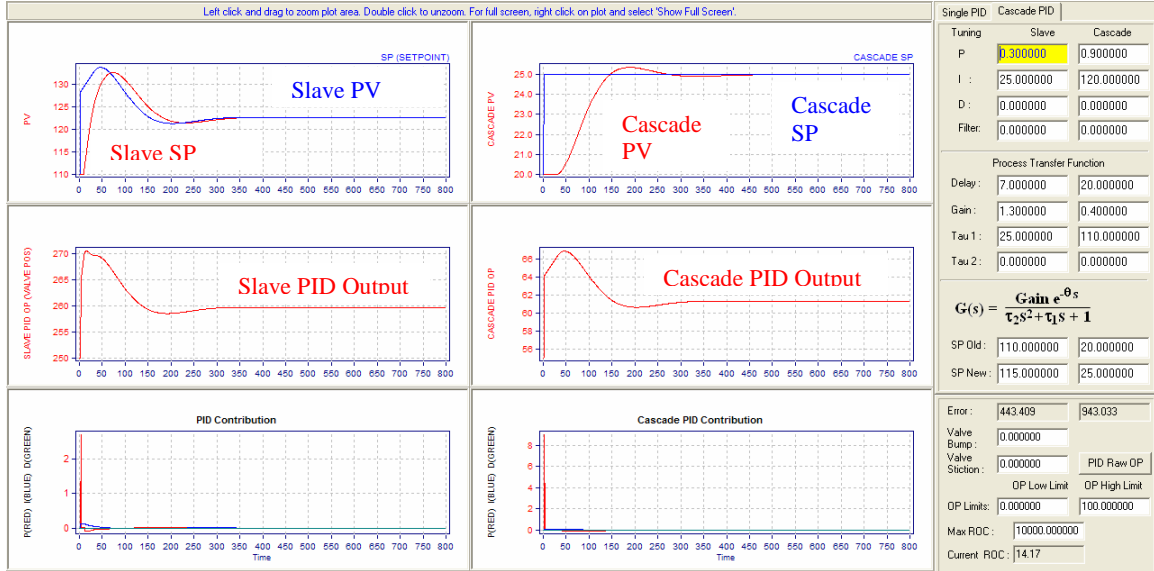
Figure 8 – PID Tuning Optimization in presence of SP change and typical disturbance



PID Cascade Control

Cascade controllers are common in all chemical processes. Cascade controllers can be fast as in PC to FC chains or slow as in AC to TC or TC to TC cascades controlling product stream quality measured by online analysis or temperature inferential controllers. Pitops PID simulates both slave and cascade process dynamics and optimizes cascade PID tuning. Figure 9 shows an example showing a master AC (online analysis control) to a slave TC (distillation tray temperature control).

Figure 9 – PID Tuning Optimization in presence of SP change and typical disturbance



Production Rate Maximizers

One of the most powerful schemes to maximize plant profits is by implementing production rate maximizer schemes in the DCS or even PLC, as illustrated in Figure 10. As many as ten or more constraints can be implemented as part of the constraint pusher schemes. Pitops TFI identifies the process dynamics for all the constraints and then Pitops PID precisely optimizes all the tuning parameters.

Custom Control Simulations

It is important for the control engineer or technician to easily identify dynamics and try different simulation options easily to perform “what-if” scenarios on a PC simulation provided by Pitops PID and Pitops TFI. Too often, without proper software tools, most engineers and technicians try the old fashioned “trial-and-error” approach which is too slow and ineffective. Figure 11 shows how a sinusoidal disturbance can be quickly added to a simulation to check the impact of tuning changes and controller output response.

Feedforward Control

In all chemical processes, control quality can be significantly improved on various important control schemes using feedforward control. Unfortunately, almost all feedforward tuning parameters are estimated today in the control room by trial-and-error or “best-guessed” estimates.

Pitops PID provides powerful functionality to mathematically identify the feedforward parameters - lead, lag, gain and dead time. Understanding how feedforwards work allows building creative new applications all inside in the DCS or PLC for numerous other innovative purposes.

Figure 10 – Production Rate Maximizer Controllers inside DCS or PLC

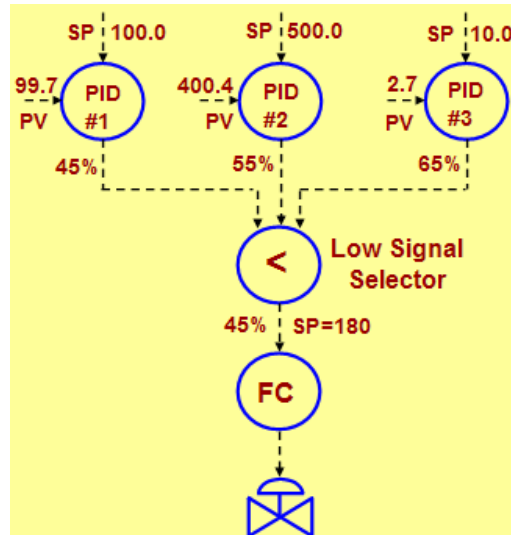


Figure 11 – Adding a Sinusoidal Disturbance to a Setpoint Change

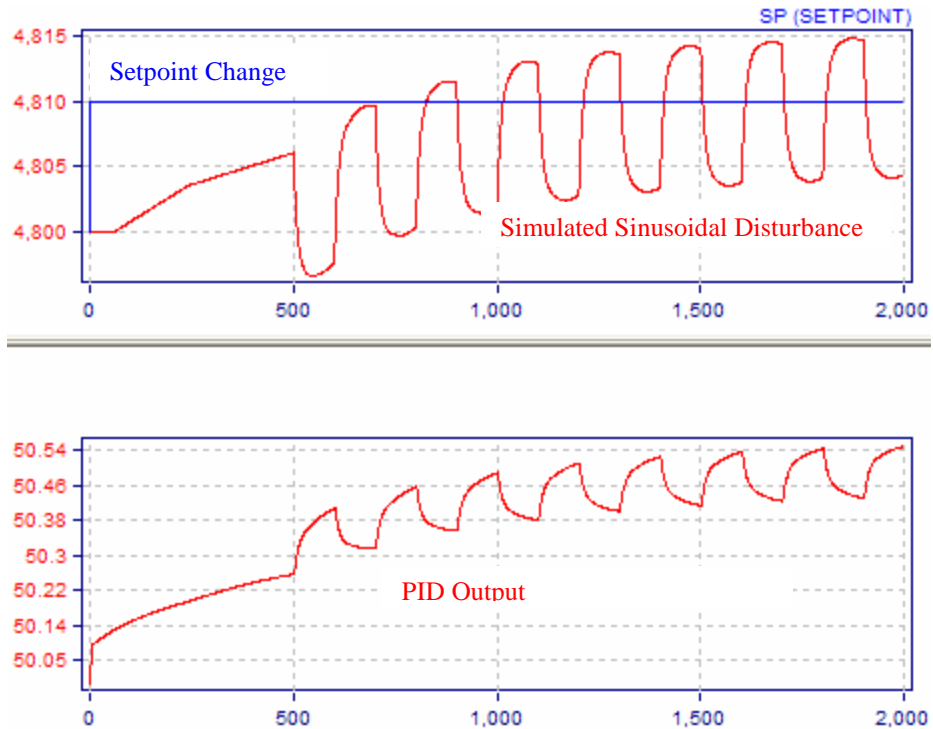


Figure 12 shows a pulse signal input to a feedforward transfer function with the lead constant less than the lag constant.

Figure 12 – Higher Lag Constant in a Feedforward Scheme

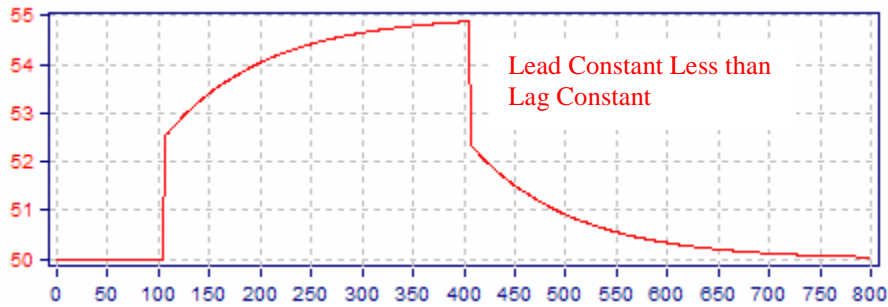
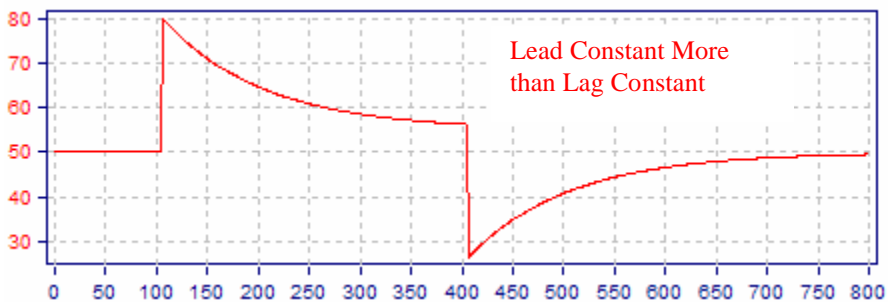


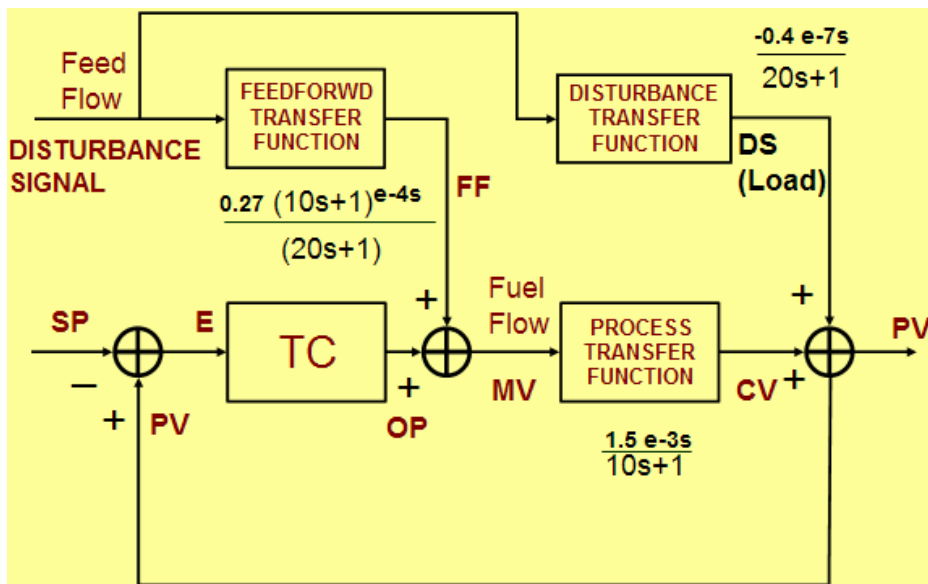
Figure 13 shows a pulse signal input to a feedforward transfer function with the lead constant higher than the lag constant. Notice the differences in the response in the two cases.

Figure 13 – Higher Lead Constant in a Feedforward Scheme



All these simulations can calculations can be easily performed with Pitops PID. By mastering the quantitative details of how feedforwards work, an engineer or technician can easily build powerful feedforward control schemes inside the DCS or PLC with numerous benefits. Figure 14 shows a sample calculation overview of a feedforward control scheme.

Figure 14 – Feedforward Parameter Calculations



Model-Based Controllers

Another big opportunity is the implementation of model-based controllers in the DCS or PLC. Any model based on rigorous, empirical, semi-empirical or regressed models can be implemented in the DCS using once through or iterative calculations. Such models can be used to implement closed-loop controllers in the DCS or PLC. Furthermore, measurement feedback such as from online gas chromatographs or laboratory analysis can be incorporated into the predictive models. Pitops helps to design model-based controllers with predictive, corrective and feedback closed-loop control action. An overview of the implementation is shown in Figure 15.

Figure 15 – Implementing Model-Based Control inside DCS or PLC

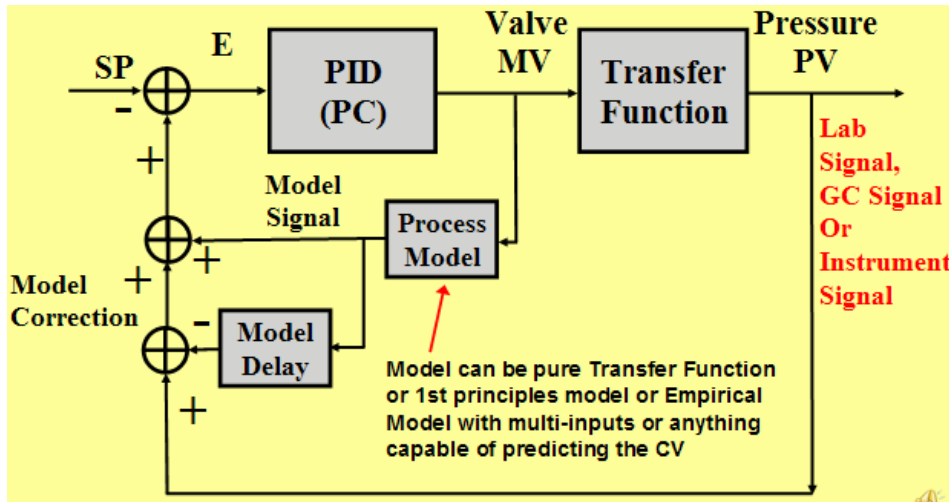
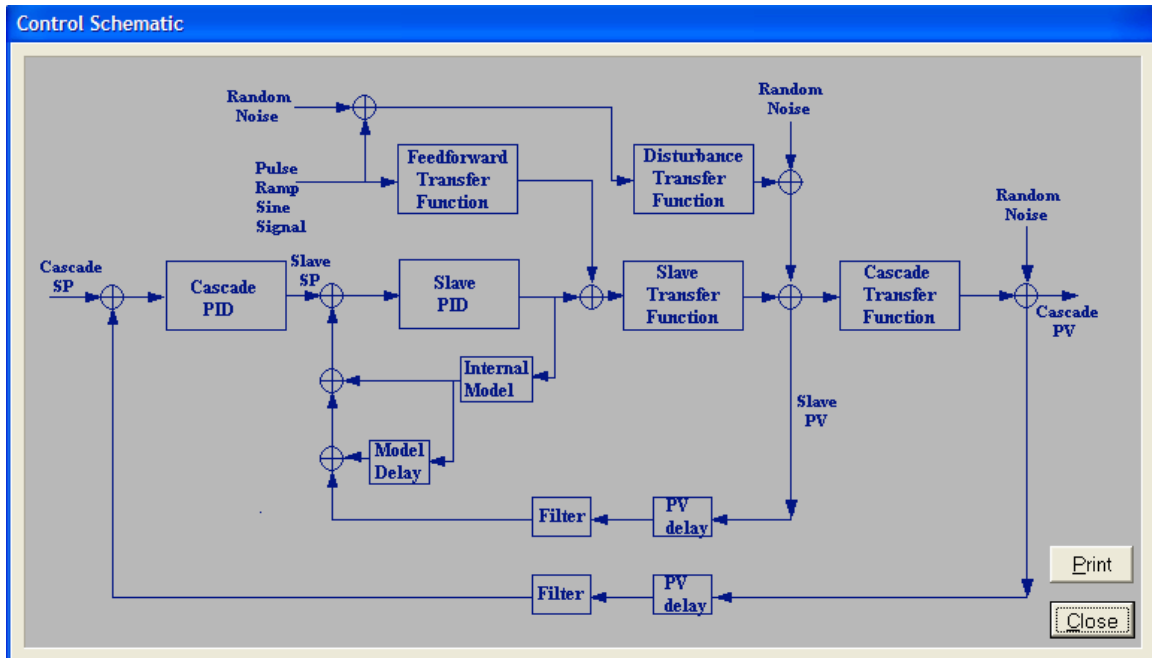


Figure 16 – Pitops PID Process Control Simulation Functions



Summary

Since the 80s, an increasingly large number of DCS and PLC systems are controlling chemical processes. For many years, the basic hardware and software skills were being learnt and mastered to ensure control system reliability and safety. Now, the control community is past that stage and is ready to push the functions and capabilities of the DCS and PLC systems like never before. Numerous powerful process control applications can be implemented in the DCS or PLC with increased recurring average annual profits ranging from \$50K to \$3 million, depending on the size and type of the plant. However, to realize these benefits, chemical plant managements need to properly train their control engineers and technicians and provide modern process control software tools to aid their implementation and design. PiControl Solutions Company has prepared several software tools to aid this effort. For more details, please visit the website at www.picontrolsolutions.com.