White Paper

OptiRamp® Accuracy Submodule

Key Driver to Successful Model Deployment

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Introduction

OptiRamp® is an artificial intelligence system for process modeling, conceptual design, real-time and off-line simulation, closed-loop optimization, financial validation, scheduling and performance monitoring. All of the components within the *OptiRamp* suite of tools have been engineered by Statistics & Control, Inc., (S&C) to adhere to the strictest accuracy demands. In fact, *OptiRamp* contains a dedicated Accuracy Submodule to ensure that all process models are within acceptable precision thresholds at any given time. This white paper provides the concept of concurrent process simulation, details the Accuracy Submodule algorithm, covers the submodule's scalability considerations, and provides an example of a recently deployed system.

S&C has created a state-of-the-art, patent pending system for "Large-Scale Process Optimization and Optimal Planning Based on Dynamic Simulation." At its core is the continuous, real-time, dynamic process simulation that runs in parallel to the actual process. The scalability of the system, cost-effective means of determining step functions (relating process variables in transient state), as well as accuracy are the unique characteristics of *OptiRamp* that provide its patentability.

Maintaining accuracy of simulated data with respect to the real process is the primary application of the Accuracy Submodule. *OptiRamp* models become more accurate as the system learns the process. This precision is achieved by carefully applying selected signal processing, optimization, and statistical process control algorithms. Depending on the nature of the process, the volume of generated data, and the presence of transient processes, the *OptiRamp* Accuracy Submodule can achieve the desired accuracy levels within just a few weeks of observing the process. Moreover, the submodule tracks accuracy for each individual component (measured variables), making the cumulative accuracy results reliable and robust.

Model accuracy (the accuracy of process identification) becomes the most critical factor for meeting system objectives. Accuracy is predetermined by optimization and diagnostic applications. For example, the optimized load balancing either reduces fuel consumption or increases efficiency by 1% to 5%. The Diagnostics Module should recognize equipment baseline variable variations when they exceed 1% to 5%. Model accuracy does not go beyond 0.5% and provides the required precision for the mentioned applications.

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Scalability is one of the patentable features of the *OptiRamp* system. S&C engineers designed the system to concurrently handle thousands of models, which is often required to execute advanced control algorithms on multi-unit systems. S&C software functions on the latest hardware releases with multi-core processing environments ensuring timely delivery of each calculation. Furthermore, this white paper provides an example of accuracy results for recently deployed models built to provide advanced process control for a geothermal reservoir with 1000+ simulated objects. It is a success story that took S&C to the next level in providing accurate and reliable process control to our clients.

OptiRamp Concept

OptiRamp combines artificial intelligence with real-time simulation technology (RTST) to optimize the performance of existing production assets to maximize sustainability. The ultimate goal of *OptiRamp* is to provide control actions that maximize current and future process efficiency. As equipment performance, production demands, and process and ambient conditions fluctuate, determining the optimal operating mode across this equipment can be complex. Control automation, supervisory control and data acquisition (SCADA), and historical servers have progressed to provide an extensive quantity of process data. However, the multidimensional analyses required to achieve maximum system efficiency are often beyond human cognitive ability, speed, and attentiveness. Efficiency gains can be significant; however, because RTST provides an exhaustive and precise methodology, *OptiRamp* can identify even the smallest opportunities. Over time, these small gains can accrue to considerable energy cost savings.

As a first step, the detailed initial models of all necessary process equipment and components are constructed based on OEM specifications and process design data to represent the complete technological process. To achieve the desired outcome, it is crucial to create a process model that accurately depicts real process behaviors. Furthermore, given ever-changing process, environment, and economic conditions, such models cannot be built once—they have to be continuously updated to reflect the current situation.

OptiRamp solves this problem by creating a virtual process that runs in parallel to the actual process and mimics it in real-time. SCADA delivers real-time data to the virtual process for comparison and analysis. Continuous, real-time, dynamic process simulation is a key part of *OptiRamp* auto-tuning and optimization algorithms.

Continuous, real-time, dynamic process simulation is part of S&C's patent-pending suite of algorithms, while the overall *OptiRamp* concept is provided in Figure 1.

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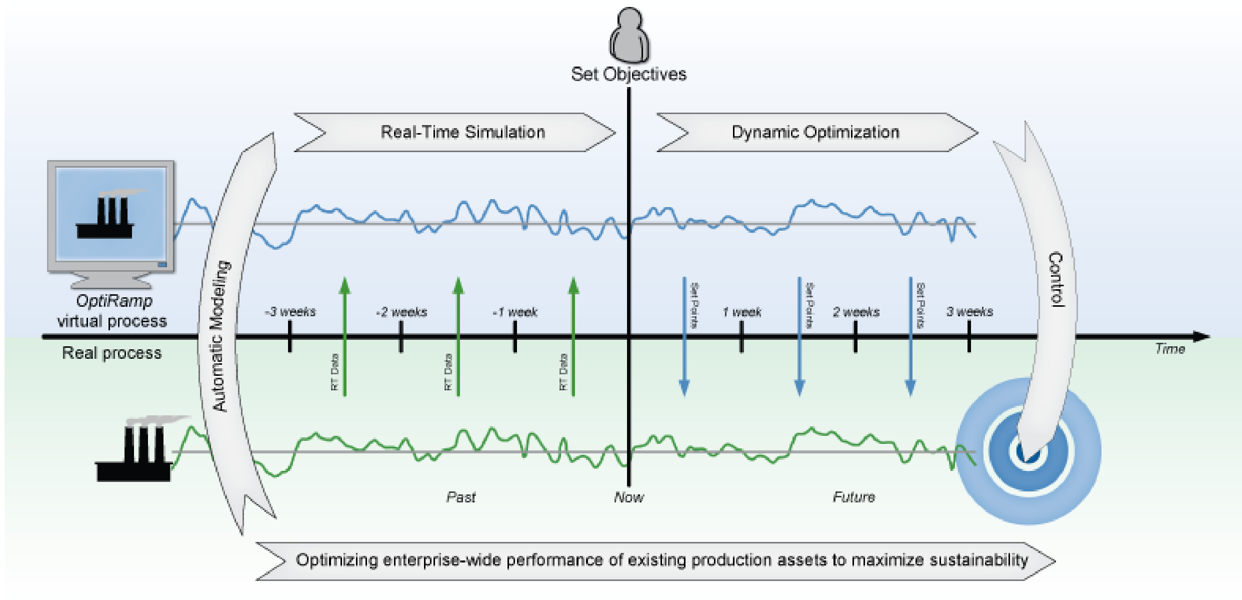

Figure 1. *OptiRamp* concept

A concurrent *virtual* process serves two major purposes:

1. Auto-tuning and Accuracy Analysis (left side of Figure 1)

The virtual process adjusts the initial model by aligning simulated variable values to real-time process values. Auto-tuning is performed to minimize the variance between the two and model coefficients are adjusted to keep it at a minimum. Then, at every time scan, current process values are compared to simulated data to determine overall model accuracy. When predefined accuracy is achieved, the Dispatcher can set process and economic objectives and initiate the Optimization algorithm.

2. Predictions, Optimization and Control (right side of Figure 1)

OptiRamp uses the adjusted model to analyze how the virtual process reacts to dynamically simulated changes in process variables in order to identify transfer functions. Next, based on defined transfer functions and Dispatcher-provided objectives, *OptiRamp* simulates the transition to the optimal operating mode. Optimization and forecasting submodules determine current and future optimal operating modes as well as control actions necessary to achieve those optima. The Multivariate Process Control (MVPC) Submodule executes control actions in real time and/or the Visualization Submodule displays a recommendation for such action.

For a detailed explanation of the *OptiRamp* concept, review S&C's patent application titled "Large Scale Process Optimization and Optimal Planning Based on Dynamic Simulation." Additionally, this white paper references other *OptiRamp* modules and submodules, such as the

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Modeling Submodule and the Real-Time Optimization Submodule. These submodules are described in detail in corresponding white papers.

Accuracy Algorithm

This section provides the mathematical foundation for the algorithm implemented in the *OptiRamp* Accuracy Submodule. The algorithm flow is depicted in Figure 2.

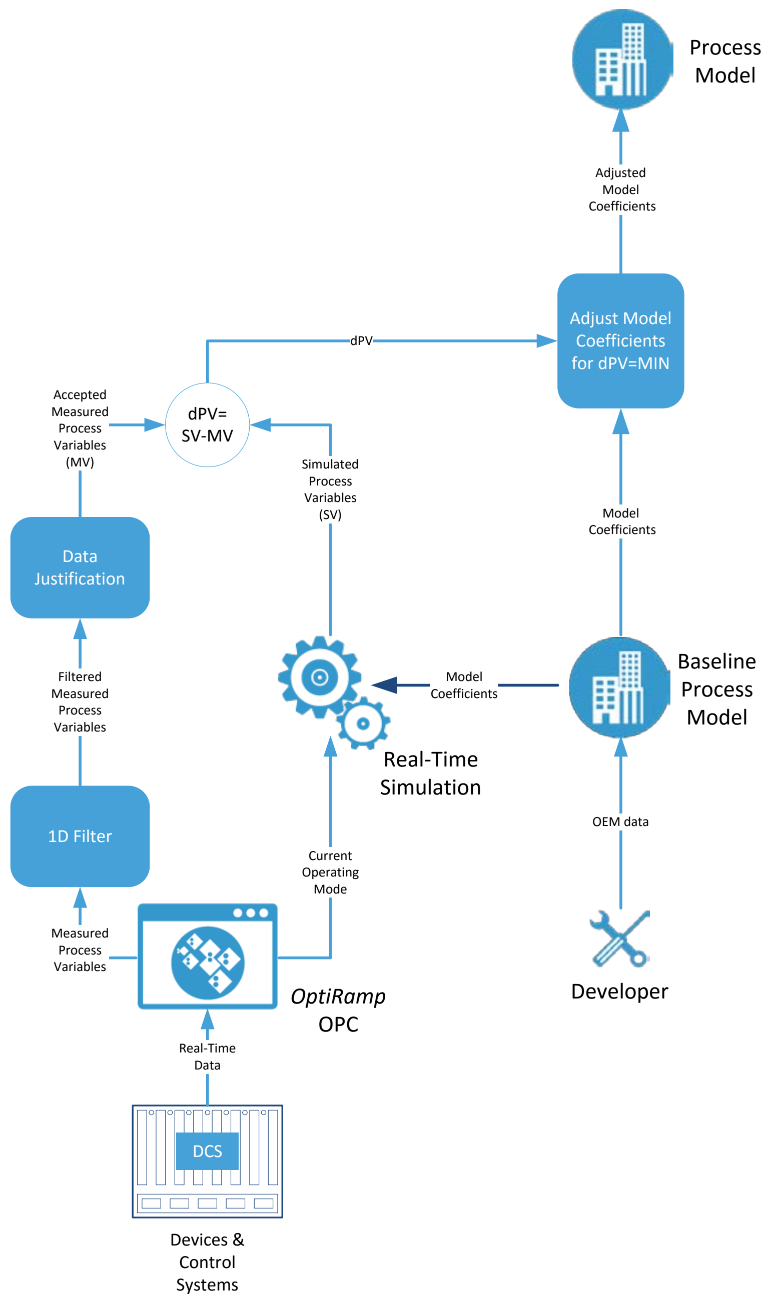

Figure 2. *OptiRamp* accuracy submodule algorithm

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The Accuracy Submodule connects to the Distributed Control System via the proprietary *OptiRamp* OPC Submodule, which outputs real-time input signals (measured process variable values) to be used for signal processing needs as well as to determine the current process operating mode.

Each measureable process variable is smoothed in the One-Dimensional (1-D) Filter Submodule. The 1-D filter employs signal processing techniques, such as Kalman filters, exponential smoothing, and auto-regressive models. A detailed description of signal processing methods included in *OptiRamp* is provided in the Modeling Submodule white paper.

The smoothed, measured process variables are fed into the Data Justification Submodule. The submodule rejects data points (outliers) whenever they fall beyond a specified distance from expected model values or whenever user-defined criteria are exceeded. In particular, let $\hat{x}(t)$ be the smoothed value of measured variable x at time t. The algorithm then creates an indicator variable R that drives rejection logic according to equation (1).

$$R\big(\hat{x}(t)\big) = \begin{cases} 1 \; if \; |\hat{x}(t)| \geq \delta_x \\ 0 \; if \; |\hat{x}(t)| < \delta_x \end{cases}, \quad (1)$$

where δ_x is either a calculated value based on the distribution of $\hat{x}(t)$ over all $t \in [T_0, \dots, T_1]$—e.g., $\delta_x = \mu_{\hat{x}} \pm 2\sigma_{\hat{x}}$ (where $\mu_{\hat{x}}$ is the distribution mean and $\sigma_{\hat{x}}$ is its standard deviation)—or is a process engineer defined value (e.g., Upper Control Limit or Lower Control Limit). The output of the Data Justification Submodule is the set of all accepted measured process variables values.

Process simulation concurrently occurs with data justification. The inputs of the Online Simulation Submodule are the current operating mode and the manufacturer-configured plant model (e.g., compressor characteristics at different speeds, piping diagrams, etc.). These models are embedded into the Accuracy Submodule via the *OptiRamp* Developer Module and the Baseline Plant Model Submodule. Simulated variables corresponding to measured variable values are generated for every time scan.

The simulation algorithm uses particle filtering methods that are based on dynamic state space models described by equation (2).

$$\begin{cases} w_t = f(w_{t-1}) \\ x_t = g(w_t) \end{cases}, \quad (2)$$

where f and g are estimated using polynomial regression, w_t is a vector of state parameters at time t, and x_t are observed (measured) variables. Then, w_t is estimated using sequential importance sampling or Sequential Monte Carlo sampling (from a simulated distribution).

The output of the Data Justification and Online Simulation Submodules is fed into the Value Comparison Submodule, where the difference between smoothed measured variable values and corresponding simulated values are continuously evaluated. Specifically, let $y(t)$ be the simulated value corresponding to $\hat{x}(t)$. Then set $\hat{x}(t) - y(t)$. The Accuracy Submodule then optimizes objective function (3) by applying Ordinary Least Squares line of best fit techniques. Ultimately,

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simulation parameters are adjusted and the process model is tuned to reflect predefined accuracy criteria.

$$\sum_t \left(\hat{x}(t) - y(\mathrm{t})\right)^2 \rightarrow \min \quad (3)$$

Accuracy is measured according to statistical process control concepts described below. The idea is to build the distribution of *dP* over time such that its mean is as close to zero as possible while most observations fall within a predefined Upper Specification Limit, *USL*. This concept is illustrated in Figure 3.

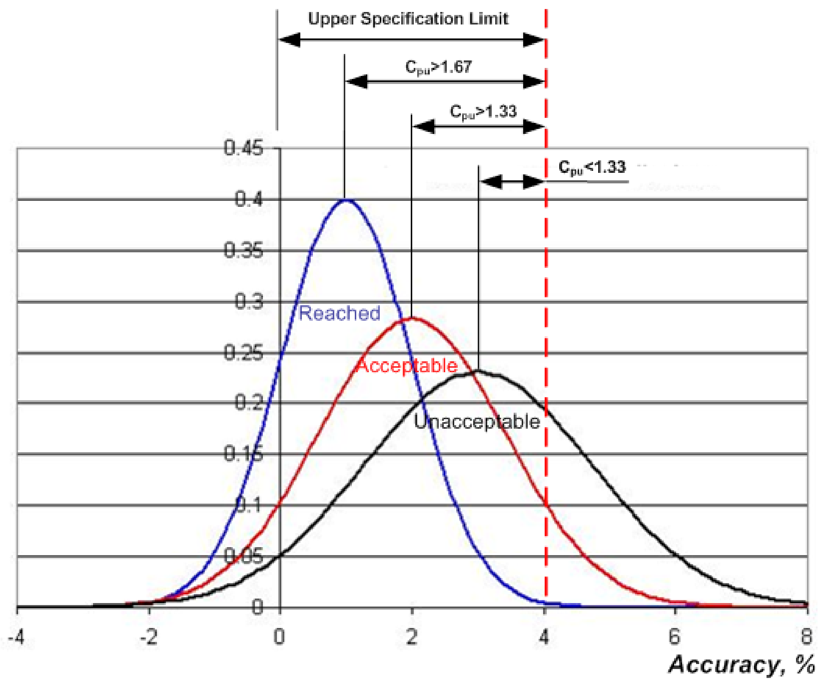

Figure 3. *OptiRamp* accuracy submodule concept

The algorithm starts with calculation of the so-called process capability index, which is illustrated in equation (4). Note, in the case of accuracy, calculations involve only the Upper Specification Limit.

$$C_{p,u} = \frac{USL - \mu}{3\sigma}, \quad (4)$$

where μ is the mean of *dP* distribution and σ is the standard deviation within a parametrically defined time period. The Accuracy Submodule allows the user to change *USL* online. In this case, the accuracy calculations will be adjusted in real time. Since accuracy has one-sided specifications, the demands on $C_{p,u}$ values are not as stringent as with two-sided specifications. Thus, following generally accepted statistical process control principles, the process is considered "capable" or "in control" whenever $C_{p,u} \geq 1.33$. In this case, *OptiRamp* will identify

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the accuracy level as acceptable. Typically, the system learning and optimization processes will continue until $C_{p,u} \geq 1.67$. In this case, the desired accuracy level would be considered reached.

The final output of the algorithm is a set of adjusted coefficients that are provided to the Plant Model. The overall algorithm repeats whenever process changes occur.

Scalability

Software system scalability describes maintaining efficiency and effectiveness when a large number of components are added. *OptiRamp* has been designed to do just that by utilizing parallel processing available in multi-core hardware systems as well as by working with very large data sets, also known as big data. The system is prepared to carry out advanced control actions for massive multi-unit operations. For example, an oil field may contain hundreds of active wells with steam injectors, etc., which results in thousands of parameters that need to be simulated and modeled. These parameters may need to be tracked at a millisecond level, which produces massive quantities of data (thousands of columns, multiple millions of records) that need to be analyzed, smoothed, and used in the model process.

S&C has engineered the *OptiRamp* system to handle this massive data in real time by applying state-of-the-art data processing algorithms and techniques combined with industry best practices for multithreaded processing.

Accuracy Submodule Example

OptiRamp process simulation has recently been deployed to provide advanced process control for a geothermal reservoir with 40+ simulated variables. See Figure 4 for details. The system reached desired accuracy within just one week of deployment, with a $C_{p,u}$ value of 2.14 and overall model accuracy of 99%.

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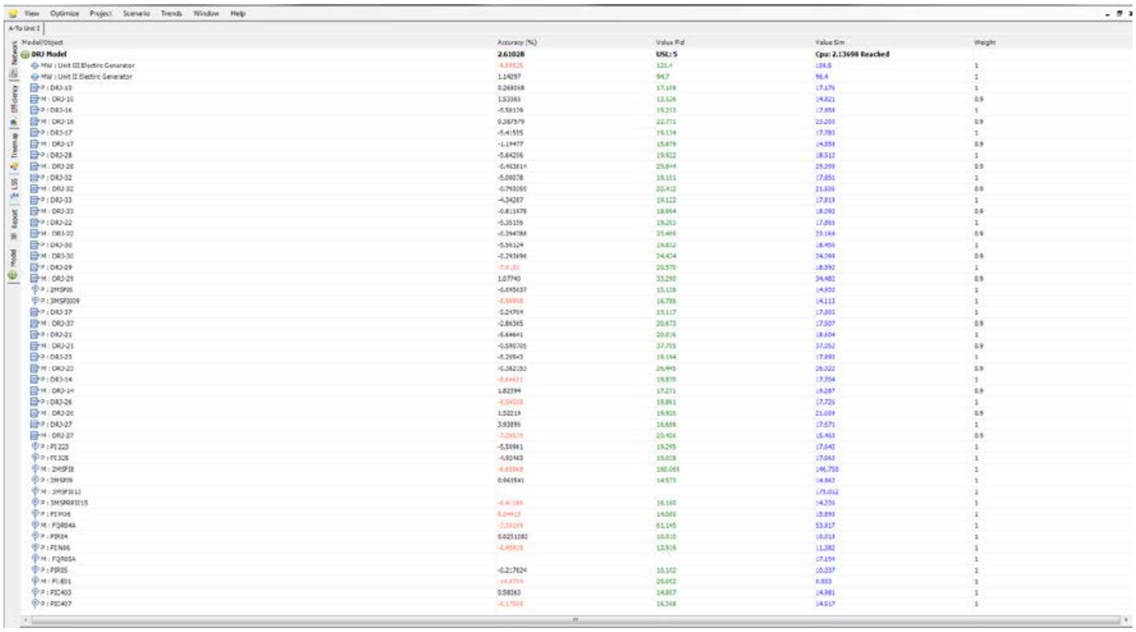

Figure 4. *OptiRamp* accuracy calculations example

Figure 4 shows accuracy values for every modeled process characteristic as well as the overall plant model. The **Accuracy %** column is the mean of the *dP* distribution during the one-week time period the system has been in training. The system also shows current **measured variable values** and the **simulated variable values** for the corresponding time scan. The **Weight** column indicates the importance of each subcomponent in calculating the overall accuracy, which is the weighted average of its subcomponents. The user is allowed to change weights online. The accuracy calculations will instantaneously reflect those changes.

Figure 5 shows distribution parameters of the selected model. This distribution provides an "at-a-glace" view of the process and allows S&C engineers and plant operators to monitor the inner workings of the system. This feature allows the user to enter the Upper Specification Limit as well as tolerance for accepting outlier detection errors. The date and time stamp on the left hand side of the screen shows the currently analyzed time scan. The counters of good and bad points indicate how many outliers have been rejected and how many observations have made it through the Data Justification Submodule. The distribution parameters are then visually displayed via the box plot in the middle of the screen as well as the distribution function on the right-hand side of the screen. The $C_{p,u}$ value at the bottom of the data table is the critical component that the user should monitor to identify whether desired accuracy has been reached.

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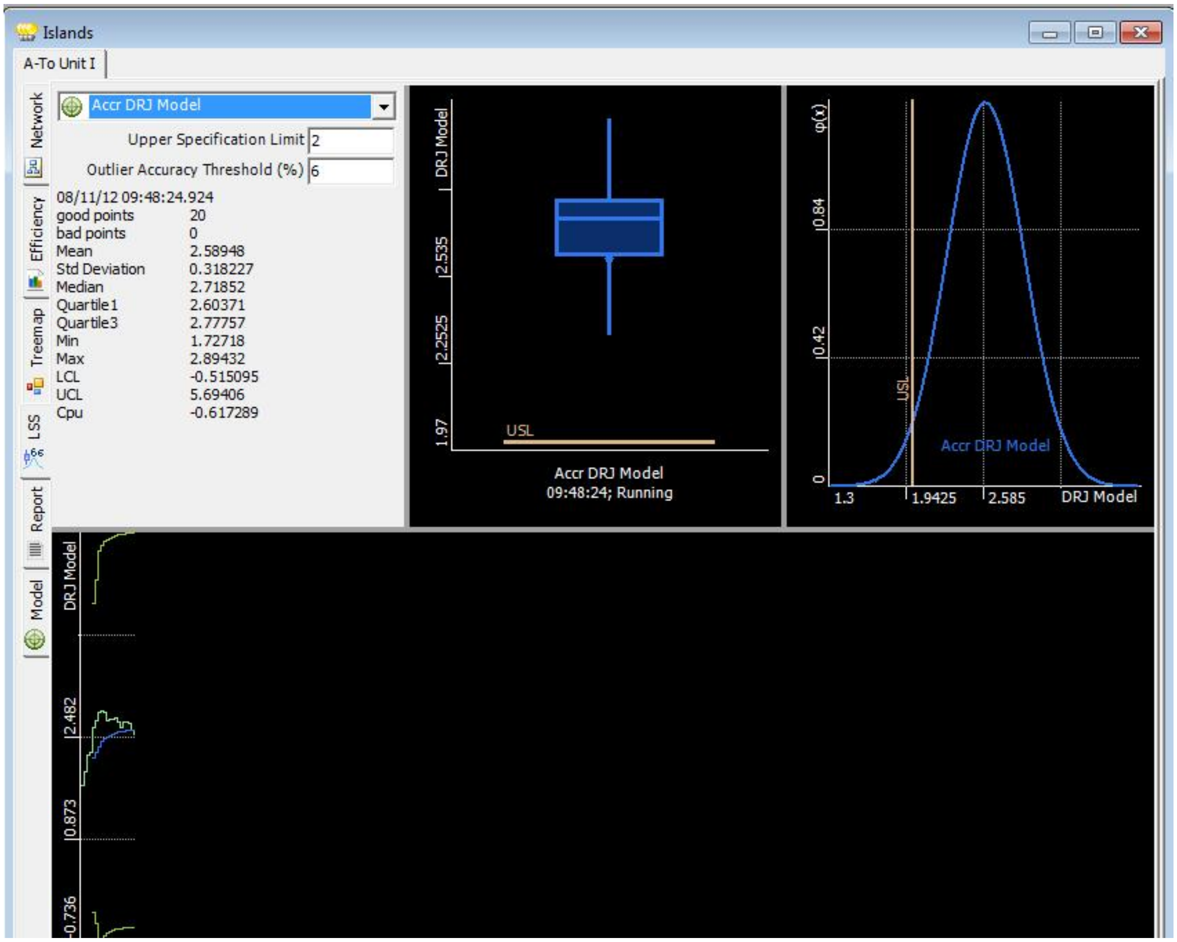

Figure 5. *OptiRamp* accuracy graphics example

The bottom part of the screen in Figure 5 shows the learning process comparing measured process variables (blue line) to the simulated data (green line). All information is updated either by reading signal logs or by incorporating real-time process variable values. To describe all features presented on each screen, S&C provides a comprehensible user and help manual post-installation. S&C also provides multiday software training for its customers across all system modules and submodules at the customer's site.

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S&C—an engineering consulting and technology company headquartered in West Des Moines, IA—solves complex challenges for customers through its unique technology and its highly seasoned team of professionals. The company has a global portfolio spanning the energy, oil and gas, utility, and digital oil field industry sectors. S&C provides clients with turbomachinery control solutions that easily integrate with the existing system as well as *OptiRamp*® solutions, which focus on process and power analytics to optimize processes and, in turn, reduce costs and increase reliability. S&C also provides consulting, dynamic system studies, modeling, automation, training and OTS, and support services.

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