Abstract—Online real-time Steady and Transient State identification is demonstrated for a multi-variable commercial scale process by monitoring seven key variables. The results are consistent with visual interpretation and are used to guide operators in managing sampling and transitions within a sequence of trial conditions.

I. INTRODUCTION

Steady state and transient state identification is an important consideration for pilot plant operations. Most pilot plant data are necessarily collected at steady state or transient state. Especially for large pilot plants that are expensive to run, quick and efficient identification of steady state and transient state results economic and quality benefits.

Often, steady state is identified from visual observations of the process trends and from operator experience. Visual observations are tedious, require constant operator attention, and rely on operator experience. Delays in visual identification of the steady state could result in longer test times than are necessary.

Automatic steady state or transient state identification offers the benefits of reduced operator effort and improves data quality. Any transients, for instance, can be immediately identified during steady state data collections and corrected as necessary.

In this paper, the R-statistic based automatic real-time steady state and transient state identifier [1], detailed in the tutorial paper, is demonstrated on a commercial scale distillation unit at Fractionation Research, Inc. (FRI). The implementation steps, method, and preliminary results are presented in the following sections.

II. THE FRI UNIT

A. Unit Description

Fractionation Research, Inc. (FRI) (www.fri.org) is a research consortium comprising 74 member companies from major petroleum, chemical, and engineering companies from around the world.

The FRI unit, shown in Fig. 1, has two commercial scale distillation units – a low pressure (LP) column that operates from deep vacuum to 165 psia (11.4 bar) and a high pressure (HP) column that operates from atmospheric pressure to 500 psia (34.5 bar). Both columns have a 4-ft (1.22 m) diameter 28-foot (8.53 m) long section, and the LP column has an additional 8-ft (2.44 m) diameter 12-foot (3.66 m) long section above the 4-ft section.

In addition, both columns have associated auxiliary equipment (reboilers, condensers, etc) and interconnected piping. The auxiliary equipment is sometimes used in parallel, but only one of the two columns is in operation at a given time.

FRI routinely tests distillation column internals (e.g. trays or packing) using hydrocarbon systems. The active test tower, operating conditions, test systems, and column internals change from test to test. Each test has several run conditions designed to test the internals for performance characteristics such as capacity and efficiency. Liquid and vapor rates are varied over the course of the test to span the entire design range of the column internals.

Essentially, all of the FRI data are collected at steady state. Once the desired test conditions are established, and steady state is confirmed, data recording is initiated, and simultaneously, off-line tests are initiated (e.g. gamma-scan of tower, collecting composition samples, etc.). Once the data collection is complete, new conditions are approached and the wait for steady state begins again. During the course of a test, steady-state identification is a constant need at FRI.

Likewise, since all of the data are collected at steady state, any transients due to plant disturbances should be detected and corrected, if necessary, so that high data quality is maintained.

Evidently, automatic steady state and transient state
III. IMPLEMENTATION OF THE STEADY STATE IDENTIFICATION ALGORITHM

A. Sampling Interval

As described in the tutorial paper, the steady state and the transient state identifier requires data that are not auto correlated.

The degree of autocorrelation in the process data governs the choice of the sampling interval to be used for the automatic steady state identifier.

Prior to the implementation of the identifier, all of the process variables were analyzed for autocorrelation using steady state historical data.

Autocorrelation test plots were plotted as follows. The process variable was plotted against itself, but with a lag of one sampling interval. A linear pattern in such a plot indicates the presence of autocorrelation.

Fig. 2 shows the autocorrelation test plot for a sampling interval of one second for a flow process variable (PV). Clearly, the linear pattern indicates autocorrelation at the one second sampling interval.

Fig. 3 shows the autocorrelation test plot for a sampling interval of 60 seconds for the same process variable. As is evident from Fig. 3, the shot gun pattern seen in the figure indicates that no autocorrelation is present at a sample interval of 60s.

All of the FRI process variables of interest were studied for autocorrelation. The sampling interval to eliminate autocorrelation varied from 10s to as much as 50s. A sampling interval of 60s always insured that the process variable was free of autocorrelation. Therefore, a sample interval of 60 seconds was chosen for implementing the steady state and transient state identifier program.

B. Program Features

The steady state identifier program has several attractive features for use at an industrial facility. The program works well with offline data so that it can be tested extensively before deployment. The steady state identifier tool identifies both steady state and transient state, and the program works with one variable or several variables therefore making it easy to progressively increase the complexity of the program. The program runs in the background and therefore does not require new resources for implementation in the control room.

C. Variable selection for steady state monitoring

The overall steady state of the unit is often not the sole concern. For a column internal capacity test, for example, the process variables representing the hydraulic nature of the column internals are of importance; flow and levels are more important than temperatures. For a mass transfer efficiency test, temperatures and compositions become important.

In addition, by grouping variables with similar dynamics into a representative group, the number of variables to be monitored can be minimized.

Therefore, for the purpose of this demonstration, seven key variables were identified representing flow, pressure, level, and temperature dynamics of the process.

The implementation was carried out in two stages: offline historical mode and real-time mode. The offline and real-time input data were collected from a standalone Yokogawa Exaquantum™ historian client. The steady state and transient state identifier program was implemented in Microsoft® Excel™ VBA.

IV. RESULTS AND DISCUSSION

In the first stage, using offline historical data, the program was tested to check for potential implementation issues for future real-time implementation.

Upon successful execution, the program provides a steady state identifier value (SSID) for each of the process variables at each sampling instant in both offline and online mode. The SSID value is always between zero and one. An SSID value of zero indicates that the process is in a transient state. Likewise, an SSID value of one indicates that the process is at steady state. No definitive conclusion about the process state can be drawn when the SSID value is between
zero and one.

An overall SSID is calculated for the entire process as the product of all the individual SSIDs. When the overall SSID equals one, the entire process is at steady state. This occurs when all of the process variables are at steady state and their individual SSIDs are one. The overall SSID has a value of zero even if one of the process variables is in a transient (SSID of zero).

A. Offline Tests

In the first stage, the program was run with a single variable and using historical data. Historical data free from plant upsets and disturbances were collected from the Yokogawa Exaquantum™ historian, and the program was run on the entire data set at once. Fig. 4 through 6 show the results from the offline test.

Fig. 4 shows the flow process variable and the SSID for the flow variable. As shown in the figure, two transients occurred at 1:00 and at 5:00. The program correctly detects the transient and the steady states as shown in Fig 4. Note that it takes longer for the program to detect steady state than transient state because the steady state detection is performed over a larger window of data to avoid false positives.

Fig 5 shows a pressure drop variable over the same period. Similar to the result in Fig. 4, the program correctly identifies the transient and the steady states.

Fig. 6 shows the results for a multivariable test, wherein the overall steady state or transient state of the process is indicated by the overall SSID. The transient state is indicated by an overall SSID value of zero, and the steady state is indicated by an overall SSID value of one. In both cases, the results are consistent with visual observations.

With the success of the offline tests, no additional changes to the program were needed, and online real-time implementation was effected.

B. Real-time Online Tests

The real time program reads process data in real time, from the Yokogawa® Exaquantum™ historian, and the program is executed once every minute – the same rate at which data were read into the spreadsheet from the historian.

Trends were updated to show, in real time, the status of the unit as steady or transient.

Fig 7 shows the results from real time implementation of the program for a single-variable case and Fig. 8 for the multivariable case with seven variables.

As seen from Fig. 7 and Fig. 8 the results from the real time implementation are very similar to the offline implementation results. Fig. 7 and 8 show that the program is able to detect steady state and transient state in accordance with the visual observations.

During the real time implementation, FRI unit operators agreed with the steady state and transient state predictions by the program.

The steady state and transient state identifier clearly showed potential to be a useful tool to the operators for managing steady state data collections and transitions.

V. CONCLUSIONS AND FUTURE WORK

The steady state and transient state identifier was demonstrated on the commercial scale FRI distillation unit using offline historical data and online real-time data.

The results showed that consistent steady state and transient state identification can be done using the program.
automatically and in real-time. Especially for pilot plants where virtually all of the data are collected at steady state, the steady state identifier program has the potential to reliably assist operators during data collections and transitions.

In its current form, however, the steady state identifier program can be affected by an occasional bad reading, for instance, on a flow meter. Work is underway to improve the robustness of the program by using a median-based statistic in place of the current mean-based statistic to counter an occasional bad reading in the process variables, especially when such behavior is expected.

Eight to ten new process variables will soon be added for monitoring in addition to the seven key process variables that are now monitored.

Work is also underway to exploit the feature of the program to provide individual SSIDs to group variables into hydraulic (flows), pneumatic (pressure, pressure drop), and thermal (temperature) groups and provide customized steady state predictions for the FRI unit such as hydraulic steady state, pneumatic steady state, and thermal steady state.

REFERENCES