Installation and startup of advanced process controls

What went wrong and how to fix it

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Advanced process controls do not come with a giant green button labeled "optimize." Nor is installing and commissioning a system as simple as dropping some sensors around the plant and plugging all of the cords into the central control system. But the right methodology can provide successful approaches to time and project management, programming, and process troubleshooting.

The startup of an advanced control system in 2010 at an upgraded Modified Ludzack–Ettinger (MLE) wastewater treatment plant led to such challenges as operational complications and instrument and system failures. Several challenges were encountered which, in some cases, resulted in the need to repair equipment, retune parameters, or reprogram the controls to accommodate the various atypical events observed. But these challenges cultivated the development of a robust commissioning protocol capable of responding to and preventing the recurrence of many of the difficulties related to bringing a control system on-line.

Case in point

Over the course of several months, the MLE plant was expanded using a combination of new and existing tank space and hardware. The upgraded plant was designed to operate under the direction of advanced control systems to maximize energy efficiency while providing the operational flexibility required to achieve the plant's effluent goals. The advanced aeration-control system adjusts the blowers and automated control valves (ACVs) to drop legs that feed into the fine-bubble diffusers.

Designers took great care to size the aeration and hydraulic systems to handle a wide variety of influent flow conditions, based on historical and projected flows. Three variable-frequency drives were installed to control positive-displacement blowers. This configuration was selected for its flexible turndown capacity (see Figure 1, p. 54).

The blowers were programmed to operate based on an airflow-based proportional–integral (PI) feedback control loop connected to a total mass airflow meter (AFM) located on the main header. Each aeration-control zone, designated physically in the system through a series of baffles, includes its own high-efficiency fine-bubble diffuser grid fed by a single aeration drop leg. Each drop leg is fitted with a butterfly-type ACV and individual mass AFM.

The diffuser density, aeration-pipe diameter, valve size, and airflow measurement range of each of the aforementioned devices were sized and tapered to accommodate the longitudinally decreasing loading profiles characteristic of most semiplugflow systems. Each aeration-control zone also is outfitted with a dissolved-oxygen (DO) meter, and each of the two trains at the plant is equipped with meters for mixed liquor suspended solids, influent ammonia, effluent nitrate, effluent ammonia, and temperature.

Data signals are relayed via remote input/output (I/O) panels, where necessary, to a central supervisory control and data acquisition (SCADA) system, which then distributes the data over a common Ethernet protocol to all control subsystems. The plant and instrumentation layout can be seen in Figure 2 (p. 54).

Once the wastewater treatment plant was operating in static manual control, the systems integrators and control providers were invited to the plant to begin commissioning their respective control systems.

Confidence building

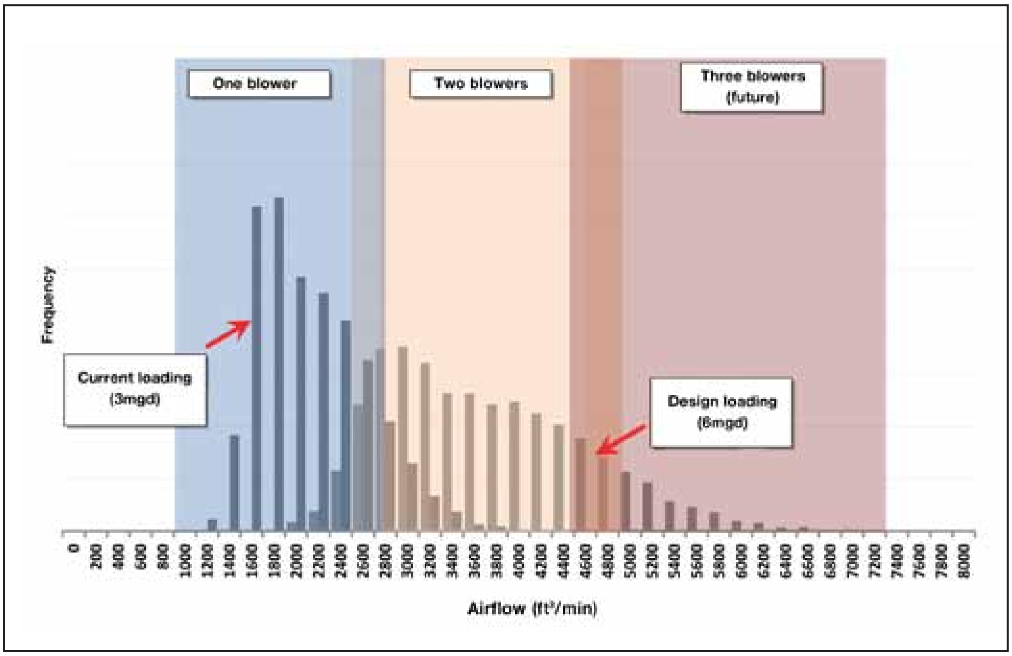
Once the equipment is functional, the greatest obstacle to advanced automation is earning the confidence of the plant operations staff. Extensive training and clear and continual communication are paramount to the commissioning of any system.

In addition to providing operations and maintenance manuals with each control system, onsite training is an important staple in earning the operator's trust and identifying additional features plant staff may want added to the control system interface to facilitate plant operation.

Some operators can be skeptical of a control system's robustness or capability to respond to atypical events, and understandably so. Seldom do startups go without faults.

Therefore, before activating control systems, it is advised to seek the permission and cooperation of the plant personnel and clearly define the details and timescales of all desired performance tests to be executed. Having the operators aware of the acceptance tests being performed allows for atypical behaviors to be quickly and effectively identified, isolated, and mitigated. This also provides the commissioning engineer with the additional benefit of having an alternative perspective on the control's effects on the plant's operation. Attempting to perform tests without informing plant personnel can result in damaging equipment and loss of process stability.

Figure 1. Multiple airflow scenarios accounting for transitional operational regimes



Device miscommunication

During the initial stage of system commissioning at the MLE plant, several inputs to the advanced control system provided by the SCADA appeared blank and inaccessible to the advanced control system's programmable logic controller (PLC), which functions as the control system's central processing unit and communication hub. To rectify this simple miscommunication, revisions were made to the preliminary communications tables that had been produced before the project started. The changes ensured that mapping of process-essential variables was consistent between the PLCs.

In addition to clerical-type errors, because a control system's PLC must be configured to utilize one of the many communication protocols available, it often can be difficult to foresee problems that arise from a certain communication protocol's limitations. In this case, a produce–consume-type protocol was employed, which generally enables data to be transmitted via the network for consumption. To configure this type of system to receive or consume data, one simply points to the location of the host and consumes a tag if it is being produced. In order to host tags, before transmitting data for consumption, one must first specify the maximum number of consumers.

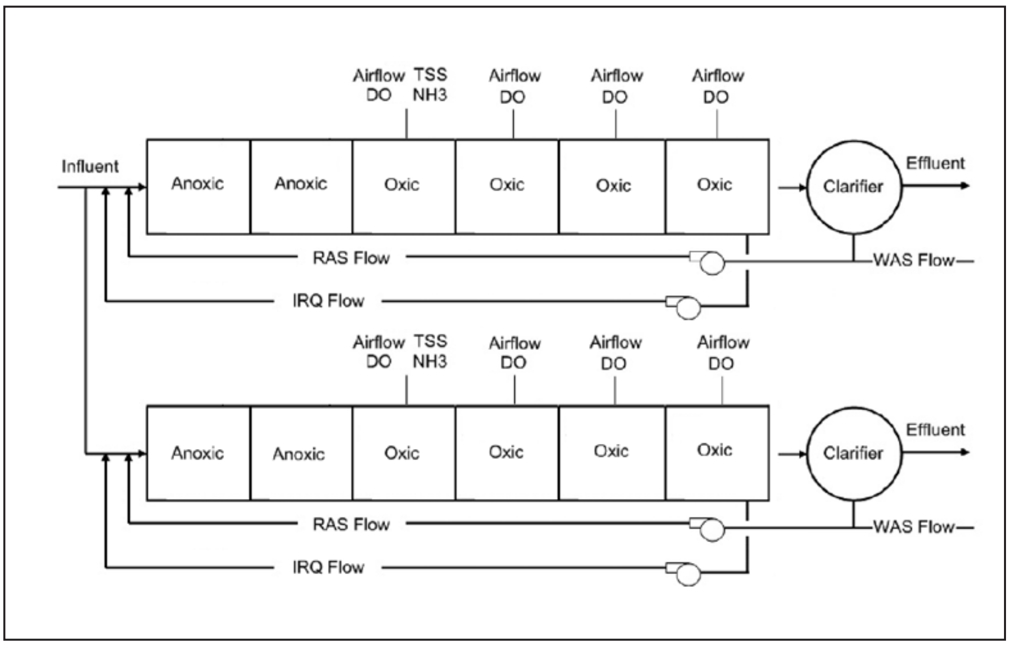
Because the network of consumers had grown beyond what the SCADA was originally configured to serve, as certain PLCs would come on-line and go off-line during their testing phases, tags were being consumed on a first-come, first-served basis, leaving some PLCs with either inconsistent or no access to the process variables they needed to operate. To rectify this, the system drawings were updated to include all possible networked PLCs, and the tag production limits were raised to accommodate simultaneous access from all onsite PLCs.

Signal verification

Next came the process of checking the consistency of the signals provided via the network with the readings provided by the field instrument's local indicators. Verifying these signals with their physical counterparts one-by-one via shortwave radio revealed that there still were some discrepancies.

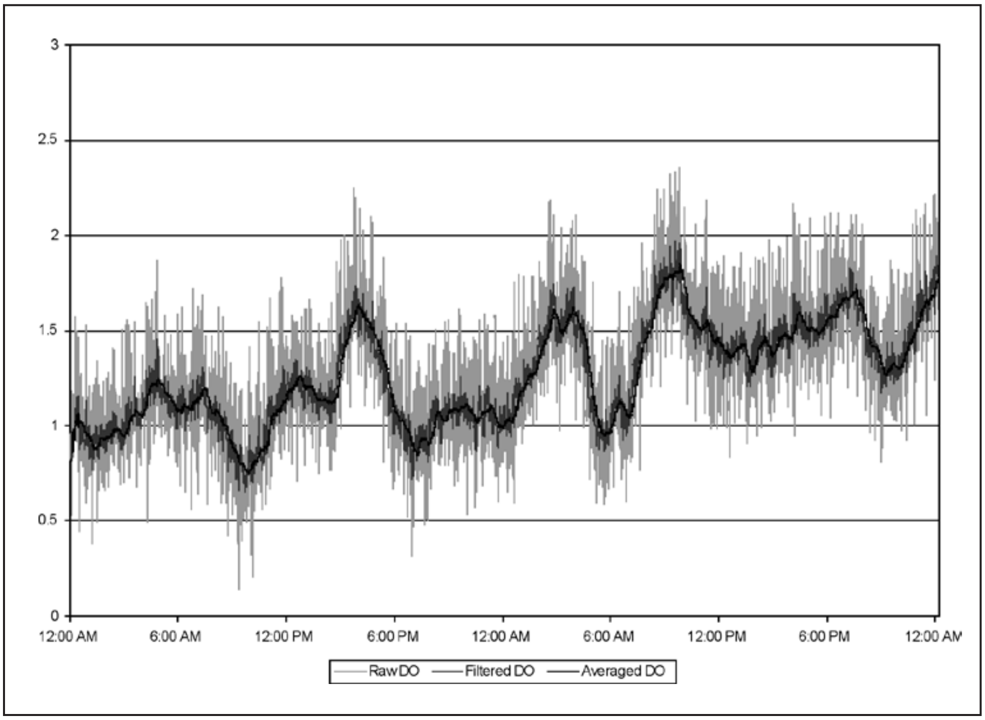
By comparing the 4–20mA signals at the I/O panels to the 4–20mA outputs of the devices using a hand-held multimeter, several miswired contacts were identified easily. It should be noted that while these mixed signals easily could have been solved using software variable mapping,

Figure 2. Piping and instrumentation diagram



DO = dissolved oxygen.
TSS = total suspended solids.
NH3 = ammonia.
RAS = return activated sludge.
IRQ = internal recycle.
WAS = waste activated sludge.

Figure 3. The effect of filtering and averaging on raw-data signals



DO = dissolved oxygen.

it was felt that adhering to the drawings for ease of troubleshooting and consistency years later would prove to be the most prudent and the onsite contractor was contacted to rectify the situation.

Verifying the quality of the signals provided is an essential step in operating an advanced control system. Signals from DO meters, AFM, and valve-positioning feedback indicators, among others, were checked for noise, and control action response tests were performed to test their operation.

Noisy 4–20mA signals observed were checked for grounding issues and in some cases resolved with additional wiring checks. However, because of the large electromagnetic disturbances of the control building, not all the noise could be removed. To manage the residual noise, software filtering techniques were used to remove outliers and clean the data before processing in the control algorithms. Raw data, compared to filtered and averaged data, can be seen in Figure 3 (above).

To produce the signals depicted in Figure 3, a simple first-order digital filter was applied to the raw data to aid in reducing the sharp and frequent spikes seen in the raw-data signal. These filter types are robust and excellent for times when data signals are not expected to change rapidly and can be tuned manually to accommodate almost any sample frequency.

Low-pass filters also are commonly used to condition data by excluding noise spikes above a certain frequency; this method is commonly used to filter out known causes of interference, such as the 60-Hz noise commonly associated with a sensor's proximity to a 120-V AC power line.

After the filter was applied, the data were passed into a 50-sample moving average algorithm. This average, considering the data collection frequency, amounts to a moving average of approximately 10 minutes. It is important not to make the average sample too large, because averaging causes a delay on signals and could affect controller performance.

Blower controls

At the MLE plant, control subelements were started up sequentially in an attempt to reveal, diagnose, and address additional startup complications, as well as gradually introduce the control system to the plant operators. The most immediately apparent issue after starting up the aeration-control system was that the PI-control loop for the positive displacement blowers was undertuned, resulting in slow and inconsistent blower responses to total airflow setpoint changes. Secondly, it was observed that the blower rotation algorithm would occasionally shut down an incorrect number of blowers, resulting in a situation that would leave the system unable to reach the desired airflow setpoint as specified by the advanced control system. To further complicate the issue, operators did not trust the blower controls to allow the system to run in automatic mode, resulting in manual adjustments using local controls.

Resolving these issues was a matter of providing the blower-control provider with suggested PI tuning parameters, along with the data needed to isolate the programming errors, as well as providing test results to the customer for the changes made to the system. PI tuning parameters can be determined by multiple approaches, including step–response analysis, algorithmic determination, and manual tuning methods.

Once tuned, the control was able to provide an airflow consistent with the total airflow setpoint throughout the majority of the day and has subsequently earned the confidence of the plant operators.

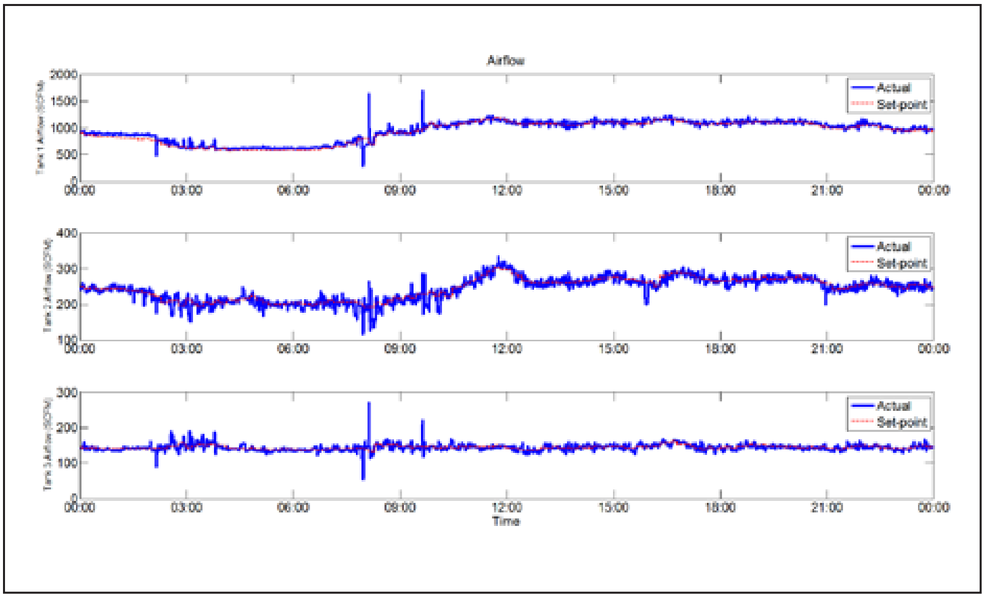
A related obstacle is the apparent discrepancy between the readings from the total AFM and the sum of the individual zone AFM readings. This discrepancy can be attributed to multiple factors that are both electrical and physical in nature, including inconsistent calibration of the AFMs and physical leaks of air between the blower building and the tank's meters.

Unless there is a control action taken to address this offset, the system will fail to control the residual DO as intended. The answer was a soft-coded, tunable solution accessible from the human–machine interface to correct the total airflow setpoint periodically so that the airflow demands of each individual tank could be satisfied. The result of this change is a total airflow setpoint that often is unequal to the sum of each individual zone's setpoint.

Startup flows

Because the influent flow to the plant is below the design flow, the plant has had to use only one of its two process trains to meet its treatment requirements. To preserve the operational value of the equipment, each off-line aeration basin routinely is exercised to

Figure 4. Airflow to process-control basins



prevent seals from failing and actuators from seizing. So, 3.7 m (12 ft) of water is kept over the diffusers to avoid ultraviolet radiation from damaging the membranes and to provide additional static head.

As part of daily maintenance, operators open the ACVs to each of the off-line train's drop legs. This flexes the diffusers to prevent clogging and to maintain their elasticity. The aeration provided during this exercise also prevents the tank from going stagnant.

However, during these daily events, a large portion of air is taken away from the active process train due to the off-line train's lower static head. This causes the airflow to plummet rapidly in each active aeration-control zone if the increased airflow demand is not accounted for properly.

To prevent process disturbances, the aforementioned airflow discrepancy algorithm promptly compensates by telling the blowers to temporarily increase their output until the control zones' airflow setpoints are once again satisfied. It is important to note that despite these large adjustments in total airflow, the process basins did not experience periods of overaeration or underaeration once the airflow discrepancy algorithm was activated (see Figure 4, above).

Because AFM discrepancies are a common problem associated with airflow-based blower control systems, the correction algorithm developed for this project to combat the periodic aeration of the off-line train has been modularized and employed at several different plants. It has effectively prevented disturbances caused by leaks, AFM failures and discrepancies, and other aeration sinks.

Airflow meters

An additional issue arose months later, after an extended period of successful operation, related to the reliability of the mass AFM hardware. The AFM enclosures provided for this project were fabricated and installed in a manner that was not conducive to weathering the hot and humid summer months common to the local climate.

Specifically, the heat and direct sunlight exposure of the small electrical enclosures wore out the seals of the upward-facing indicators, and water leaks eventually shorted the electronics, causing the AFM readings passed on to the plant controls to be unreliable.

The plant operators contacted the control system provider to explain the issues. The provider advised the operators to put the affected zones into a backup DO-control mode until the equipment was replaced. Additionally, a remote-connection Ethernet protocol was established between the provider's office and the treatment plant so that engineers could monitor and troubleshoot the plant by uploading minor patches to address operator concerns without the need for a costly onsite visit.

Remote fine tuning

Remote connection has proven to be an effective method of diagnosing and responding to atypical plant events, in addition to being an important tool used to improve performance through extended tuning. Later in the year, during a routine check of the plant, it was observed that DO responses had slowed, compared to historical data, and that because of this, air use was up. Examining plant data led remote engineers to instruct onsite operators to clean the DO-probe tips manually. The cleaning corrected the slow DO response, returning air use to its historical level.

Portable solution

It has been made standard policy to inspect all installed equipment for potential problems. The functionality and signal health of the various instruments installed at the plant are essential to the performance of the control system, and catching small issues early can improve process performance and stability.

The general methodology developed during this installation includes the following steps:

1. Identify and test all I/O points and communication protocols.
2. Process, verify, and condition all control signals.
3. Verify operability of advanced controls' subsystems (*i.e.*, blower and valve control).
4. Validate advanced control system setpoints.
5. Test remote-control functionality of subsystems.
6. Tune for stability and performance.

The control fixes required at this plant have been modularized and successfully used at similar plant sites that have since been commissioned, resulting in faster, less costly, and ultimately more reliable controller package installations.

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