Co-Benefits of Detailed M&V: Piggybacking Off Required Measurement and Verification to Improve System Savings and Performance

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ABSTRACT

Energy-efficiency measurement and verification (M&V) of complex industrial systems can involve highly technical metering equipment, data acquisition, and engineering analysis. Such an effort can also appear costly to efficiency programs and invasive to industrial end-users. However, if done properly, significant side benefits beyond simply quantifying rebate savings can be extracted from the M&V process, bringing value to both the program and customer.

Since providing M&V requires detailed data collection and expert eyes on the system, it is highly conducive to identifying mechanical issues within systems or additional efficiency opportunities. Such identified issues and opportunities occur frequently and it is easy to piggyback off the already necessary M&V analysis and provide quantified recommendations for the customer to take action on.

This paper pulls from common M&V experiences to demonstrate specific side benefits. This paper places heavy focus on compressed air systems, since it is a complex system common to almost every industrial facility. The goal is to discuss what detailed M&V looks like and how it streamlines with identifying issues or improvements within a system. Examples of common compressed air issues exposed through M&V are provided, such as compressors operating at partial capacity due to stuck slide and inlet valves, staging and controls mistakes, or improper equipment installations. In many of the provided examples, the issues and opportunities were communicated to customer and action was taken, resulting in improved system maintenance and increased program energy savings.

Introduction

The industrial sector makes up about 32% (EIA, 2016) of the U.S. total energy consumption and is a treasure trove for energy-efficiency. This is especially true in industry intense Midwest states, such as Ohio, where the case studies in this paper take place. As efficiency programs evolve, more complicated projects are being incentivized on large industrial systems requiring the use of measurement and verification (M&V). M&V of energy savings is a necessary component of almost all energy-efficiency programs because it validates program cost-effectiveness and quantifies program impacts on both the electric grid and the environment. This paper briefly highlights the typical M&V requirements for non-prescriptive projects, which involves quality data collection and analysis performed by system experts. After explaining the already existing M&V requirements, the paper discusses how additional value can be "piggybacked" from the M&V being performed. Lastly, compressed air system case studies are presented to highlight examples of how this occurs. This added piggybacking value not only benefits the customer through increased energy savings and resolved maintenance issues, but also benefits the utility or efficiency program through increased cost-effectiveness and relationship building.

Current M&V Requirements

There exist a number of guidelines and practices to help match appropriate M&V requirements to varying project types and program goals. Additionally, there are some requirements set by electric grid operators so that energy efficiency can be treated as a resource to the grid. Most of these guidelines reference each other and are similar because of the nature of M&V. One such document commonly referred to by multiple organizations internationally is the International Performance Measurement and Verification Protocol (IPMVP, 2012). As an example, the IPMVP is referenced by both utilities and the grid operator in the mid-west region of the United States. Other notable M&V guideline documents include ASHRAE Guideline 14-2014 (ASHRAE, 2014) and ISO 17741:2016 (ISO, 2016).

The IPMVP categorizes M&V into four options; Option A and B pertains to metering the system being affected, Option C relates to facility level metering, and Option D relates to calibrated simulation. This paper specifically focuses on M&V typically utilized for large non-prescriptive projects which would fit within IPMVP Option A and B.

Options A and B require metering of the system being affected by the efficiency measure. This requires installation of accurate metering equipment to measure energy consumption of the systems, and any significant variables, before and after implementation of the efficiency project. The measured data is then used with appropriate engineering calculations and analysis techniques to determine the energy savings. The calculations and techniques used are dependent on the data available and the complexity of the project. There are guidelines for such techniques but no set standards since each non-prescriptive project is unique and cannot be generalized. Hence it is up to the party performing the M&V to understand the system and determine which techniques are appropriate for the M&V. A pre-requisite to perform such M&V effectively is a high level of technical expertise with the energy system being evaluated. The strong technical expertise helps the engineer to evaluate if the measured energy savings are the result of the efficiency project or if it is due to other influential variables in the system that are not related to the efficiency project.

The impact an engineer's understanding and analysis of a project has on the accuracy of M&V was demonstrated by Kleinhenz, Seryak, Brown and Sever in 2013 (Kleinhenz, 2013). The paper demonstrated that the accuracy of good M&V for custom projects is much more dependent on the engineering analysis than the metering equipment. It also presented a real scenario where the accuracy of the metering equipment only impacted the calculated energy savings by 3%, but the engineer's decision of variable normalization and time duration selections could impact the measured savings by over 25%.

To summarize, providing quality M&V for large custom projects requires unbiased expertise, analysis, and data collection of a system. These three components are also necessary when engineers provide quality efficiency recommendations through energy audits, system commissioning, and Strategic Energy Management (SEM) or equipment diagnostic services. Therefore, M&V requirements are a gateway to provide a version of these services to specific systems and projects, at a minimal extra cost to the efficiency program.

Piggybacking Opportunities

The concept of piggybacking extra value to customers from required M&V is briefly discussed in Section 2.1 of IPMVP, where the document lists eight primary purposes for M&V. Within the list includes co-benefits such as "increasing energy savings" and "improve engineering design and facility operations and maintenance" through providing valuable feedback. Creating this extra value out of M&V is important. This is because conducting M&V by itself on a project can feel like an invasive distraction to the customer and can be viewed only as required overhead cost to the program administrator. For example, in Ohio we have conducted hundreds of M&V projects in industries that operate nearly all hours of the year. In these facilities it can be highly difficult for plant personnel to take time from their day to help accommodate a project's M&V. It can be even more difficult when installation of necessary metering equipment requires their electrician's time or even temporarily powering down equipment. To the manufacturer, this M&V is only seen as risk, and it does not take much risk to outweigh the benefits of the potential project incentive.

For example, a potential $30,000 incentive for an efficiency project on a large compressed air system might sound great to a customer, until the M&V requirement is explained. Plant personnel are very aware that this incentive can quickly be outweighed by several minutes of potential process downtime, increased risk of electrical issues from the metering installation, or tying up the time of valuable skilled plant personnel. This barrier to energy efficiency is generally described as the "hidden costs" barrier within the energy efficiency world (Sorrell et al 2011).

In addition to being a perceived nuisance or risk, strictly providing M&V can also be damaging to customer relationships if the resulting calculated energy savings turn out less than expected. This leaves a negative impression of participating in the program with the customer and providing M&V to projects with disappointing savings hurts program cost effectiveness.

For these reasons it can be highly beneficial to present M&V as a service with co-benefits. Customers can be more receptive to the M&V if they feel they are being provided a skilled, unbiased, system expert with the ability to do an in-depth analysis of how the system uses energy and identify issues or areas for improvement. In other words, the act of providing M&V can also be presented as a form of project commissioning or a focused audit.

It is also important to understand that it is not uncommon for energy efficiency projects to be implemented incorrectly or slightly incorrectly. This can be especially true for large complex systems, such as industrial compressed air systems with multiple compressors. For example, for a single regional utility, in 2016 we provided, IPMVP Option A & B type, M&V for nine large compressed air systems, of which five projects had potential for efficiency improvement after the vendor deemed the project complete. Thus, added value from the M&V process was applied to 55% of the large compressed air systems projects.

The next section of this paper strives to demonstrate how co-benefits can be provided to efficiency projects through detailed M&V. Additionally, the examples demonstrated focus on compressed air because it is a large energy using system found in virtually every manufacturing facility. It is also a system that can be highly complex to analyze, requiring strong expertise and data collection, especially when consisting of multiple staged compressors. Therefore, this is a fairly universal system for industries to relate to. The examples of issues found were specifically chosen because they are identified regularly within our company's experiences. A secondary goal of this paper is to bring these common issues to the attention of manufacturers, program administrators and M&V providers.

Case Studies

Case Study 1: Multiple New Opportunities Identified in Large Compressor System

This first case study is discussed in greater detail than the others. This is because it was a larger example of piggybacking co-benefits off of M&V and touches on multiple intended takeaways from this paper.

- Project highlights:
  - General Project Scope: Install a sequencer controller on a nine compressor system with total installed power of 1,200hp.
  - Energy savings after initial M&V = 264,800 kWh/year
  - Additional energy savings identified by M&V evaluator = 211,700 kWh/year
  - Identified issues were fixed
  - Increase in incentivized energy savings = 80%

This was a large and complex compressed air system receiving a new centralized sequencer (controller). Through the M&V process of collecting significant data and providing expert analysis on the system, multiple system issues and efficiency opportunities were identified, beyond the initial sequencer. The identification of these issues and implementation of the opportunities caused the M&V process to last over 12 months from start to finish. This is because the utility decided to allow implementation of each identified opportunity to take place before the post-metering period was officially captured. It can be seen in this example, that the co-benefits piggybacked off the M&V were very similar to the benefits one would receive from a service like commissioning, energy auditing or even Strategic Energy Management. However, in this situation, such a service can be lower cost, since it builds off the already necessary data collection, investigation and analysis. In this example, the identified system improvements significantly increased the project rebate, strengthened the relationship between the utility's efficiency program and the customer, improved system performance and significantly increased system capacity, which halted the plant's plans to add more compressors.

In the pre-scenario the compressed air system was served by nine compressors. The compressors were controlled through staggering pressure settings on each local compressor. This resulted in multiple compressors frequently operating unloaded or under loaded, which is the least efficient operation of a compressor. Pre-scenario metering and investigation was performed in December 2015. The metering equipment consisted of true power meters on each compressor capturing data at one minute intervals. It also consisted of amperage loggers capturing data at one second intervals. One second interval resolution is necessary to properly evaluate compressor capacity control modes. System pressure was also metered at a representative location in the system.

In the post-scenario, the new centralized compressed air sequencer was fully installed May of 2016 and our metering data was collected for analysis. However, we left the physical metering equipment installed just in case the data did not work. It turned out, through our data analysis that several issues existed within the system that were not associated with the new sequencer project. After explaining these issues to the plant and the program manager, it was decided the issues would be corrected and post-scenario metering postponed to also capture the savings of the new modifications. The post-scenario metering ended January 2017. The issues identified and captured through the M&V process were:

Co-benefit #1 – Failed slide valve/poppet valves on variable displacement compressor:

This is a very common issue we identify in compressors with "variable displacement" capacity control. This is commonly identified by observing a compressor's peak power draw. If the peak power draw is lower than expected, it is important for an engineer to investigate why. We often find compressors do not perform to their full power draw, and thus their full capacity, due to issues with inlet valves, slide valves, poppet valves or generally bad air ends.

Through the metered data we noticed one of the larger variable displacement compressors only achieved a max power draw of about 60% of its rated draw. We suggested to facility personnel to investigate the air end. Through investigation they determined the variable displacement slide valve was not functioning at its full range, causing the compressor to always run at a part load. As a first step they lubricated the valve which resulted in a significant improvement in capacity. However, this did not fully fix the problem, the issue eventually became worse and the air end was fully replaced in December 2016. All of these events can be seen through analysis of collected data, as shown in the figure below. Replacing the air end returned the variable displacement compressor back to full operating capacity like a new compressor. The air end replacement resulted in considerable energy savings as it allows some of the smaller compressors to simply turn off. This repair also helps reduce the plant's capacity concerns, and they shelved a plan to install more compressors. It can be seen in Figure 1 that there are three distinctly different maximum power draws of the compressor as repairs are made. As the compressor maximum power increased, so did its flow capacity and efficiency. Figure 2 displays a typical capacity versus power curve for a variable displacement controlled compressors and how the compressor operated in the pre-scenario versus the post.

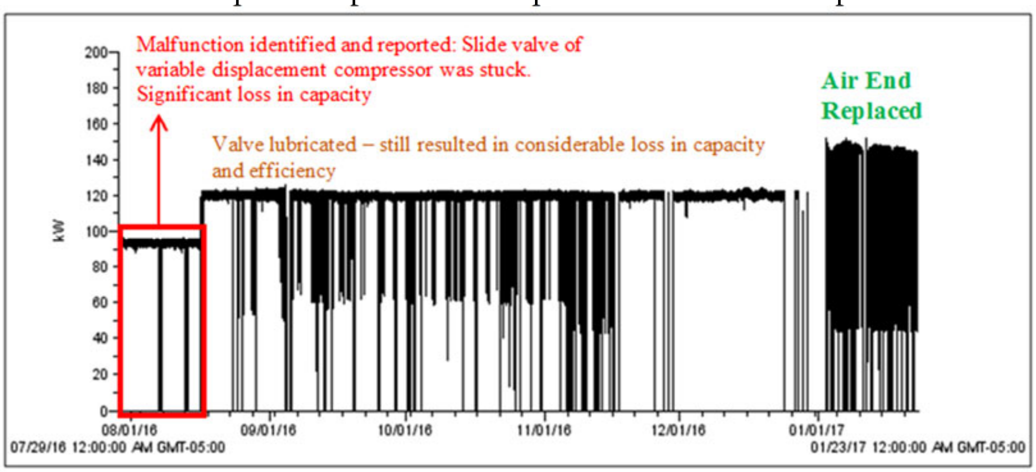

Figure 1. Stuck slide valve issue was identified and addressed.

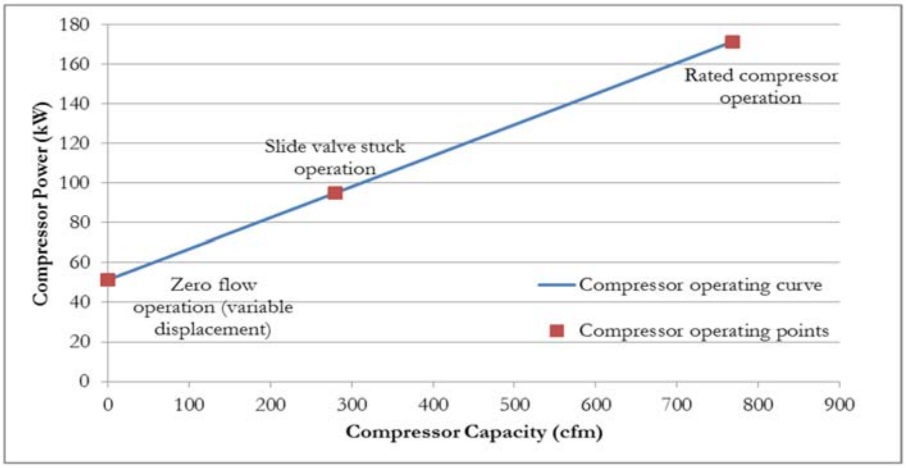

Figure 2. Effect of a stuck slide valve on the compressor capacity and efficiency

Co-benefit #2 – Motor contactor failure:

After initially evaluating logged data in June 2016, which was after the sequencer was installed, we realized one of the compressors continued to operate unloaded without cycling off. After investigation facility personnel found an issue with the motor contactor failing, which was fixed in early July 2016. This issue did not exist in the pre-scenario, but it did negatively impact the energy savings potential of the post-scenario. So correcting it increased the overall project savings by allowing the compressor to cycle off. Figure 3 displays when the compressor seized to cycle off after unloading and when the issue was resolved.

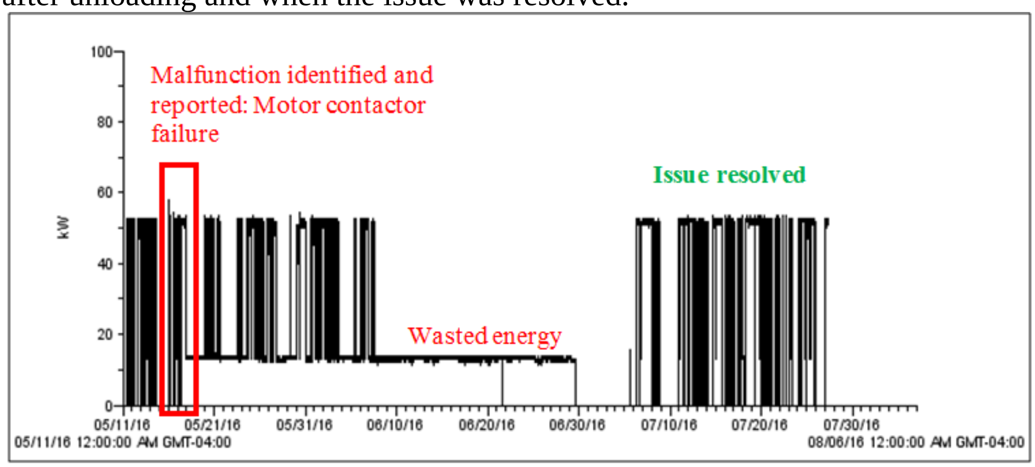

Figure 3. Air compressor motor contactor failure that did not allow the compressor to turn off, identified and fixed.

Co-benefit #3 – Stuck inlet valve to VFD trim compressor:

The nine compressor systems had one VFD trim compressor. In October 2016, our logged data determined this compressor could not operate at full power. As shown below, the compressor power draw shows it was limited in its trimming capacity. Facility personnel investigated the issue and determined that the inlet valve mechanism was stuck partially closed. This prevented the compressor from supplying its full capacity. This valve was replaced and some motor repairs were performed, resulting in energy savings since the compressor could then operate more effectively as the trim compressor. Figure 4 displays the VFD compressor's power draw characteristics with the broken inlet valve and motor issues versus a properly functioning VFD compressor.

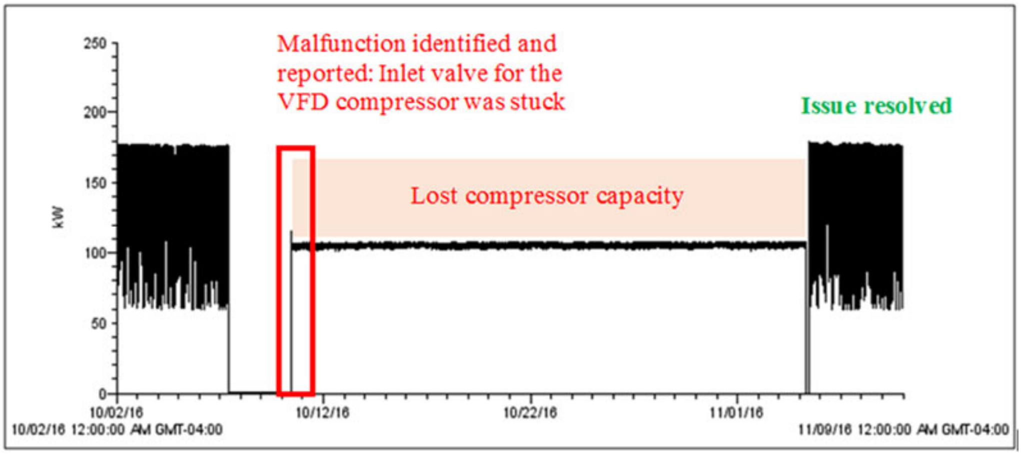

Figure 4: Inlet valve stuck on a VSD air compressor, identified and fixed.

Case Study 2: Identified Room for Improvement On Existing Project

- Project highlights:
  - General Project Scope: Install a sequencer controller on a 16 compressor system with total installed power of 2,350hp.
  - Energy savings after initial M&V = 675,100 kWh/year
  - Additional energy savings identified by M&V evaluator = 249,000 kWh/year
  - Project was not implemented yet
  - Potential increase in incentivized energy savings = 37%

In the pre-scenario the facility had sixteen air compressors that were controlled locally. The upgrade consisted of facility personnel installing a sequencer to centrally control all the air compressors to improve system efficiency. Observations from the metered M&V data showed that the sequencer was operating as intended, except on the weekends. Figure 5 presents an example where weekend operation is not very efficient.

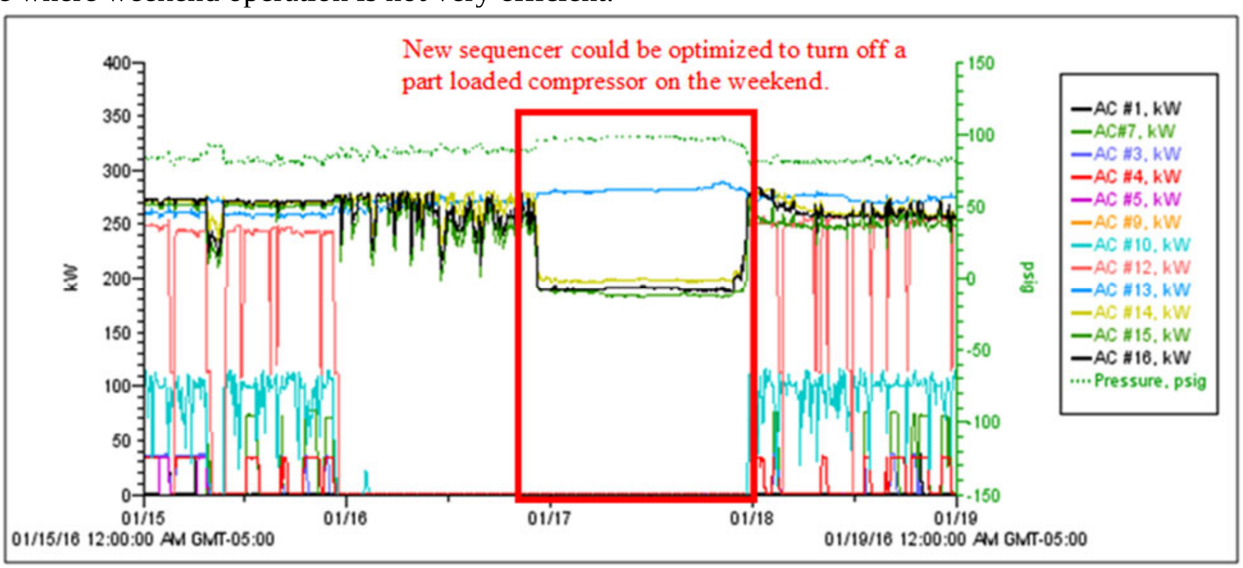

Figure 5. Room for improvement in sequencer operation in a system with new centralized controls

It can be observed that on the weekends four compressors are operated, three of which operate at part-load and one operates close to full load. Based on a flow analysis about 4,000 cfm of flow is needed on the weekend which can be achieved by operating the three compressors, that are already running, at full load and shutting down one of the compressor. This would result in 200 kW savings for one day per week throughout the year, a total annual savings of about 249,000 kWh, which is a 37% increase in the savings. In this project the facility personnel and vendor were informed of the missed energy savings. However, they wanted to move forward with processing the rebate before implementation of added savings. The facility personnel greatly appreciate the findings and recommendations. However, they did not have much bandwidth at that time to properly address the project. It was our impression that they intended to implement the suggested improvements when they had time.

It should also be noted that the control system installed at the facility was not sophisticated enough to log and trend system power which would provide this level of insight to facility personnel to improve system performance. Hence this a prime example of where an M&V evaluator can shed light on system operations and help facility personnel optimize the system further.

Case Study 3: Improperly Implemented Project

- Project highlights:
  - General Project Scope: Install a sequencer controller on a four compressor system with total installed power of 425hp.
  - Energy savings after initial M&V = 0 kWh/year
  - Additional energy savings identified by M&V evaluator = 87,000 kWh/year
  - Project was implemented

This case study demonstrates how M&V can be a form of commissioning for an efficiency project. In this case, there was originally little to no energy savings after installing a compressor sequencer on a four compressor system. However, through M&V it was determined that the new sequencer had not actually been fully programmed. At first when this issue was brought to the vendor and customer's attention, the vendor simply explained that nothing was wrong and that we couldn't capture energy savings because we were not accounting for an increase in airflow. However, we were able to provide the vendor our data and our airflow normalized analysis showing otherwise. After reviewing the data, the vendor agreed to recheck the system. After re-investigating it was realized by the vendor that the sequencer programming had not been fully completed. The system was then fixed by the vendor, free of cost to the facility, and new metered data was obtained to verify the savings. Figure 6 displays the system after post-metering which shows that the system was not well sequenced. Multiple compressors are operating at part load. No one compressor appears to be the obvious trim. It can also be observed that multiple compressors were operating around midnight when the plant was not in production. It can also be observed that one of the compressors, AC#4, was always unloaded and never turned off.

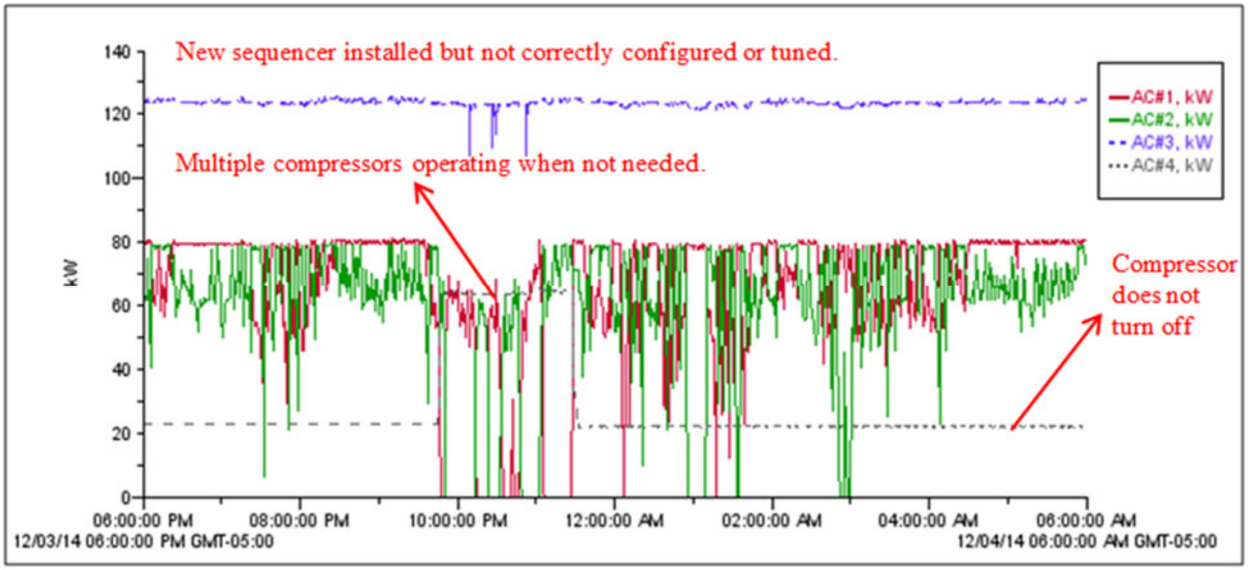

Figure 6. Room for improvement in sequencer operation

This system never did get fully correctly implemented within the incentive program. However, it got corrected to the point of 4% system energy savings. Our analysis predicted that when implemented perfectly, system savings of about 10% would have been realized. However, the vendor is continuing to investigate the system and facility personnel were appreciative that the utility helped them realize the savings because if this issue was not caught through M&V the facility would have never realized that there were no savings initially.

Case Study 4: New VFD Compressor Not Staged Correctly

- Project highlights:
  - General Project Scope: Install a sequencer controller on a four compressor system with total installed power of 800hp.
  - Energy savings after initial M&V = 0 kWh/year
  - Additional energy savings identified by M&V evaluator = 859,000 kWh/year
  - Project was implemented

This case study provides an example where two issues were occurring in the post-scenario. First, multiple compressors were constantly operating unloaded without cycling off. Second, the compressor staging had not been properly implemented to ensure the newly installed VFD compressor operated as trim, while the fixed speed compressors served as base load. In the pre-scenario the facility had three constant-speed modulation-controlled air-compressors that were controlled locally. The upgrade consisted of facility personnel installing a new variable speed compressor in an adjacent building and tying all the compressors together such that the VFD compressor would operate as the trim compressor and the three constant speed compressors would operate as base load, cycling off when not needed.

Observations from the metered M&V data showed that the compressors had not been properly staged or perhaps facility personnel had not been trained on the intended efficient control operations. The two examples of inefficient operation are presented in the following two figures. Figure 7 demonstrates where all the constant speed compressors operated at part-loads, or even unloaded during the weekend, when the system airflow requirements were low. It can also be observed that the VFD compressor, alone, could easily meet the load of the plant during this time. The intended control for the base load compressors was to turn off after operating unloaded for a few minutes.

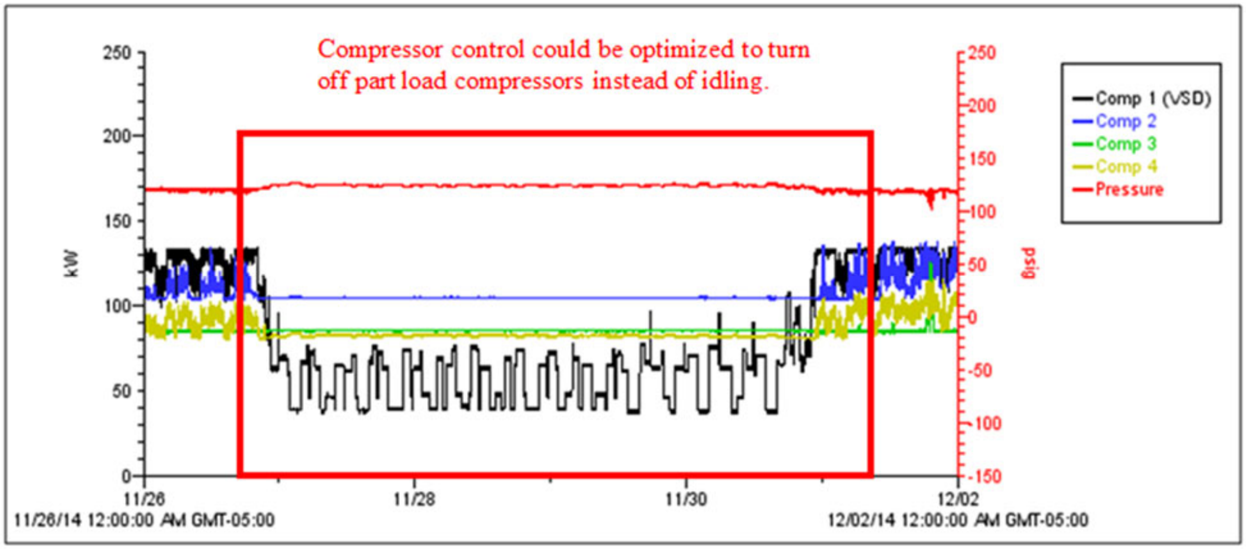

Figure 7. Room for improvement in compressor controls - unloaded compressors should be turned off.

Figure 8 shows that the system also had issues during the typical production week. It can be observed that three of the four base load constant speed compressors were simultaneously operating at part-load along with the VFD. Unlike the VFD compressor, the constant speed compressors operated in modulation mode, which has a very poor part-load efficiency. These compressors are most efficient only when operating at full capacity. The intended control was for the constant speed compressors to operate as base loaded compressors either at 100% capacity or cycled off.

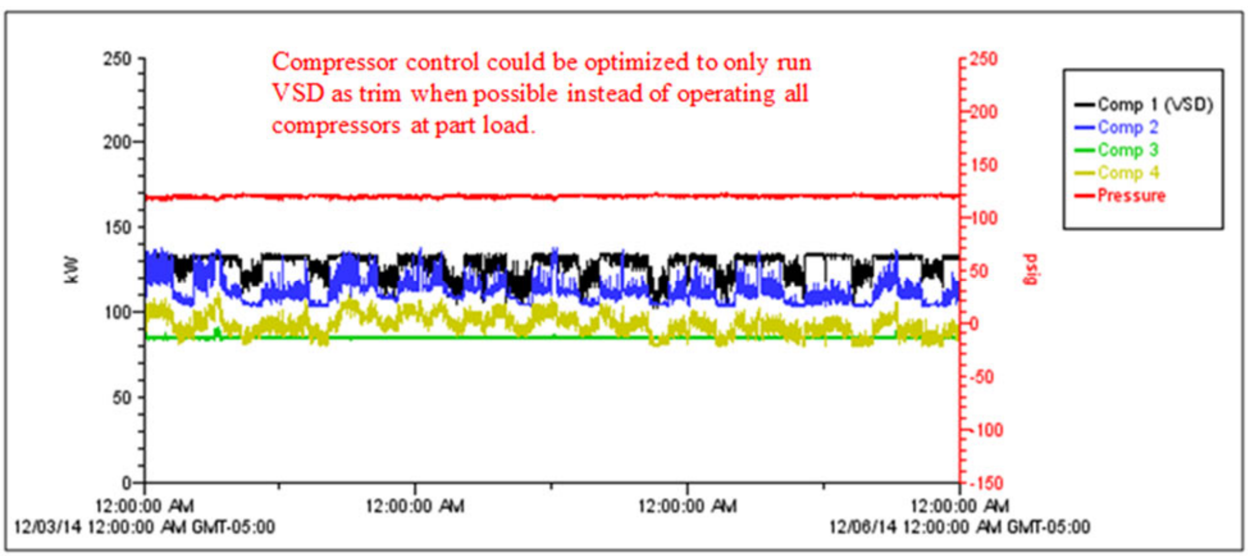

Figure 8. Room for improvement in compressor controls - only one compressor should operate as trim

Initially the post-scenario metering found no energy savings and both the facility and vendor were notified of the issue with insight on why there was no savings. After investigation it was realized that plant personnel were starting the compressors in the “constant run” mode instead of the “automatic” mode as intended by the vendor. The modes available on the compressors are shown in Figure 8 below.

Figure 8. Control modes available on the compressors

This issue was addressed by standardizing a start-up procedure for the compressors at the facility. Correct implementation of the project resulted in compressed air system energy savings of about 26%. Additionally, facility personnel were appreciative that the utility helped them realize the savings. If this issue was not caught through M&V the facility would not realize the savings after making the capital investment.

Conclusions

Unfortunately, since M&V is a required component of virtually all efficiency programs, it can easily be viewed as an added cost to program managers and can be viewed as an invasive nuisance to industrial customers. However, this paper discusses how and why M&V can instead be presented as a valuable service/resource to the customer, with co-benefits. These co-benefits include having an expert provide detailed data collection and analysis on the applicable system and allowing this process to result in a system study with recommendations. This study can provide deliverables similar to those found from energy audits, commissioning or strategic energy management. The cost effectiveness of providing this information can be high, since it is built off of the already required cost for data collection and analysis. These studies can be beneficial to customers and efficiency programs because they help build trusted relationships between the two parties and helps ensure the systems within the project are achieving optimal efficiency and incentives. It can be seen in the case studies how the customers were able to realize energy savings opportunities they were previously unaware of, similarly to receiving an energy audit (Case study 1), and also allowed customers to see when their efficiency projects were not implemented properly and how to correct the issues, similar to receiving system commissioning (Case studies 2, 3 and 4).

Many efficiency programs already provide incentives for commissioning, auditing and SEM services to customers. However, these services are usually provided before a customer identifies and implements a project. This paper focuses on piggybacking off of M&V of large complex projects and providing such services to already existing projects. This is needed and valuable to a client. For example, we previously point out that over 50% of the large compressed air projects we did M&V for in 2016 were not implemented properly to optimize energy savings. Lastly, allowing an M&V engineer to provide customers such services to enhance energy saving on existing projects, the program manager can receive a return on the required investment of M&V.

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