Applying Data Analytics to Overcome Efficiency Measure Implementation Barriers in an Industrial Production Facility: A Case Study

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ABSTRACT

Industrial production facilities managers are typically willing to resist installing energy efficiency measures if there is any perceived risk to production. This resistance can be true regardless of the economic benefits of the efficiency measure, or whether the risk is real or perceived. However, data analytics and intelligence from measured data can help managers overcome the perceived-risk barrier. In fact, when the efficiency measure is shown to have real benefits to production, the perceived risk frequently disappears, enabling the project economics to drive the measure to completion. The case study presented in this paper demonstrates an applied method of data analytics, using measured electrical motor and facility interval data. These analytics make it easier for plant personnel to recognize the production advantages of the efficiency measure. When the data analytics are complemented by intelligence generated from the electrical measured data, the perception of risk to production diminishes and efficiency measure implementation can be seen as an advantage. The case study shows capital savings of $40,000 from an avoided and unnecessary equipment purchase, a facility demand reduction of nearly 100 kW, an increase in production quality, a decrease in production downtime, annual kWh savings of nearly 200 MWh, and annual costs savings of $30,000. The paper also presents examples of data analytics for another technology.

Introduction

Efficiency Vermont, a statewide energy efficiency utility, uses a two-tiered approach when it works with its largest commercial and industrial customers: (1) an account manager creates and manages the customer relationship; and (2) an energy consultant provides technical expertise in determining cost-effective and appropriate efficiency measures. This model is the foundation of a trusted energy business advisor relationship—and results in dramatic efficiency investment successes for these large energy ratepayers. The following case study illustrates both how the model works and how a resourceful technical approach has made a significant difference to a large energy user's bottom line.

The focus of the case study is on the technical aspects of an implementation project involving customized efficiency measures, from discovering the roots of the customer's energy pain to completing the project. The technical expertise applied to the project involves:

- Data analytics using facility interval data.
- A presentation of analysis, to enhance confidence in the energy consultant's technical expertise and customer understanding of project implementation.
- A realignment of the customer's energy pain,
- Applied analytics to explain the energy consumption profile of existing production equipment.
- Presentation of data analytics to production and non-production personnel.

- The cost and payback implications of the proposed efficiency measures on production.
- Measurement and Verification of installed measure.
- There was no discussion with the customer concerning maintenance savings or the total cost of ownership.

The Door Opens

An account manager from the efficiency utility responded to the concern of a customer operating a pine processing saw mill. The customer's primary concern was energy cost. Mill River Lumber runs a single-shift sawing and planing operation and a 24/7 drying operation. The customer contacted the efficiency utility to discuss an equipment purchase of $30,000 to $40,000 for sub-meter installation. The customer's hope was that, by learning more about the mill's power flow, he could decrease his peak demand charges. The efficiency utility account manager fielding the request for information brought in an in-house energy consultant to review the proposal and make a recommendation.

Before embarking on demand reduction approaches via equipment curtailment measures, the energy consultant needed to understand the scope of the facility equipment and modes of operation. The fundamental questions were:

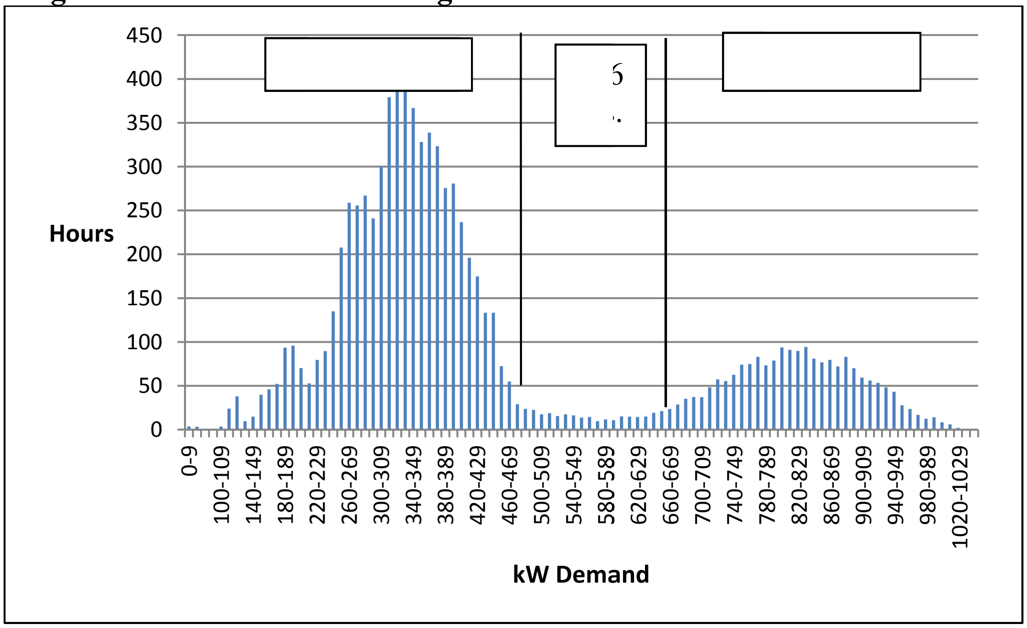
1. Does the facility have load that can be curtailed or shifted?
2. How long will the load need to be curtailed?
3. What is the effect on production output of load curtailment?
4. How much load can be curtailed?
5. What are the costs and benefits of load curtailment?

Applying analytics to facility interval data became essential to answering these questions.

Interval Data Analytics

Using 15-minute interval data and spreadsheet pivot tables, the energy consultant scoped the energy consumption patterns of the facility. Figure 1 shows a load duration histogram for one entire year of interval data. Because the sawmill runs two energy-intensive processes, the histogram has a bimodal shape. Roughly speaking, the major portion of the first mode represents the lumber-drying process during hours when the sawing and planing operations are down. Naturally, kW demand increases when the sawing and planing are active, as indicated by the data presented for the second mode. The valley between the modes has fewer hours and represents plant idle time during lunch, breaks, and shift startup. Note that the area under the curve represents the total annual energy use during these time periods. Demand reduction, focusing on incremental kW above 900 kW, is shown in Figure 2.

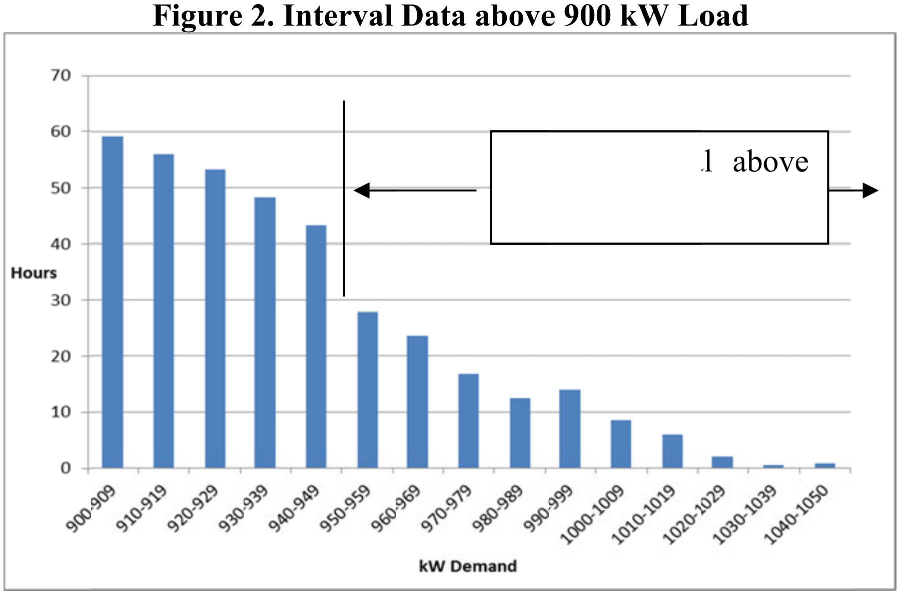
Figure 1. Load Duration Histogram from One Full Year of Interval Data



Source: Mill River Lumber Interval Data 2008

Figure 2 graphically indicates the number of hours annually that each 10 kW reduction in demand would require. Summing the hours shown in Figure 2 indicates that curtailment of 372 hours is required to reduce the peak demand by 150 kW, but curtailment of only 84 hours is required to reduce demand by 100 kW. The annual cost impact of this 100 kW reduction would be a savings of approximately $18,000; if the impact on production was acceptable to the owner, pursuing this approach would be worthwhile.

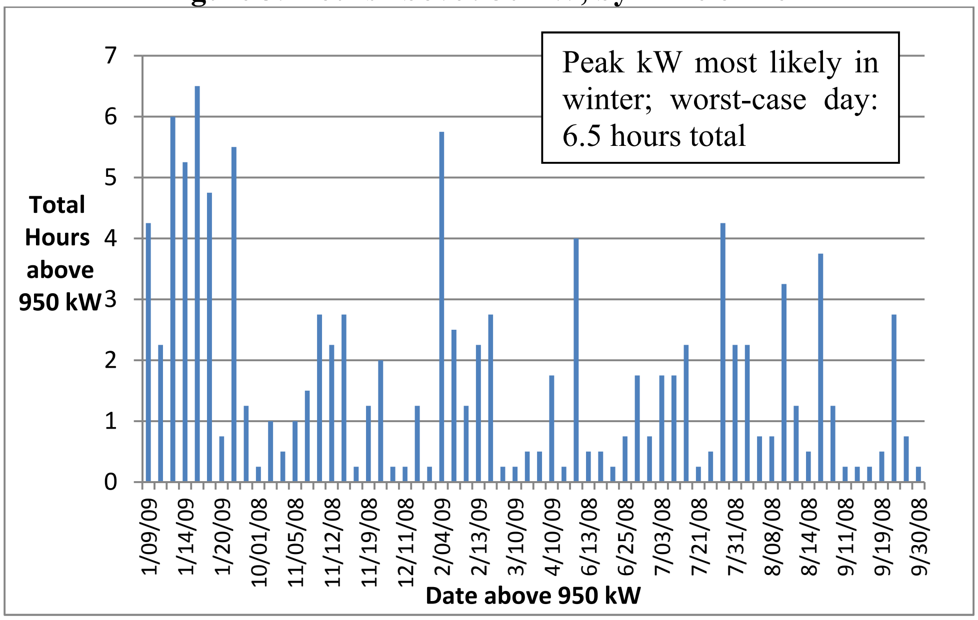
Figure 2. Interval Data above 900 kW Load



Source: Mill River Lumber Interval Data, 200

The next question for the energy consultant was to determine which equipment could be automatically shut down with minimal impact on production. Investigations with operators revealed that the dehumidification kilns could be automatically shut down for up to six hours without affecting product quality. Remaining questions were: (1) Is six hours of shut-down the worst-case scenario? (2) When would the plant likely be operating at above 950 kW? Targeted filtering of the interval data pivot table provided the answer, as shown in Figure 3.

Figure 3. Hours above 950 kW, by Time of Year



Source: Mill River Lumber Interval Data 2008

Efficiency Vermont must meet annually determined kWh savings and system peak kW reduction. Given the characteristics of the time of day and the month of year that this 100 kW reduction would occur at Mill River Lumber, the system peak was affected by only 2 kW. Furthermore, the curtailment of kiln energy consumption involved only a shift to another time, and thus no kWh savings would be realized. However, the energy consultant calculated that the facility could realize a 100 kW reduction and an $18,000 reduction in demand charges from the curtailment of this load. The owner ultimately decided that curtailing kiln operations would be too disruptive to production and did not pursue this option.

This analysis helped Mill River Lumber understand their power flow, prompted them to reconsider capital expenditures on sub-metering equipment, and opened the door for the energy consultant's entry into their world of lumber processing. (Other benefits of sub-metering equipment are well-recognized, but are not germane to this paper.)

The Walk-Through, Efficiency Measure Identification

Following the energy consultant's presentation of the interval data analysis to the maintenance supervisor, a guided tour of the process equipment in operation was next. Entering the saw mill from the rear, one goes up onto a 4-foot platform, and comes face to face with the 125-horsepower centrifugal pump in operation. The energy consultant could estimate the motor load by the temperature of the motor casing between the motor fins. At an uncomfortable surface temperature of about 140° F on the cooling fins, the motor was clearly at full load, or close to it. A large radiator above the motor was fitted with a 5-horsepower blower rejecting heat from the hydraulic fluid. The energy consultant wondered how much energy flowing through this motor was rejected by the radiator, and what work was being performed in between.

The facilities manager further explained the main saw carriage drive system, which is fitted with a hydraulic ram, using water as a fluid. The ram accelerates a 6-ton carriage that holds a log, pushing it through the band saw, decelerating to a stop, reversing direction, accelerating, and making a cut on the back stroke. The ram decelerates once again to complete the cycle. The response time for one complete cycle is about 3-4 seconds. The carriage is stopped for short durations to flip the log or load another log. This equipment is a critical component to the sawing process. Speed and control determine the quantity and quality of product output. The facilities manager confided that they loved this equipment because it performed well and did not break down. That confidence in reliable production equipment is one of the strongest barriers to getting owners and operators to pursue energy efficiency retrofits of production equipment.

The next step for the energy consultant was to send a letter to the sawmill's financial controller. The energy consultant reported his estimates of the energy consumption of the carriage drive system, and suggested a no-cost meter installation to verify the energy consumption. The energy consultant chose to err on the side of caution in the estimates, primarily because he was not fully conversant with the equipment operation, and uncertain of the potential for energy savings.

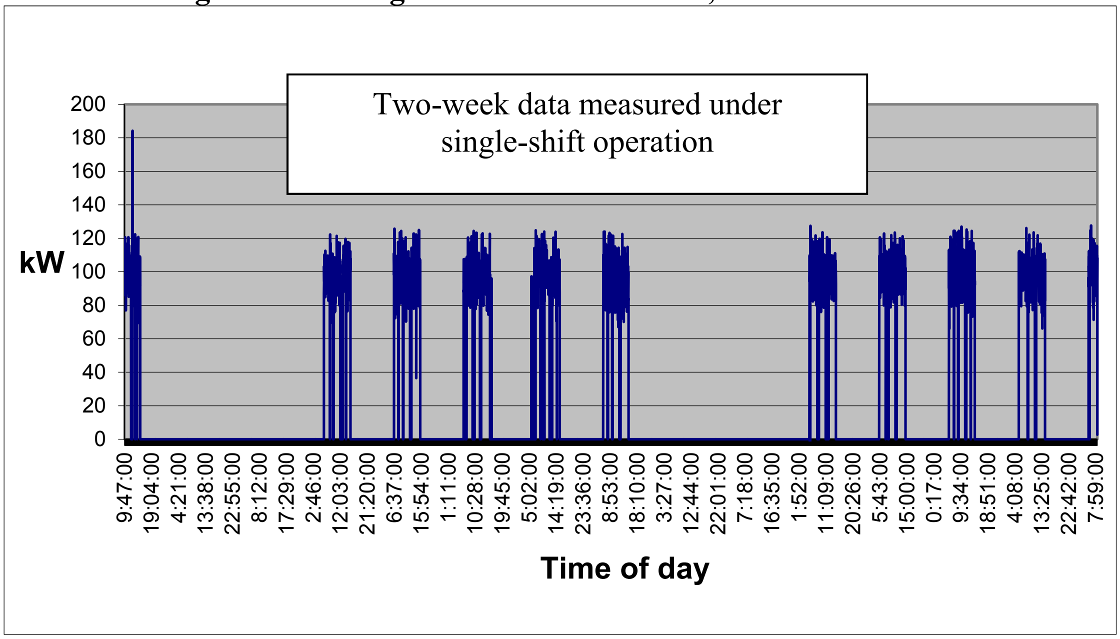
Motor Data Analytics

When analyzing motor-metered data for information beyond average energy consumption, it is necessary to understand the load the motor is driving, and how that load influences the motor power. It is important to determine, under operation, the points at which:

1. the motor is up to speed, upon start-up. This point can indicate the motor's minimum load, since motors are often started at minimum load, especially those with controls and varying loads.
2. the motor begins to operate at constant load (and the duration of that period), and why the driven load is creating this constant load.

Load duration histograms are very useful in determining these and other operating points. To illustrate this, Figure 4 presents the carriage motor's load, analyzing simple time-series measured data. Figure 4 reflects a customer report of an average of 99.6 kW, with the motor operating for 80.9 hours in a 2-week period; the yield is an estimated annual energy consumption of 205,538 kWh for 50 weeks of operation. This is a straightforward analysis, but it does not add any knowledge about how the equipment consumes energy, nor does it indicate any advantages beyond energy savings.

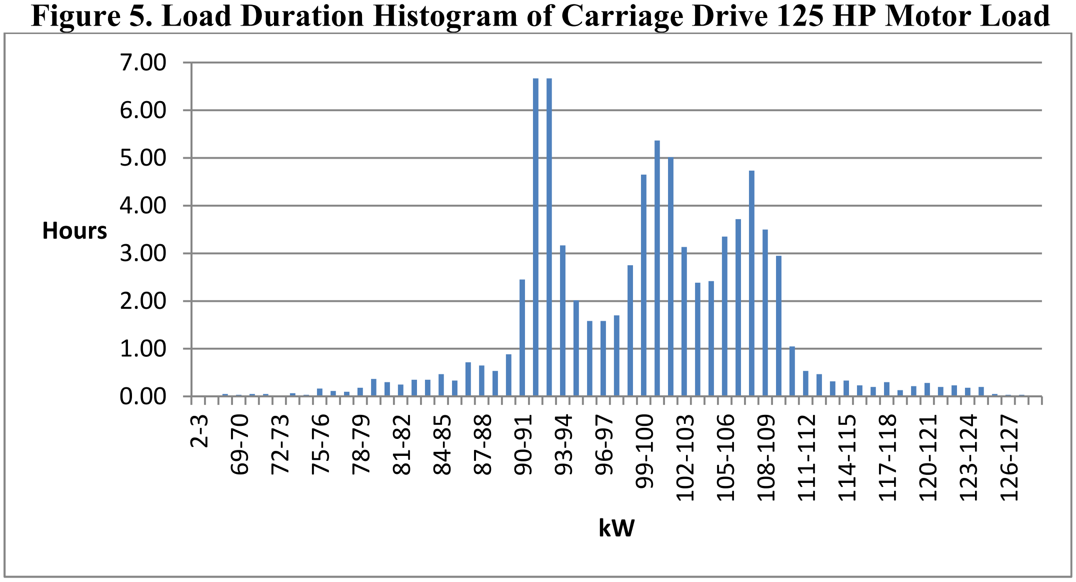
Figure 4. Carriage Drive 125 HP Motor, in 1-Minute Data



Source: Mill River Lumber Hydraulic Carriage Pump Motor

However, the profile becomes more interesting when load duration is calculated. The histogram shown in Figure 5 indicates 3 distinct motor load kW peaks. For this equipment, the spikes at 92 and 93 kW are of particular interest. What is the carriage system doing during this part of the load duration? Nearly 25% of the motor's total load across time is spent between 90 and 94 kW. Drilling further into the time-series data for the period immediately following motor start, coupled with equipment operational knowledge, led to a discovery of potential for significant energy savings.

Figure 5. Load Duration Histogram of Carriage Drive 125 HP Motor Load

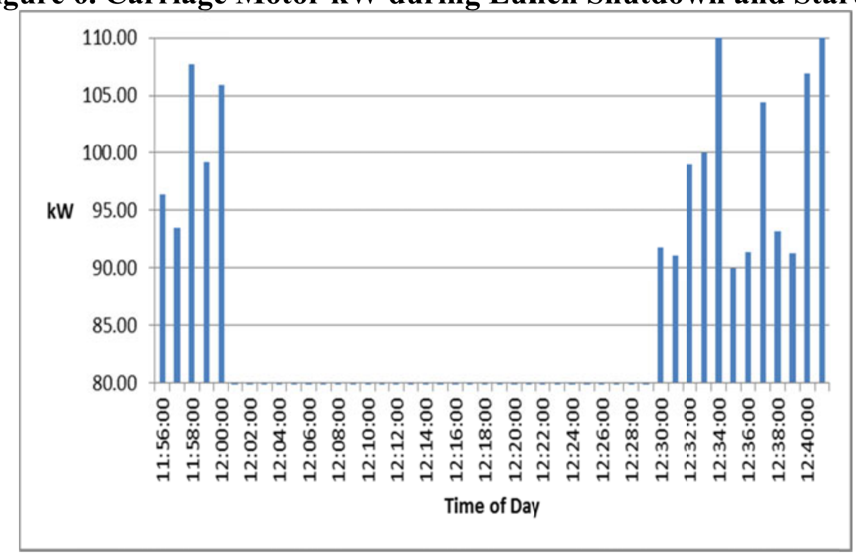


Data source: Mill River Lumber hydraulic carriage pump motor

Figure 6 represents motor kW just before and after a lunchtime shutdown. The measurement equipment samples one 60-cycle waveform every minute, then calculates and records the true power. It is important to note the 92 kW readings just following motor startup. When the carriage is idle for 2 minutes, the motor is consuming 92 kW! Furthermore the motor load is ~92 kW for 25% of the measured time, as indicated in Figure 5's load duration histogram. This is believed to be the total carriage idle time for startup, shutdown, log adjustment, and log loading.

It can be inferred from the data that this system requires energy, at all times, because it needs to respond quickly in the sawing process. That is, the hydraulic system is charged and ready to accelerate and decelerate the 6-ton carriage. The power and energy above this 92 kW level are needed so that the log and carriage can pass through the band saw blade. The power required to actually saw the lumber was estimated to be 8 kW on average. It was with this realization that the energy consultant understood what the motor was doing to give off such high heat on the cooling fins.

Figure 6. Carriage Motor kW during Lunch Shutdown and Startup



Data source: Mill River Lumber hydraulic carriage metered data

Realigning the Customer's Energy Pain

After the data analysis was complete, the energy consultant prepared charts to assist the customer in understanding the energy operation of this system. It is important to note that most customers do not view their kW data every day. The energy consultant annotates his charts so that customers can see and understand the message that the charts present—and hold on to that evidence long after the energy consultant departs the premises. Figure 7 shows the charts the energy consultant presented to Mill River Lumber. He estimated the accelerating and decelerating data, according to the carriage motor analytics. Upon presenting this evidence, the facilities manager and the financial manager immediately understood that the idle times for that equipment represented 10% of their plant's kW load, and recognized the implications of this system—however reliable—on their operating costs.

Customers are frequently surprised to learn where their energy is being consumed. It is not necessarily the largest motor that consumes the most energy; it is actually the motor with the largest kW load, in combination with long run hours.

Figure 7. Carriage System Analytics Presented to the Customer

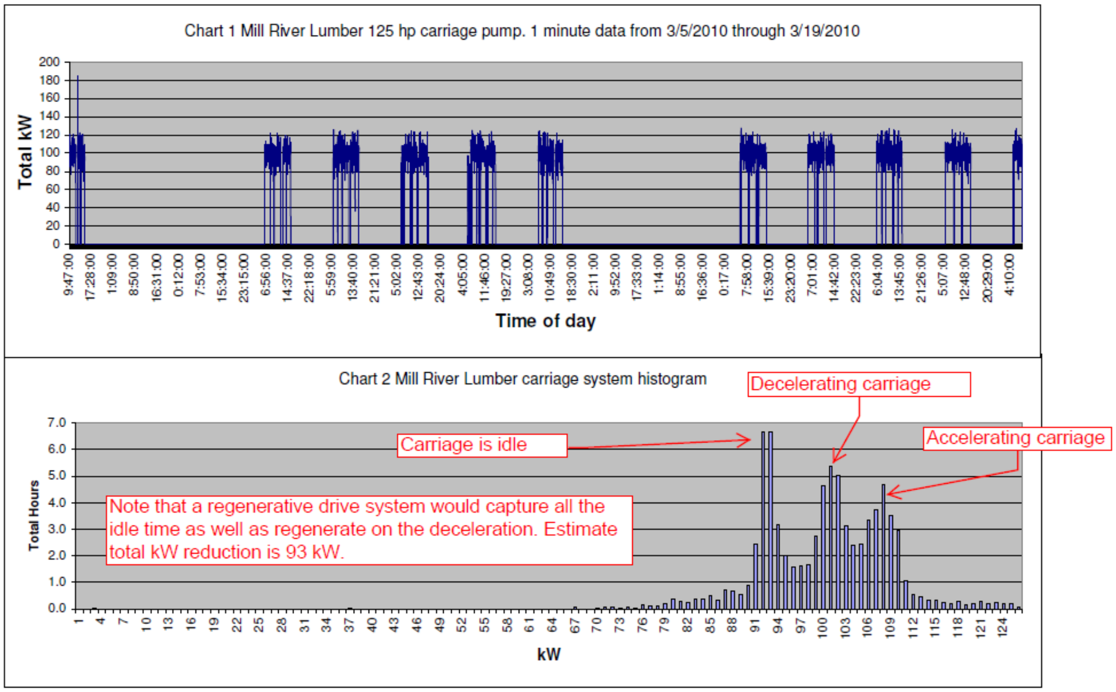


Chart 1 Notes:
This is a graph of the measured total kW. The total on time is 80.9 hours. The average kW is 100 kW. See 3 second data for additional info.
Chart 2 Notes:
Note the three peaks in this distribution. These peaks are not associated with the wood being sawn or you would see similar peaks on the head saw distribution. My best analysis is the first peak is when the carriage is idle. Idle time is total of 13.2 hours. The second and third peak are associated with accelerating and decelerating the carriage and product. With accelerating requiring more energy than decelerating.

Source: Efficiency Vermont

Advantages to Production

The energy consultant proposed a regenerative drive system for a replacement motor on the carriage. This system incorporates a 150-hp inverter duty motor controlled by a variable frequency drive system. The load on the system is ~2 kW when the carriage is idle; the required energy to accelerate is drawn only during acceleration; 8 kW is then input to move the log through the saw blade; and finally carriage deceleration helps regeneration by feeding carriage kinetic energy back onto the grid. The estimated energy and demand savings are compared to actuals in Table1.

Table 1. Comparison of Metered Consumption to Estimated Energy Savings

Description	Pump and Fan kWh	Load in kW
Existing equipment, before energy efficiency (metered)	213,246	103.7
Estimated annual energy savings, based on motor data analytics	198,610	96

The cost of the retrofit was estimated to be $137,490; with incentives, the simple payback was calculated at 4 years.

Although this seems like an attractive investment, production managers very understandably are reluctant to retrofit acceptable operating production equipment for energy savings alone. Any production downtime can quickly offset the financial gains achieved from having implemented an efficiency measure. However, information about additional non-energy benefits associated with this new equipment revealed the possibility of: (1) greater control of the log-sawing process, from more finite carriage speed control offered by the regenerative drive over the existing hydraulic system; (2) increasing the quality and quantity of product through the more finite speed control; and (3) reducing downtime from carriage bumps into the band saw blade, through the increase in speed control (carriage bumps occur mostly while sawing frozen logs during winter operation).

Fortunately for this project, the saw operator is also a principal owner in the business. He spoke to the energy consultant about the merits of the proposed project, and then traveled to another state to observe and operate a carriage equipped with a regenerative drive system. Seeing the equipment in action effectively sold him on the system; the energy efficiency cost savings financed the measure.

Post-Installation Measurement and Verification

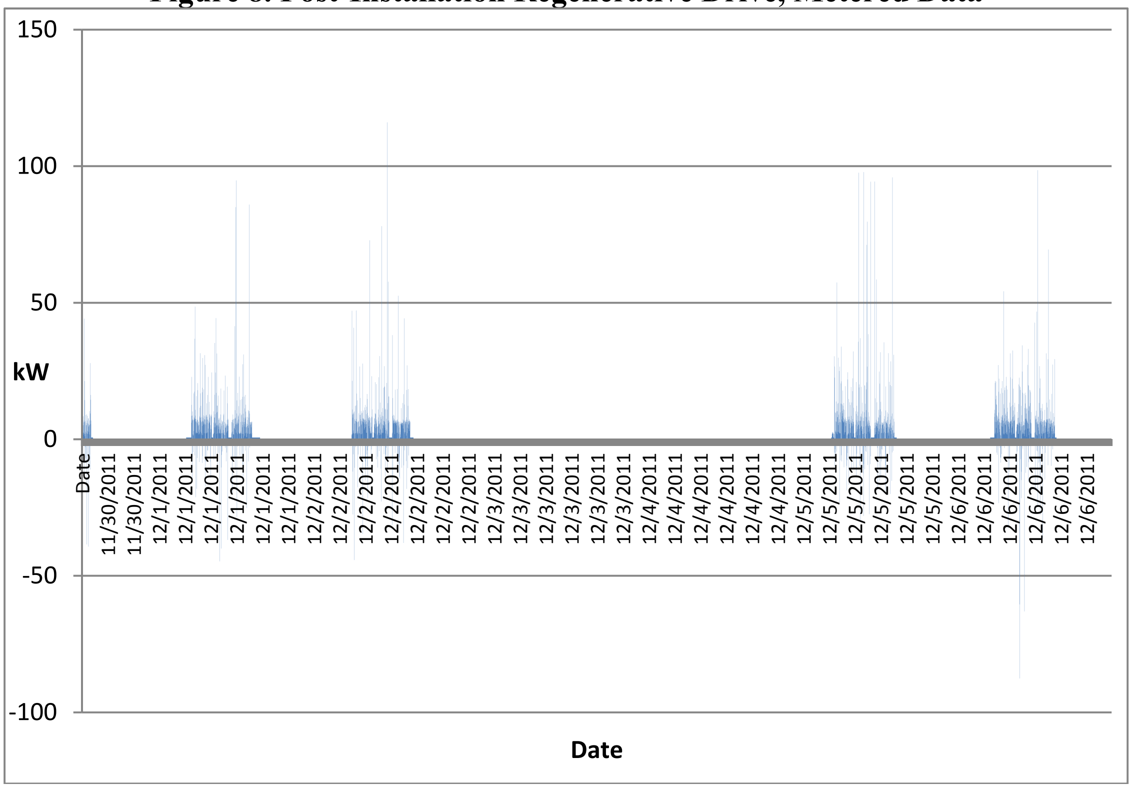
The sawmill purchased and installed the equipment. Figure 8 presents metered verification of savings from the installed regenerative drive. The average load is 6.6 kW with an estimated annual consumption of 13,566 kWh. Table 2 summarizes pre and post-retrofit energy consumption and kW demand.

Table 2. Estimated Annual Energy Consumption before Installation, and Estimated Annual Savings after Installation

Description	Pump and Fan kWh	Demand or Demand Reduction in kW
Existing equipment before energy efficiency	213,246	103.7
Estimated annual energy savings, based on motor analytics pre-retrofit	198,610	96
Post-installation annual consumption based on measured motor data analytics.	13,566	6.6

Description	Pump and Fan kWh	Demand or Demand Reduction in kW
Actual difference between existing equipment's energy consumption before efficiency measure and measured energy consumption after installation.	199,680	96.8

Figure 8. Post-Installation Regenerative Drive, Metered Data



Source: Efficiency Vermont, from Mill River Lumber regenerative drive system meter data

Although the data show asymmetry about the horizontal axis, they accurately depict the new reality. The test equipment captures one 60-cycle waveform, 15.7 milliseconds every minute. The large spikes are likely indicators of acceleration. The energy to push the log into the saw blade is always positive, regardless of the direction. The negative spikes occur only on deceleration, when the motor is driven by the carriage momentum and regenerates electricity. The deceleration spikes will always be smaller than the acceleration spikes, because the measurement is made at the input of the variable frequency drive. Therefore, all the energy input includes losses from the variable frequency drive, the motor, gearbox losses and carriage frictional losses. When regenerating, the carriage drives the motor; the energy starts from the carriage momentum; some of the energy is lost through carriage friction, gearbox losses, losses from the motor acting as generator, and electronic inverter losses. The measuring equipment measures the remaining energy.

Additional Analytics Example

Data analytics have significant potential for uses beyond this particular process case study. The load duration histogram approach can be used for pumping systems, too. An existing pump system operated in the following manner: Fluid was either directed through a process, or the process was bypassed and the fluid re-circulated to a holding tank. During the process circulation mode, the fluid volume was controlled with a control valve. The motor was always started and shut down while the pump was in bypass mode.

The energy efficiency measure installed was a variable frequency drive to control flow during the process, to slow down the pump during bypass, and to control starts on the pump. Metered data at motor start revealed a 53 kW demand immediately following start-up. A load duration histogram indicated the number of hours in which the motor was operating at this load. The energy consultant used pump curves to estimate motor load at lower pumping speed, during bypass. The result: substantial energy savings and a relatively short payback period.

Similar to the sawmill operation, the owner's perceived risk to production was a major barrier to implementing the measure. However, production personnel recognized an advantage to production: less downtime occurred from piping leaks if pumps were soft-started with a variable frequency drive, instead of across the line. The decrease in downtime moved the project into the active list, while energy efficiency cost savings were the main reason for going ahead with the project.

Conclusion

When experiencing difficulties implementing energy efficiency measures in an industrial production facility consider: Energy Cost can be a small part of total production cost and the risk to production output from equipment changes can be perceived as high. To overcome these barriers consider:

- Measure the equipment kWh consumption.
- Apply data analytics to understand the energy consumption profile.
- Understand the weaknesses of existing equipment.
- Discover the production advantages of new equipment.
- Present the data analytics and equipment weaknesses / advantages, with simple, well annotated visual aids. Leave multiple copies with plant personnel. These visuals will be referenced when your presentation is forgotten.