



## **Using undergraduate engineering students to develop practical methods for reducing energy costs at a grain receiving, storage and transfer facility based on an energy study in the State of Michigan**

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Robert Fletcher joined the faculty of the Mechanical Engineering Department at Lawrence Technological University in the summer of 2003, after two decades of various industry engineering positions in research, and product development.

Dr. Fletcher earned his Bachelor of Science Degree in Chemical Engineering from the University of Washington, in Seattle, and the Master of Science and Ph.D. degrees in Chemical Engineering, both from the University of Michigan.

He teaches a number of alternative energy courses at Lawrence Tech. Dr. Fletcher and his student research team is focusing on energy usage and efficiencies of several traditional and alternative energy systems.

## **Using undergraduate engineering students to develop practical methods for reducing energy costs at a grain receiving, storage and transfer facility based on an energy study in the State of Michigan**

**ABSTRACT:** This paper is a continuation of work presented at the 2014 American Society of Engineering Education Annual Conference and Exposition. Here the author provides a brief summary of the work undertaken from the spring of 2012 into 2014 by Lawrence Technological University in conjunction with DTE Energy (the parent holding company of the local utility company) to have students and faculty undertake an applied research project with the Michigan Agricultural Commodities, Inc. (MAC) to undertake an energy assessment of the MAC Marlette, MI facilities. MAC is a private company in the business of buying, selling, storage and distribution of agricultural commodities such as corn, wheat and other grains, dry beans and edible soya beans. Rising utility costs and fixed commodities prices necessitated the need for a concerted effort by MAC to reduce their energy costs. The previous 2014 ASEE Annual Conference and Exposition presentation focused on how the project was organized, managed and carried out with undergraduate engineering students, with a detailed discussion regarding student benefits and educational content of the effort. No data, however, were presented. This paper presents examples of representative test data from that effort and document and quantify specific energy savings opportunities learned in this project.

Included in the paper are a discussion of energy reduction strategies and good energy management practices using various technology options, such as variable frequency drives (VFDs). Also included are improved operational procedures and approaches that were implemented that helped develop energy awareness for operators and that could change energy wasting practices.

Lastly, a discussion is presented on how improvements could be implemented at the facility with specific lessons learned on how to develop a practical and realistic strategy to save energy at this facility. The undergraduate engineering student who were part of this project had significant opportunities for learning in virtually all areas of the effort. A summary of student benefits is also listed, with how students were able to interact with other business personnel, and technical specialists.

### **1) Background:**

This paper is a continuation of work initially documented in the proceedings and also presented at the 2014 American Society of Engineering Education (ASEE) Annual Conference and Exposition. Only a summary of the work undertaken from the spring of 2012 into 2014 by Lawrence Technological University in conjunction with DTE Energy (the local utility company) and the Michigan Agricultural Commodities, Inc. (MAC) Marlette, MI facilities is presented here. The previous 2014 ASEE Annual Conference and Exposition presentation focused on how the project was organized, managed and carried out with undergraduate engineering students, with a detailed discussion regarding student benefits and educational content of the effort. No data, however, were presented in that previous paper. For a significantly more detailed description of this project and its educational content it is suggested that the reader review the paper written by the author in the 2014 ASEE Annual Conference and Exposition proceedings.<sup>(1)</sup>

To briefly review, in the spring of 2012 Lawrence Technological University was approached by the local utility company, DTE Energy, with funding from its Energy Optimization Pilot Programs group to have students and faculty work on an applied research project with Michigan Agricultural Commodities, Inc., to undertake an energy assessment of the MAC Marlette, MI facilities. DTE Energy wanted to investigate the situation and provide energy usage data to facilitate the possible implementation of new incentives for the agricultural community in Michigan. DTE Energy was also interested in balancing the electric power utility distribution load in the predominantly rural area where the MAC Marlette facility is located.

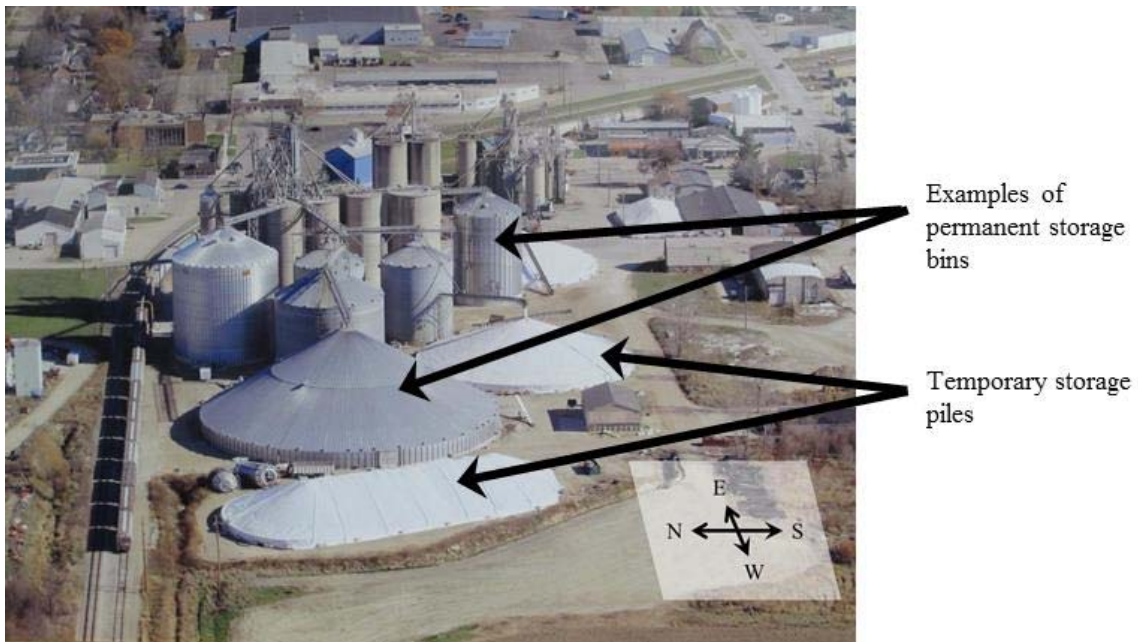
Michigan Agricultural Commodities (or MAC) is a privately held, for-profit corporation that purchases, sells and stores agricultural commodity grains (primarily corn, soybeans, and wheat) throughout the United States and Canada. MAC is Michigan's largest grain handler with 8 locations in Michigan at Blissfield, Breckenridge, Brown City, Jasper, Lansing, Marlette, Middleton, and Newaygo. Michigan Agricultural Commodities does not produce flour or undertake any other grain milling or processing. Rising utility costs and fixed commodities prices necessitated the need for a concerted effort by the MAC to reduce their energy costs.

Lawrence Technological University is located in Southfield, Michigan, two miles directly north of the City of Detroit, and was founded in 1932 with direct assistance from Henry Ford. This close proximity to the “motor city” has created a long-standing affiliation with the automotive industry and to the industrial base supporting the design, development and manufacturing of wheeled vehicles. Detroit Edison, the primary electric utility supplier in Southeast Michigan is wholly owned subsidiary of DTE Energy. The Detroit Edison/DTE Energy service area extends up to the central part of the “thumb” of Michigan, and to the MAC Marlette, MI facilities. Over the years Lawrence Tech has collaborated with DTE Energy on numerous projects, and DTE Energy is one of the largest employers of Lawrence Tech alumni in the State of Michigan. For this project engineering students served as part-time paid employees of the university working under the direct involvement and supervision of university faculty.

There were two major phases for this project. Phase 1 concentrated on establishing a reliable and useful power and energy usage data acquisition capability, and also the testing of grain hopper aeration and drying fan systems both with and without the use of variable frequency drive power regulators at Lawrence Technological University. Phase 2 involved a full energy assessment of the MAC, Marlette facility including grain receiving, grain drying (which uses electric and natural gas), and outdoor temporary grain storage piles. Work on this project was conducted from the early summer of 2012 through the late fall of 2013. A comprehensive report was written and submitted to DTE Energy’s Energy Optimization Pilot Programs group. This report is titled “DTE Energy – Lawrence Technological University – Michigan Agricultural Commodities Energy Assessment of a Grain Storage and Transfer Facility Project”, and is dated December 15, 2014, revised January 16, 2015, by Robert W. Fletcher. Copies of this report can be obtained by request from the Energy Optimization Pilot Programs group of DTE Energy’s Energy.

## 2) The Michigan Agricultural Commodities facilities in Marlette, MI:

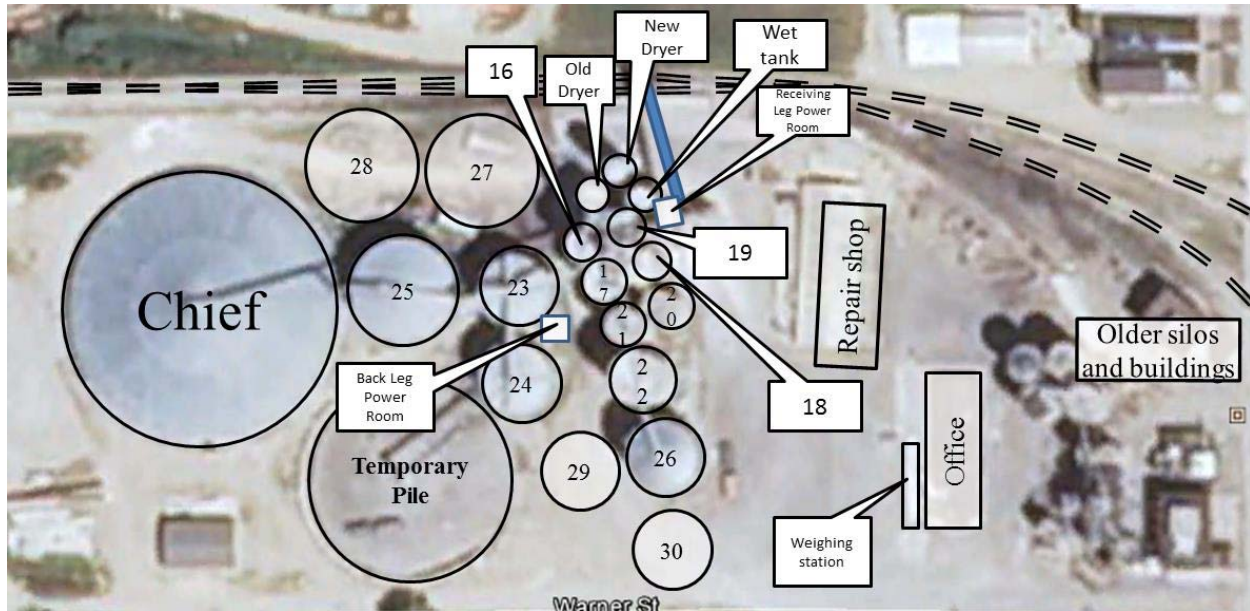
The Michigan Agricultural Commodities facilities in Marlette, MI primary-use storage facilities are located towards the rear of the property. The MAC facilities has a rail spur that allows transfer of stored grain directly into rail cars that can then be transported by rail train for distribution around the United States, or even abroad. The MAC Marlette facility has sixteen permanent storage bins in their primary-use storage area for a total storage capacity of 3.754 million bushels (4.693 million ft<sup>3</sup>) of grain. The facility can also accommodate an added 1.055 million bushels (1.319 million ft<sup>3</sup>) of temporary pile storage. See Figure 1 below showing an aerial view of the facility looking east. Grain is primarily received from local farmers at the Marlette facility in trailers pulled by trucks or tractors. There are two receiving stations. The first is the front receiving station that allows grain dumps to the “front receiving pit” that transfers grain to the front receiving leg for routing to any of the permanent grain storage bins on the site. The second is the back receiving station (located towards the rear of the facility) where grain can also be dumped into its own receiving pit that also allows grain to be distributed to all storage bins on site.



**Figure 1:** An aerial view looking east of the Michigan Agricultural Commodities facilities in Marlette, MI prior to addition of bins 28, 29, 30. Permanent storage bins and temporary storage files are indicated. The rail spur with train cars on it is located on the north side of the facilities (left side of the photo).

Figure 2 below, taken from Google Earth, shows a second aerial view of the Marlette facility. The various storage bins are indicated by number or name. The “Chief”, as labeled in the photo, is a cone-shaped grain storage bin with a capacity of 950,000 bushels. The “Temporary Pile” in the lower center of the figure is used for the transient temporary storage of grain for a few weeks or longer, until it can either be sold or transferred into a permanent on-site grain bin. In the summer of 2013 the MAC erected two new permanent grain storage bins and are indicated as #29 and #30 in Figure 2 below with capacities of 225,000 and 310,000 bushels respectively.

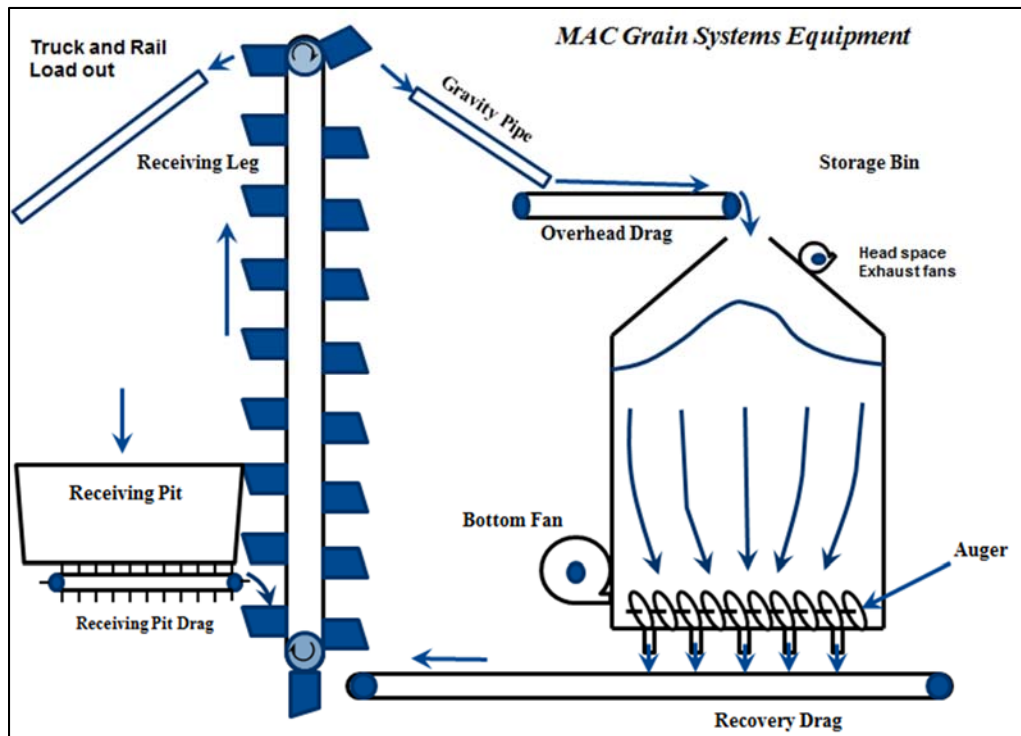
The grain delivery by local farmers has been extensively discussed previously and is not reviewed here.<sup>(1)</sup> If the grain evaluation at receiving indicates that the grain is not dry (above 16% to 16.5% moisture by weight) the grain can be routed to a bin for later drying, or it can be sent directly to the grain dryer.



**Figure 2:** A second aerial view, copied from Google Earth, of the Michigan Agricultural Commodities facilities in Marlette, MI. The top of the photo is north. Each permanent bin or facility system is identified by number or name. The dashed line drawn shown in the upper portion the photo shows the position of the rail spur with a split for train car short term holding. The weighing station, facility offices, and older grain storage facility are to the lower right in this image. Bins 29 and 30 are drawn into this photo and postdate the Google Earth image used here.

The grain drier (a Brock® dryer, installed in 2008, and heats at 45 million BTU’s per hour) is a tall cylindrical structure that intakes outside-air at the bottom of the unit, and heats that outside-air using a natural gas burner and blows the heated air into the dryer to dry the grain. Once dried, the grain can then be routed to longer term storage bins, or temporary bins, as needed. For shipping the target moisture must be between 15% and 15.5%. The 0.5% to 1.0% moisture difference from dryer-processed grain to the targeted shipping moisture percentage can usually be removed later during storage by aeration of the grain in the bins. Figure 3 below shows a diagrammatic illustration of the major grain handling operations and storage systems at the Marlette facility.

It is important to note that all grain received at the Marlette facility is handled at least twice, once at receiving for storage, and once again for sale and shipment. In some additional instances grain can be mixed with similar grain in other on-site bins. This involves yet another handling of the grain. Repeated or excessive handling and movement of the grain is undesirable because this can cause damage to the individual kernels of grain, which lowers the dollar-value of the grain.



**Figure 3:** This diagram shows the major equipment components used at the MAC Marlette facility.

The predominant electric energy consumption at the Marlette facility is from the operation of electric motors for the operation of fans, legs and drags. All legs and drags electric motors are powered using 480 VAC delta connections. No motors in Marlette use a 240VAC wye-start that switche to a 480 VAC delta-run mode.

Once the grain has been routed to its initial storage destination within the MAC Marlette facility it can be routed to three other on-site destinations. These are 1) to the dryer if it is initially received with moisture above 16%; 2) to a longer-term storage bin, if dry; 3) if additional foreign materials are present then it can be blended with other similar grain with lower foreign material levels to meet sale specifications. The final disposition of all grains at the MAC Marlette facility is to be sold to external customers. This process has been previously documented in detail.<sup>(1)</sup> Minimal handling and movement of grain at the facility is always desired. Excessive grain transport can have two financial impacts. First each grain movement activity can cause damage to the grain. Such damage is undesirable because it negatively impacts the quality of the grain and, thusly, lowers the value of the grain. Second, additional grain movement requires electric power use to energize motors for drags and legs.

### 3) Electrical Systems Data Collection:

The first place to start in any energy assessment process is with a detailed review of energy usage through the review of historical utility billings for the Marlette site. On-site power meters were documented and multipliers were cross-checked with utility billing invoices. The Marlette facility has five power meters. These meters are noted in Table 1 below indicating meter number location

at the facility and their respective multiplier and are pictured in Figure 4 below. Figure 5 below shows the areas each meter services at the Marlette facility. A two year plot of power usage from the two main facility meters is also provided in Figure 6 below.

**Table 1:** The MAC Marlette utility meters for tracking ad billing by DTE Energy.

Meter number	Location	Multiplier
1409536	Facility offices	1
9302056	Work shop	80
1699986	Older silos	120
9413322	Front receiving leg power	240
6030724	Back-leg receiving	204

An additional area of review for energy usage at the MAC Marlette facility was their natural gas consumption. The Brock grain drier uses natural gas to heat ambient air that is forced through the unit to dry overly moist grain. Grain dryers are critical to prevent commodity spoilage and to meet customer moisture limits upon sale. The Brock drier does have controls and monitoring systems, but for efficient operation proper maintenance and cleaning of vents and inlets are required. These require operator training to assure best operation of the unit. One area of possible prediction of natural gas usage for the grain dryer at the MAC Marlette facility could be the tracking of the local area’s relative humidity just before and through the harvest season.

Table 2 below shows data for the years 2008 through 2012 showing grain moisture and natural gas usage. Figure 7 shows a plot of the upper central “thumb” area’s average hourly relative humidity for the harvest period from early August through the end of November for each corresponding year. These relative humidity data are taken from the Enviro-weather Automated Weather Station Network for the State of Michigan (as tracked and operated by the Michigan State University Extension at <http://www.agweather.geo.msu.edu/mawn/> ) for the Lapeer weather tracking station. The Lapeer automated weather station is approximately 22 miles from Marlette and on average sees comparable weather to the MAC facility in Marlette.

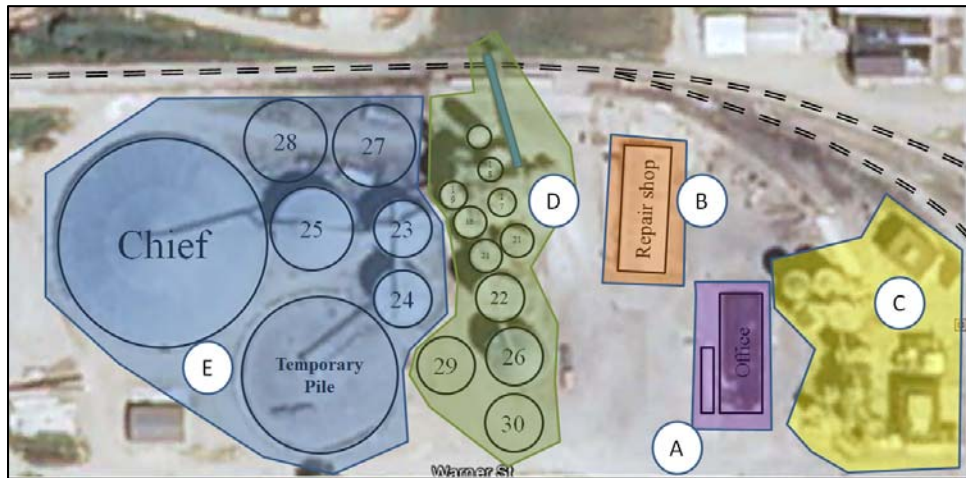
As can be seen in Figure 7 there is reasonably good correlation to average hourly relative humidity and the need for natural gas usage to dry grain. Tracking this over time during the harvest season by MAC Marlette personnel could be a useful predictor for the demand on the dryer, to anticipate personnel support and system maintenance, as well as the obvious natural gas demand.

**Table 2:** Recent yearly moist and dry grain compared to natural gas usage

Year	% Grain Moisture	Wet bushels	Dry bushels	% Wet Bushels	Thousands Cubic Feet NG
2008	20.28	1,120,359	1,027,046	0.521726922	10,246
2009	24.56	1,190,074	1,022,527	0.537862	15,954
2010	17.82	1,105,682	1,052,527	0.512314609	2,257
2011	21.25	981,186	886,728	0.525284355	8,951
2012	20.25	1,429,766	1,312,047	0.521467365	9,073

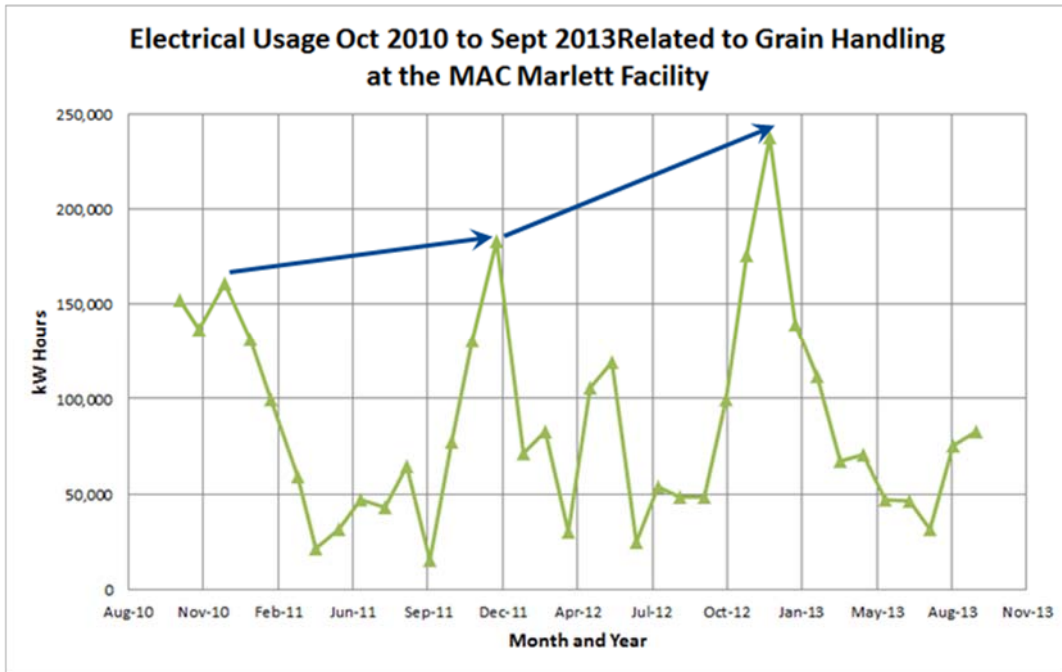


**Figure 4:** The five on-site power meters tracking electrical usage for billing by DTE Energy at the MAC Marlette facility. Meters (A), (B) and (C) are meters for the site office building, the work shop and the older silos used for specialty storage needs respectively. Meter (D) #9413322 tracks electric energy usage at the front area of the facility and meter (E) #6030724 tracks electronic energy usage in the back-leg receiving area of the facility. These two latter meters track the bulk of the energy usage at the Marlette facility. These meters provide power service to the areas indicated in Figure 5 below.



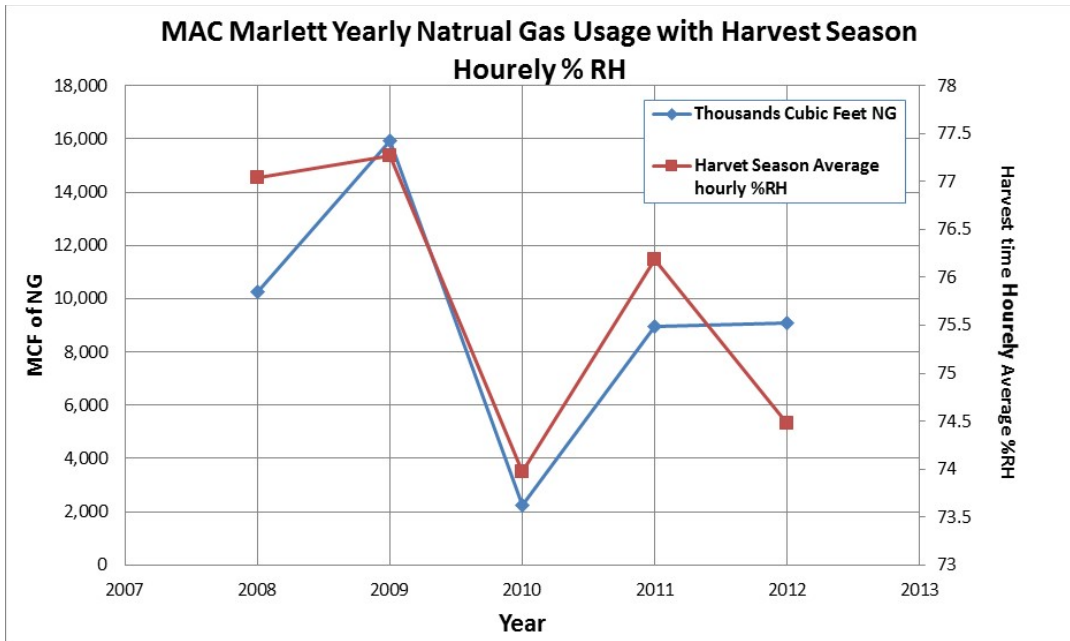
**Figure 5:** The five on-site power meters indicated in Figure 4 above provide electrical service to the areas indicated in this Google Earth photo. Meters (A), (B) and (C) are meters for the site office building, the work shop and the older silos used for specialty storage needs respectively. Meter (D) #9413322 tracks electric energy usage at the front area of the facility and meter (E) #6030724 tracks electronic energy usage in the back-leg receiving area of the facility.





**Figure 6:** The energy usage from October 2010 through September 2013 at the MAC Marlette facility. These data show that peak demand at harvest time is growing each year at Marlette, and off-harvest-time grain transfer, storage and handling energy usage is also growing each year.

For this project the on-site data collection needed to be accomplished with a portable, robust and reliable electric power and energy data acquisition (DAC) system. Initially it was thought that a small portable DAC system using a laptop and custom assembled current transducers and voltage sensors could be developed at Lawrence Tech. But after seeing the facilities and need for out-door data collection, it readily became apparent that such an approach was not at all practical. It was decided that the Fluke 435 II three-phase power quality and energy analyzer portable power meters were best suited for the project. See Figure 8 showing the showing a Fluke 435 II unit and also in use at the MAC Marlette facility. Five of these units were purchased from TEquipment.NET, of Long Branch, NJ.



**Figure 7:** Comparative plots of the MAC Marlette yearly natural gas usage for grain drying compared to the harvest season’s hourly average percent relative humidity for each year. There are other factors, but grain dryer natural gas usage tends to follow air moisture at the time of harvest, and will increase with this facility’s growing grain handling volume capabilities.



(A)



(B)

**Figure 8:** (A) shows a close-up picture of the Fluke 435 II Power Quality and Energy Analyzer meter display and control buttons; (B) shows one of the Fluke 435 II power monitoring meters in use in one of the electrical power rooms at the MAC Marlette facility. These meters monitored both current and voltage and record each value four times per second. Data storage was a function the size of the SD card contained in each meter.

#### **4) Possible technology options and applications at Marlette:**

The MAC Marlette facility uses three-phase AC induction motors for its drags, legs and fans. Few of these motors need to be left on at full power, and could often run at reduced speeds at various process times without any detriment to product, process or productivity. Because of this it was natural to investigate possible motor control options for the facility. The options are discussed below.

##### **4.1) Wye-start to delta-run starting option:**

A wye-start to delta-run starting option (or wye-delta starting) has been employed for many years in industry and is used to reduce the significant current inrush encountered when starting AC motors, especially large motors. For such motors these uncontrolled inrush currents can be significant. This current inrush induces significant stress on motor components and the resulting instantaneous loading of motor components and related connected hardware can eventually cause permanent failure. An option to help control this is by using a wye-start to delta-run starting option. In this option a motor is connected in an electrical “wye” configuration for initial starting and then with an electromechanical device is switched to a “delta” wiring configuration for run mode. Wye-delta starting, though an improvement over on/off motor starting in reducing high in-rush currents for large motors, does not eliminate it. Wye-delta starting is not used at the Marlette facility, and was not considered for use in the Marlette facility.

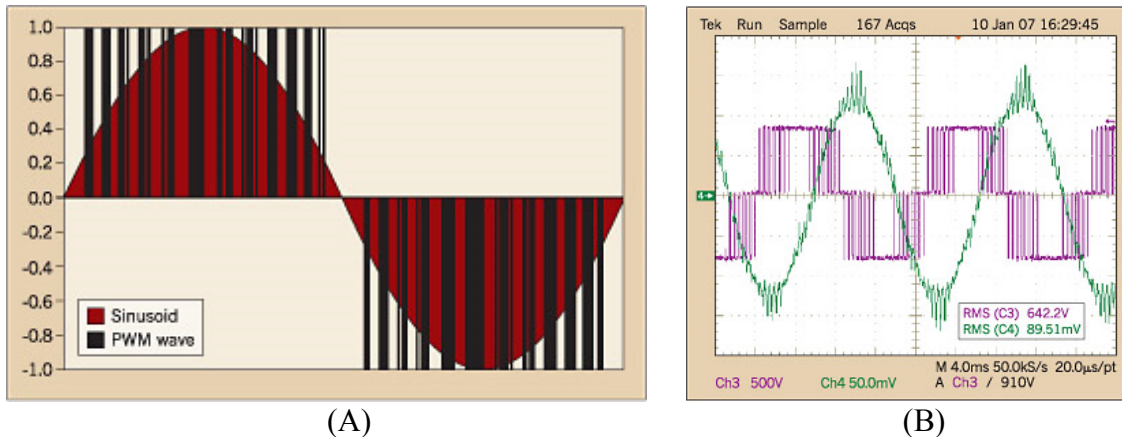
##### **4.2) Soft-start controllers:**

A soft-start controller is an electronic solid-state device placed upstream from an electric motor that ramps up the power to the motor using a programmable ramp rate so as to eliminate any significant current draw upon start-up of the motor. They operate by gradually ramping up the voltage to the motor over a programmed starting time, permitting smooth starting of the motor and eliminating high in-rush currents to the motor when starting. Most soft-start devices also have a soft-stop option which reduces the voltage to the motor over the programmed stopping time. Soft-start controllers are good for motors that undergo frequent starts and stops, and especially when the motor is under load when started. They are best for motors that do not need to immediately come to full speed, and where the motor can tolerate ramping up to speed over several seconds without detriment to the process. This can help reduce significant wear-and-tear on the motor and other connected process equipment. The MAC Marlette facility has soft-start controls on the two 125 horsepower motors in the Brock® grain drier there.

##### **4.3) Variable frequency drives:**

There are numerous on-line references, as well as scholarly and technical literature documenting in great detail the operation and functionality of variable frequency drives (typically used for fans and pumps) and variable torque drives (typically used for conveyors and drive systems with fluctuating loads).<sup>(2-11)</sup> There are four basic types of variable frequency drives commercially available today. These include pulse width modulation (PWM), current source inverter (CSI), and voltage source inverter (VSI), and the flux vector drive.<sup>(5)</sup> The devices used in this study, and the most commonly used in industry, were PWM VFDs, and are the focus of the discussion here.

These devices operate using a standard 50 Hz or 60 Hz AC power input and through power signal processing manipulate the frequency of their output by rectifying an incoming AC current into DC to provide a fixed-voltage pulse width modulated (PWM) output signal to a motor. VFDs are able to very accurately control the speed of standard AC motors, providing speed control with full torque ranging from 0 rpm through the maximum rated speed of the motor. VFDs can also deliver speeds above the rated speed, but at a reduced torque. Adjusting the frequency of the output signal to the motor under varying motor loads can result in significant energy savings. Figure 9(A) below illustrates a typical sin-wave utility grade AC input signal with a PWM signal superimposed on the sin wave. Figure 9(B) shows a sin wave with a typical VFD signal superimposed on it.



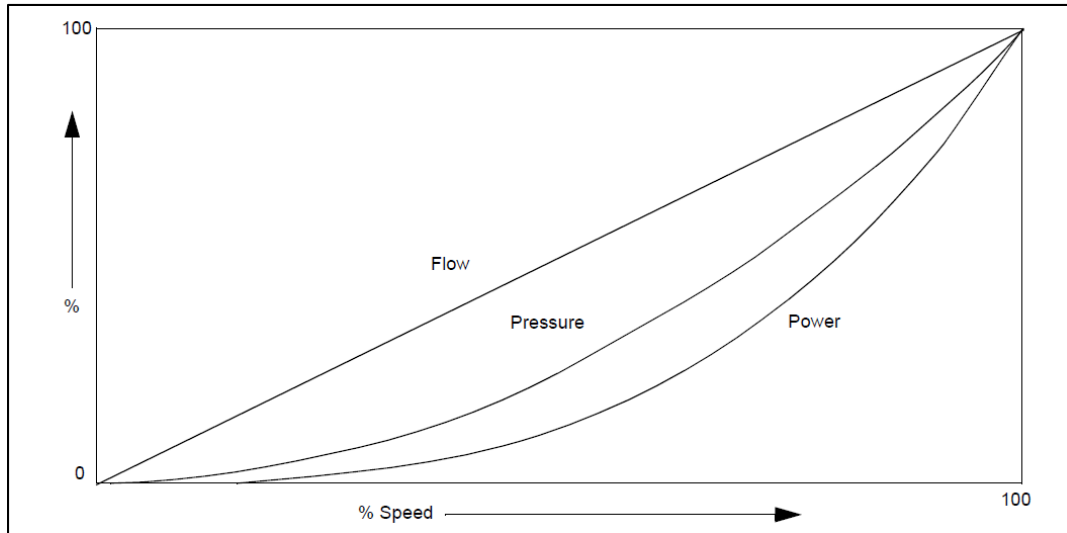
**Figure 9:** (A) A representative illustration of the standard utility-grade AC sin wave signal (the dark maroon colored area) and how an ideal VFD pulse width modulated (PWM) output signal might be represented. (B) An illustration of an actual sin wave and PWM signal. Note the signal noise (harmonics) at the peaks of the sin wave which often occurs with unregulated VFDs. Illustrations are from ecmweb.com.<sup>(3)</sup>

The basic equation for a 3-phase electric motor is:

$$\text{Motor shaft speed} = \frac{(120 \cdot F)}{(\# \text{ of poles in motor})}$$

The value “120” is an electrical constant,  $F$  = AC power frequency into the motor (typically 60 Hz in North America), and the “# of poles in motor” is a fixed value determined by the design of the motor itself. Also, AC electric motors run most efficiently when well loaded. Slowing the motor places more load on the motor and therefore will more efficiently use the energy delivered to it. The only way to vary the motor speed is to change the value of  $F$  in the equation. This change in motor speed can easily be obtained using a Variable Frequency Drive (VFD).

The theoretical relationship to motor speed and energy are best illustrated by Figure 10 below and the relationship to what are known as the Affinity Laws for a pump or a fan.



**Figure 10:** Represents the relationship of the percentage of motor speed to the percentage of fluid flow rate (for a pump for liquids or for a fan for air), pressure delivered, and power (y-axis) required by a motor.<sup>(12)</sup>

The Affinity Law equations are provided below and show that under theoretical ideal conditions the flow of a fluid or gas is linearly related to the speed, but the ratios of pressures are the square of the ratios of the speeds and the ratios of power are the cube of the speed ratios...

$$\frac{Flow_2}{Flow_1} = \frac{Speed_2}{Speed_1}; \quad \frac{Head\ Pressure_2}{Head\ Pressure_1} = \left(\frac{Speed_2}{Speed_1}\right)^2 \quad \text{and} \quad \frac{Power_2}{Power_1} = \left(\frac{Speed_2}{Speed_1}\right)^3$$

Where the subscripts refer to two different operating conditions for the motor with state 1 being at a lower speed than state 2.

So as illustrated in Figure 10 above, a small reduction in speed (by adjusting the frequency received by the motor through a device such as a VFD) can result in a sizable reduction in power consumed by the motor, especially in the mid-speed ranges of the motor. In many industry applications a motor does not need to be run at full speed in all situations, as would only be the case for a fixed 60 Hz utility-power connection without any PWM system such as a VFD.

To relate power (in kilowatts) to current and voltage in a three-phase AC system we use the equation provided below:

$$kW = \left( \frac{V_{avg} \times i_{avg} \times \sqrt{3} \times (\text{power factor})}{1000} \right)$$

Where  $V_{avg}$  is the RMS voltage (this is ultimately controlled by the square-wave frequency output of the VFD), and  $i_{avg}$  = RMS current in amperes. "Power factor" is the term for a phenomenon encountered with alternating current and electrical components (such as coiled wires, or devices that store charge and act like capacitors) that can create what is known as a reactive impedance. These reactive impedances (or reactive resistances) are important to understand with AC power

and are essentially not encountered in non-transient DC circuitry. Coiled wire, such as in motor windings, induce an inductive reactance impedance. Computers and other advanced digital circuitry can induce a capacitive reactance impedance. These reactive impedances cause the AC current to be offset from the AC voltage. The offset can either lead the voltage, as with capacitive reactance, or to lag the voltage, as with inductive reactance. The offset between AC current and AC voltage is measure in terms of phase angle.

Power factor, by definition, is the trigonometric function the cosine of  $\theta$ , or  $\cos(\theta)$ , where  $\theta$  is the phase angle between the AC current and the AC voltage. Power factor has a value between zero and one. Many industrial components induce some type of power factor into a circuit, which can have negative impacts on power coming in from the mains (or grid). Electric utility power providers do not want low power factor componentry at end-user's facilities because they must make up for the difference between apparent power and real power. So power factor is of real concern for utility power providers. The attractiveness for VFDs are that at reduced speeds equipment, such as motors, tend to run at higher load at those reduced speeds, resulting in higher power factors.

Most VFDs also now have soft-start capabilities that eliminate virtually all start and stop current spikes, which can be eight to ten times that of the stable steady-state operating current for a given motor. Thus, there are several benefits to a properly sized and controlled VFD. Variable torque drives (VTDs) operate in similar ways, but control the given torque of a motor, as opposed to speed. VTDs are best used with motors that encounter sizable load fluctuations in abrupt or short time spans. The torque control adjusts for these load induced torque variations and allows the motor to run at a controlled speed based on torque, so as to optimize (and balance out over time) energy consumption.

#### **4.3.1) Precautions when using VFDs:**

There are precautions that one must take when using variable frequency drives. As will all equipment, one must exercise caution when considering and installing a VFD to control a motor's speed. Using a VFD does not automatically guarantee energy savings, and in cases where the VFD is incorrectly specified it may increase energy usage, and in worst cases could even cause damage to a motor, or other related equipment. These precautions are outlined in detail in the previously mentioned report titled "DTE Energy – Lawrence Technological University – Michigan Agricultural Commodities Energy Assessment of a Grain Storage and Transfer Facility Project", and are only briefly listed here for general reference.

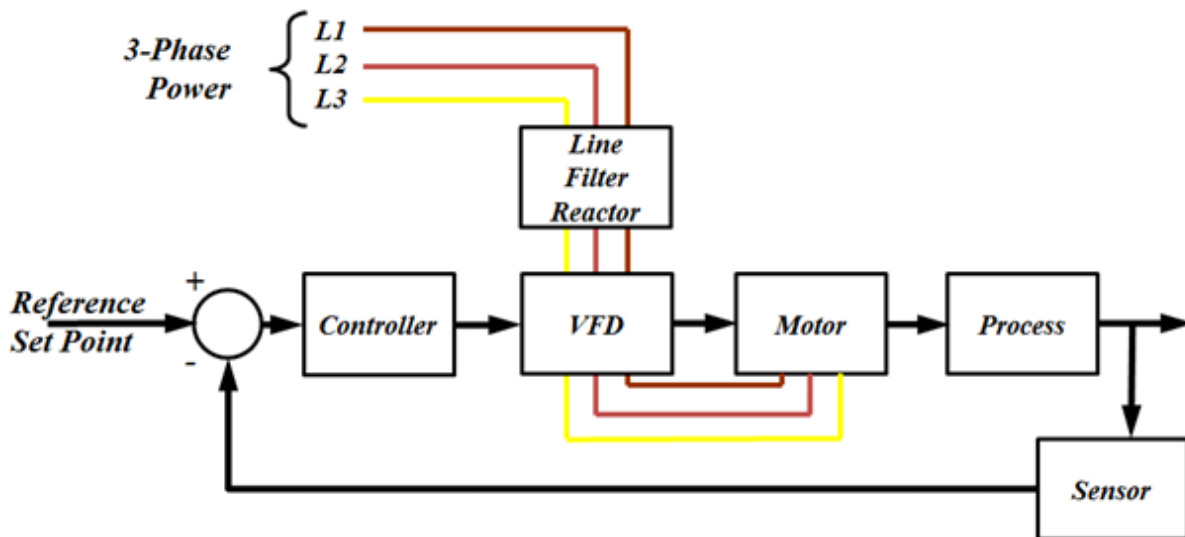
Matching a VFD to an existing motor in a given application requires great care. There are a number of precautions that must be considered, as well outlined by Manz.<sup>(13)</sup> With VFD outputs the fundamental frequencies can change and possibly match the various resonant frequencies within the motor or hardware. These can produce noise or equipment vibrations. VFDs can cause bearing problems within the motor caused by bearing current and also static discharge. These can produce pitting on the race and ball surfaces eventually causing the bearing to make noise, develop vibrations, and eventually possible bearing failure. VFDs can introduce circuit harmonics that can be signals sent back up the line side of the VFD causing overheating of buses and cross-talk between the VFD circuit and other circuits.<sup>(3)</sup> Peeran has provided a good summary of key points

to consider when matching a motor with a VFD.<sup>(14)</sup> Matching motor and VFDs input and output voltage, current, power factor, and frequency must be carefully considered.<sup>(15, 16)</sup> Using a VFD that has too low a horsepower rating (or is under-sized) will usually result in the VFD shutting down due to its internal circuit protection. Significantly over-sizing a VFD to a given motor also has potential problems and knowledgeable industry representatives recommend against it. Various industry specialist are now also recommending that attention not only be given to proper matching of the VFD to the motor, but also matching of the of the VFD to a properly shielded cable running to the motor.<sup>(17)</sup>

#### 4.3.2) Control of variable frequency drives:

VFD systems are versatile and can lend themselves for use in many different motor control applications. The latest designs have the ability to accept various process control inputs, as well as the standard 4 to 20 mA, and 0 to 5 volt signal inputs.

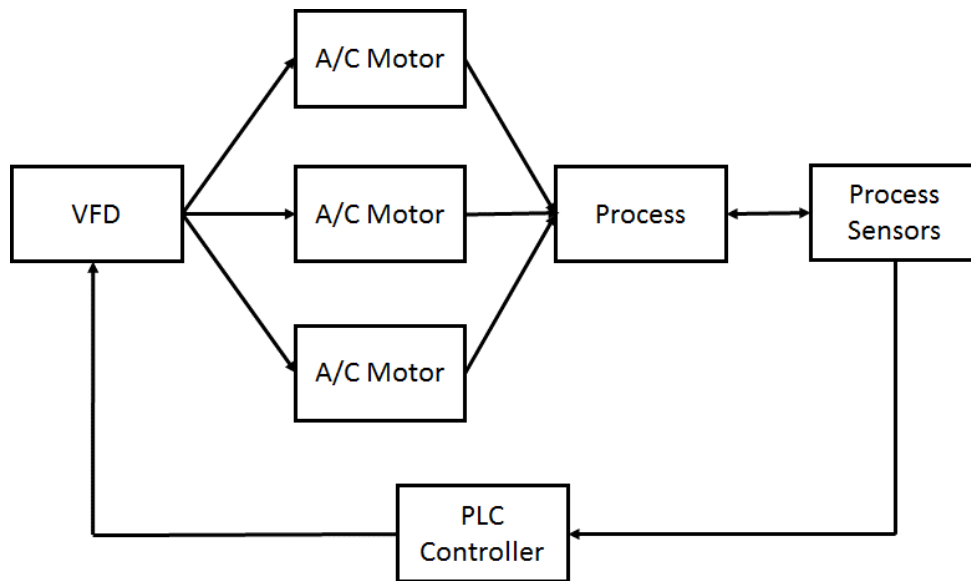
It is common that control processes be illustrated in a control loop diagram. Figure 11 shows such a basic control loop diagram for a simple feedback control of a process using a VFD controlling the motor. In this diagram a line filter reactor is placed before the VFD to help control possible harmonic feedback to the main lines from the VFD's high-frequency switching. Placing filter reactors in-line as illustrated are common for many VFD controlled processes. The brown, red and yellow lines in the figure feeding into the line filter reactor, VFD and the motor are the three-phase lines L1, L2, and L3 represent power service lines.



**Figure 11:** A typical feedback control loop diagram for a three-phase motor controlled by a VFD is illustrated here. The brown, red and yellow lines feeding into the line filter reactor, VFD and the motor are the three-phase lines L1, L2, and L3 represent power service lines.

Another option is to have one single VFD control multiple motors within a given process.<sup>(18)</sup> Care must be taken to properly size the VFD to correctly drive the multiple motors. The motors should all be the same horsepower and the process will need to be such that it can tolerate all three motors running at the same speeds. Figure 12 illustrates an example of this scenario where the VFD is

controlling three motors, however, fewer or more motors are possible. The key requirement for a multi-motor control configuration being that the VFD and control system are properly engineered for correct operation.



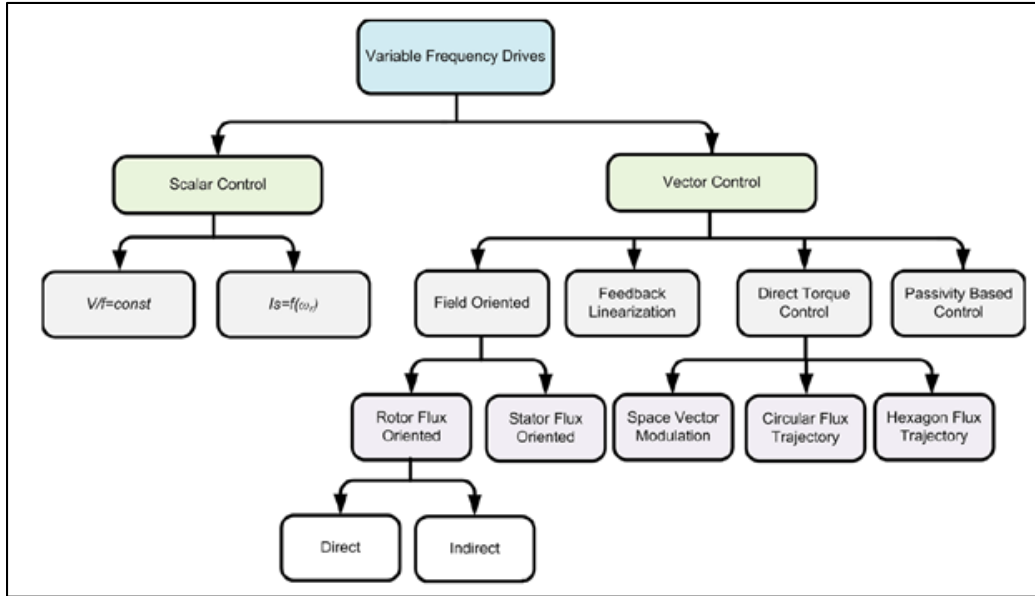
**Figure 12:** This illustration shows a single FVD regulating the speed of three motors. In this scenario all the three motors will operate at the same speed. As in Figure 8 a process sensor feeding a signal back to a process logic controller (PLC) that then in turn provides input control to the VFD. Fewer or more motors could be controlled by the same VFD, as long as it is correctly sized to the motors employed.

As would be expected, there are numerous VFD control options. Figure 13 graphically shows many of the VFD control options.<sup>(19)</sup> Many of these are advanced control techniques and may not be necessary for most applications. The figure is provided, however, to indicate to the reader the many control options available to the potential VFD user. Any option chosen must be well researched and based on an engineered solution dependent upon the user’s needs.

### 5) Examples of Testing Completed and Data Collected:

Due to the large volume of testing undertaken and data collected, only representative samples of the work done for the MAC project are presented here. These examples provide a good understanding of how energy savings can be accomplished using VFD technology. A more extensive review of all testing done and the data evaluated for this project can be found the original report titled “DTE Energy – Lawrence Technological University – Michigan Agricultural Commodities Energy Assessment of a Grain Storage and Transfer Facility Project”, and is dated December 15, 2014, revised January 16, 2015, by Robert W Fletcher.





**Figure 13:** Various possible options for VFD control are available. This illustration from Alsofyani and Idris indicates those various options.<sup>(19)</sup> Some of the options indicated represent advanced control methods that may not be necessary for many applications.

### 5.1) Fans for temporary piles and bin grain aeration:

Temporary grain piles are used for temporary storage of grain for a few days to several weeks. Figure 14 below shows a composite photo (of two separate photographs taken by the author) of one temporary pile in Marlette. An overhead drag transports the gran to the pile to deposit the grain. In the center of this photo at the base of the tarpaulin at ground level one of the suction fans can be seen. Wall panels are placed around the perimeter of the pile as side-supports to hold the grain in place.

There are three primary reasons for temporary pile fan usage. These are:

- a) To hold the covering tarpaulin in place during windy periods by creating a negative pressure within the grain pile.
- b) To help aerate the grain in the pile and thus to prevent spoilage from mold, fungi and insects.
- c) To keep the grain pile cool and equilibrate the temperature with the outside.

The temporary pile fans at the Marlette facility are either 7.5 HP or 10 HP 3-φ 480 VAC axial fans. Each temporary pile typically has six or more suction fans place around the perimeter of the pile with large flexible ducts running into the pile to provide air flow from deep within the grain pile. These fans currently are operated manually via on/off mode. An on-site wind ammeter displays wind speed and is manually monitored by workers at the site. Based on wind speed observations an employee manually turns on the fans as the need becomes apparent.

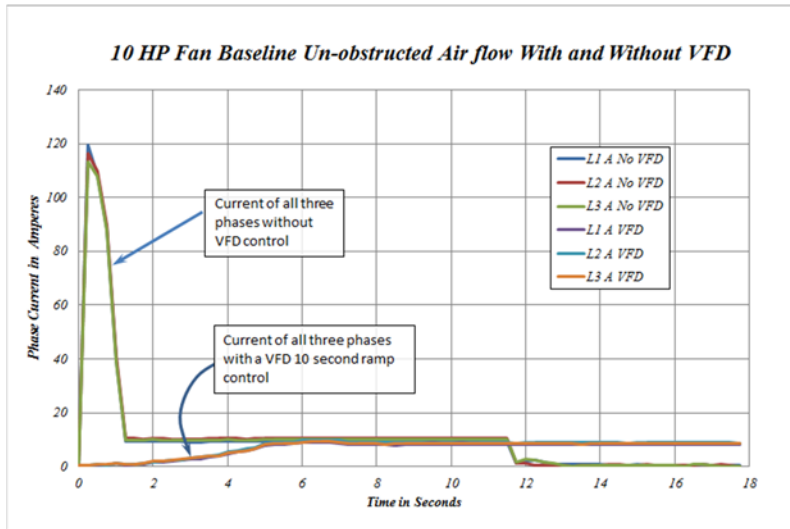


**Figure 14:** A composite photo of a temporary storage pile at the MAC Marlette, MI facility. A heavy white rubberized-fabric tarpaulin covers the pile. In the center of the photo the circular outlet of one of the suction fans with the tarpaulin draped around it can be seen. Large concrete blocks both hold the side supports for the pile and can also provide ballast to hold the tarpaulin in place. The primary method of securing the tarpaulin is through negative pressure within the pile provided by several fans around the perimeter.

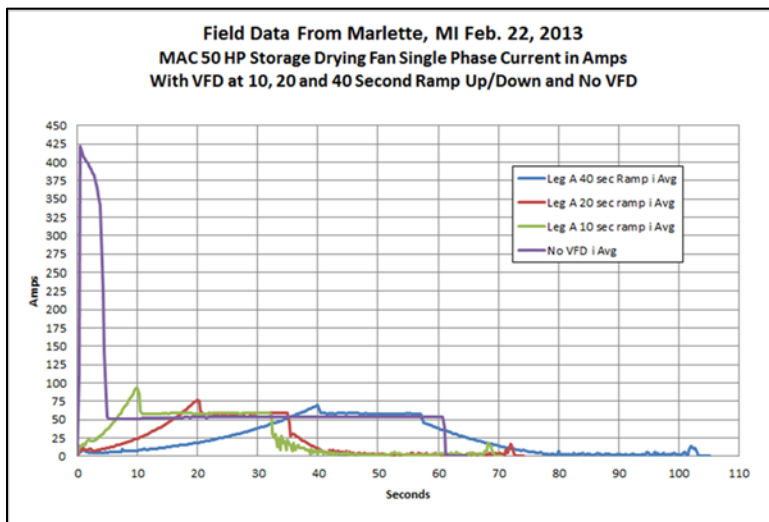
Several assessments were done on the fans at both Lawrence Tech and also at Marlette to understand the operation, energy usage and possible control of fans with VFDs. The studies undertaken at Lawrence Tech using a 10 horsepower and 50 horsepower fan, both without and with VFD motor control. Much of the data are similar from these studies, therefore, for discussion purposes only representative data are presented here.

Figure 15 below shows the current draw for all three phases in amperes for a 10 horsepower Spreads-All fan tested both without and with the ABB VFD. The ABB VFD was programmed with a 10 second ramp to full power when started. As can be seen in the figure, the sharp current spike encountered at the standard on/off start can be completely eliminated with the VFD ramp. It should be noted that the 10 horsepower motor/fan on this unit starts with an abrupt audible screech and a physical jump due to the instantaneously generated torque. Obstructions to air flow were accomplished by placing various diameters rings over the intake of the fan to control air-flow through the fan.

Numerous tests were conducted at Lawrence Tech on a 50 horsepower GSI fan. Data for these tests compare very well with testing that was also conducted at the MAC Marlette facility on identical 50 horsepower bin bottom fans. Figure 16 below plots current data in amperes from such a 50 horsepower fan both without and with a VFD. The VFD was set to ramp at 10 seconds, 20 seconds and 40 seconds to full power. A dramatic difference in inrush current without the VFD is readily seen.



**Figure 15:** Data showing the current draw in amperes for each of the three phases of the 10 horsepower fan motor, both without and with the variable frequency drive on the motor. The VFD was set to a 10 second starting ramp to full power.



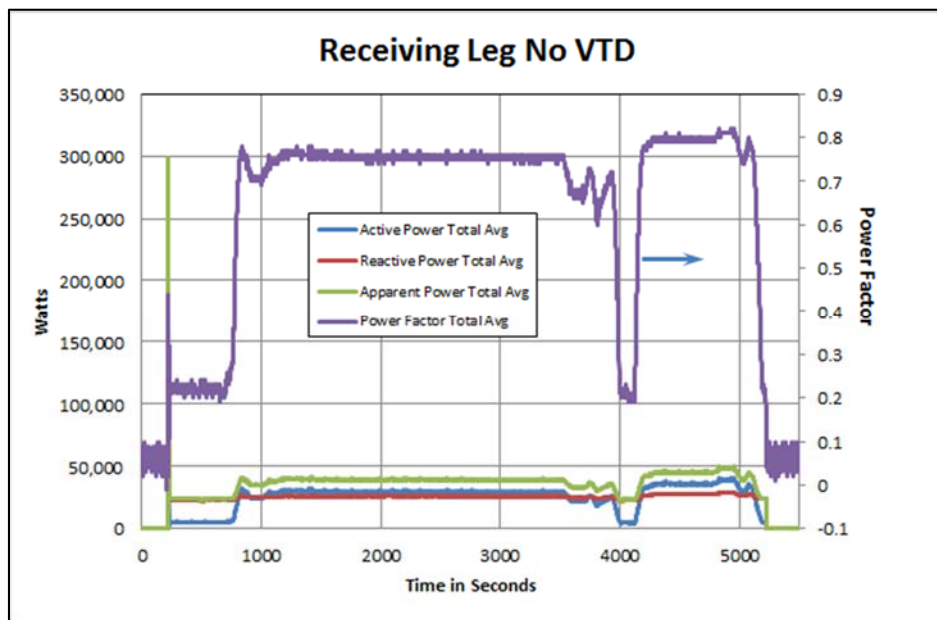
**Figure 16:** Data showing a single phase current draw in amperes for a typical 50 horsepower aeration bottom fan located at the base of a large grain storage bin in Marlette. This fan was monitored both without and then with a VFD. The VFD was set with a 10 second, a 20 second and a 40 second ramp to full power. The various ramps to full power clearly show a dramatic reduction in current draw at startup. Slight current overshoots visible on the ramp-up are due to the VFD not fully tuned for ramp control. A correctly set-up VFD could eliminate this overshoot.

**5.2) Legs and drags relating to grain transfer:**

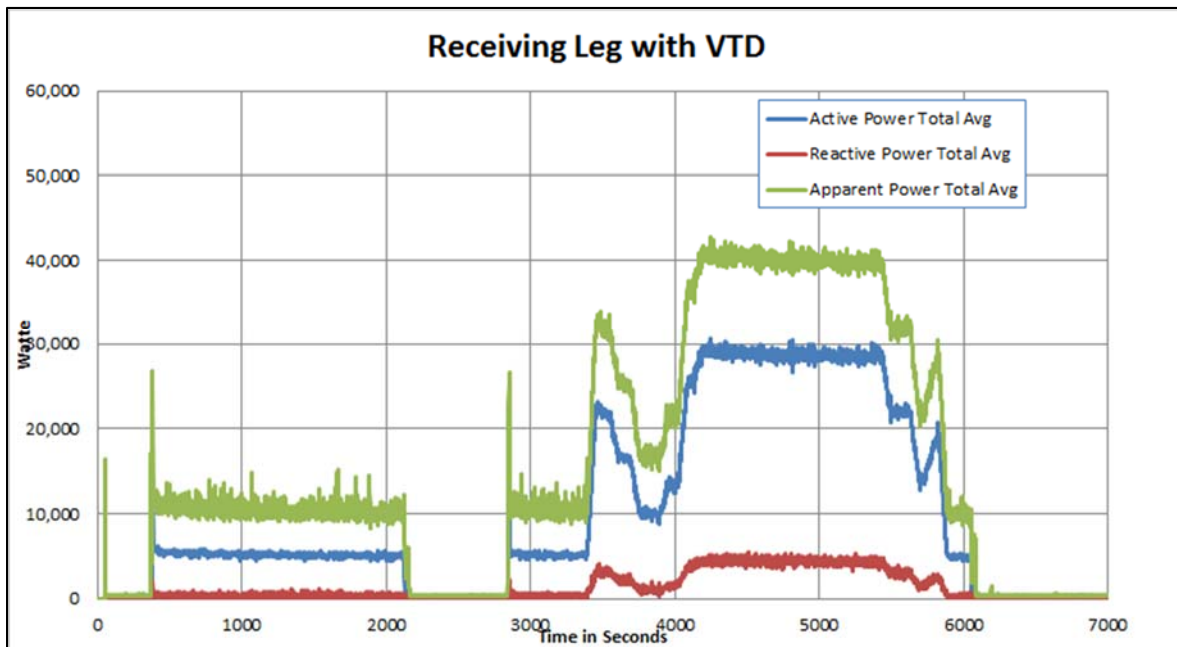
All studies evaluating legs and drags were done at the MAC Marlette facility. The initial focus was the front receiving leg, as this is the primary receiving station for the facility. During high volume

receiving days, however, a second receiving leg (called the back receiving leg) is also used. But due to the high to the level of use at the front receiving leg the initial assessment effort started there. This receiving leg has a 60 horsepower motor and lifts the grain to a high elevation above the facility to drop into gravity pipes for transfer by overhead drags to dump into a storage bin, or to a tempera pile. A receiving pit drag delivers the grain to the receiving leg and a pit fan for grain dust removal.

Power consumption data for the MAC Marlette receiving leg are shown in Figure 17, without a VTD motor controller, and in Figure 18, with a VTD controller. As can be seen in Figure 17 Power Factor is also potted for this motor. The motor exhibits the classic current spike upon activation and settles down as system comes to speed. The Power Factor, however, during leg idling is approximately 0.2. This can be a sizable problem because even though power draw during idle running is low, the operators can leave the leg running in idle for many minutes to hours during slow receiving time periods. The installation of the VTD with a ramp to full power significantly reduces the initial startup power spike.



**Figure 17:** The MAC Marlette receiving leg power consumption without a VTD motor controller. Also included is Power Factor for this motor. This motor exhibits the classic current spike upon activation and settles down as system comes to speed. The Power Factor, however, during leg idling is approximately 0.2. This can be a sizable problem because even though power draw during idle running is low, the operators can leave the leg running in idle for many minutes to hours during slow receiving time periods.



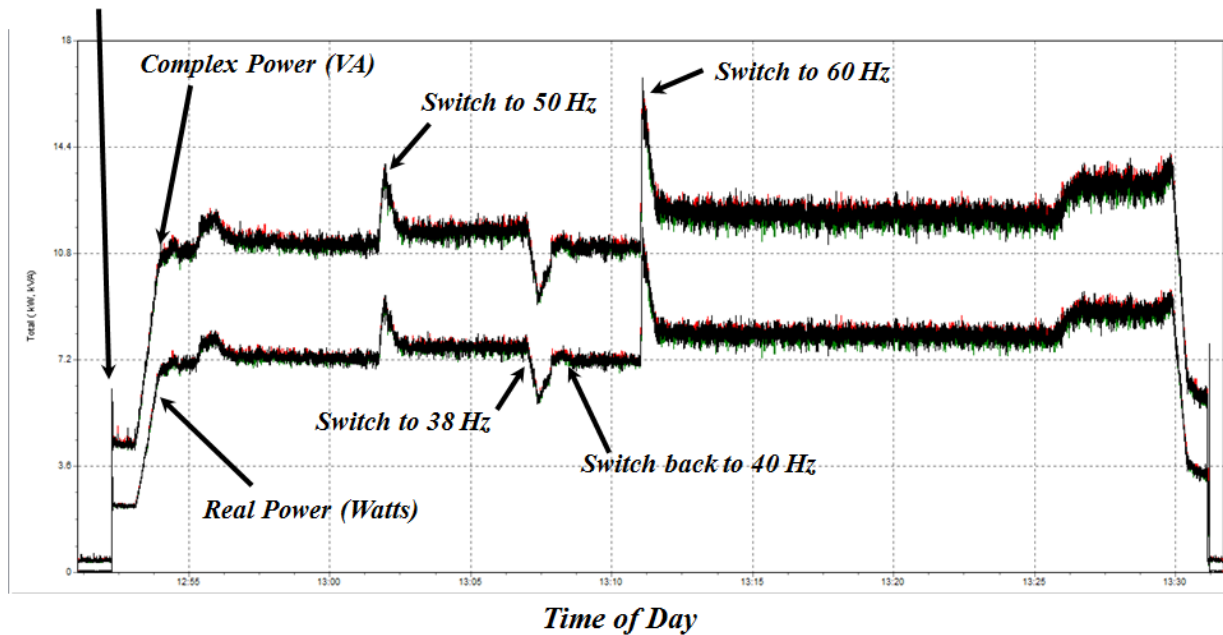
**Figure 18:** The MAC Marlette receiving leg power consumption with VTD motor controller. The classic current spikes upon activation are gone.

A variable torque drive (VTD) was installed on the MAC Marlette facility's #23 Overhead-drag 20 HP motor to assess the loading of wheat at various motor speeds by adjusting the VTD output frequency. Drag #23 was set-up to be fed approximately 50% volumetric loading of wheat. It is not unusual to have drags loaded at less than full capacity depending on the grain and the destination within the facility. Once the 50% wheat load on the drag was established then the output frequency from the VTD was reduced to various Hertz values by way of the variable resistor inserted between appropriate control input points on the VTD. As the #23 drag Hz (speed) was being reduced by the VTD the drag was still being fed wheat at the same rate, so each of the portioned sections of the #23 drag started to full to a high levels with grain, which loaded the drag motor more each time the speed was reduced. Figure 19 below shows the results of that test. Initially the drag VTD was set to 40 Hz and after a short time the wheat was conveying at a stable rate. Then at approximately 1:02 PM the VTD output frequency was changed to 50 Hz. At 1:07 PM the VTD output was again changed to 38 Hz, and then shortly thereafter changed back to 40 Hz because the drag at 38 Hz began to overflow and overload. At 1:11 PM the VTD was again adjusted to 60 Hz and allowed to operate until 1:30 PM when the unit was shut down. The complex and real total power in kW are plotted in Figure 19. Adjusting the Hz output from the variable torque drive from 60 Hz (normal line frequency) to 40 Hz for the same drag loading saved approximately 13% of energy used compared to the standard 60 Hz setting. Using this relatively simple control method for the VTD saves energy.

In a separate test a 50 HP motor attached to the "wet-leg drag" (a lifting conveyor used for carrying wet grain to a dryer) was evaluated in an unloaded condition with no grain being transported. The motor was operated with a VTD being adjusted from 60 Hz starting at 7:20 AM in 10 Hz increments down to 10 Hz and then reduced further to 5 Hz, all in ten minute increments. The output frequency was then adjusted at various levels back up to 60 Hz after every few minutes.

The data logger captured system data every 0.25 seconds. See the specific time sequences and frequency settings for this test in Table 3 below. Figure 20 plots apparent power for the time intervals and frequency settings outlined in Table 3 for the wet-leg drag running under a no-load condition. Frequency adjustments to the VTD were made on-the-clock ten minute intervals from 60 Hz at 7:20 AM down to 5 Hz, and in shorter time intervals back up to 60 Hz. As can be seen in Figure 20, the data become quite noisy at 7:50 AM, which corresponds to a VTD output of 30 Hz. The data increase in noise down to 5 Hz. After increasing the VTD frequency the data reduce in noise until about 40 Hz and remain with approximately the same noise level back to 60 Hz.

*Drag ON and starting to be fed wheat at ½ grain load capacity, drag at 40 Hz VTD*

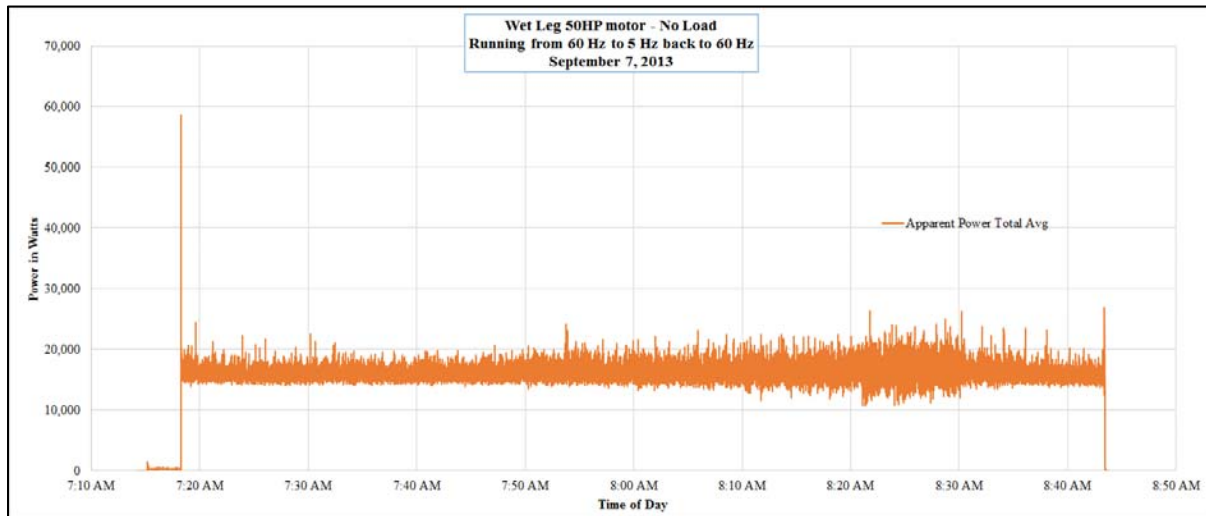


**Figure 19:** The output frequency of the VTD on Drag #23 20 HP motor at the MAC Marlette facility was adjusted and the related complex and real power in kW are plotted in this graph. These data clearly show that for a given load, it is possible to adjust the VTD output frequency to an optimal value for maximum power efficiency for that set of conditions

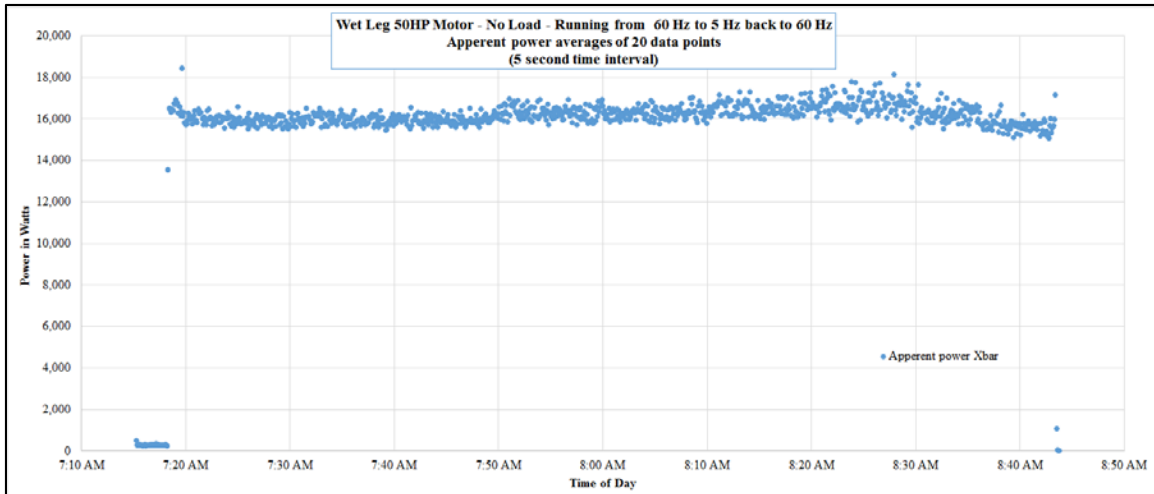
Figure 21 are data for that same test, but the data are averaged over 10 data points, or averaged over 5 second intervals. This averaging helps smooth the data and show that below 40 Hz (at the 7:50 AM time mark) the power consumed actually goes up slightly, and even the 10-point averages become noisy. The most signal noise is observed between 20 Hz down to 5 Hz and then back to 20 Hz. At frequencies above 40 Hz the power consumption drops slightly and stabilizes. These data clearly show that for an unloaded drag there is no significant advantage in running at significantly reduces VTD frequencies. In fact, doing so might actually increase energy usage.

**Table 3:** MAC Testing Data from Marlette, Michigan Facility. These data were collected: September 7, 2013, from the wet-leg (50 HP motor) running unloaded with VTD control. The sequence of test events for test for this study are given.

Time of Day	Action
7:15 AM	power to wet-leg on
7:18 AM to 7:20 AM	adjusted from 30 Hz to 60 Hz
7:20 AM to 7:30 AM	VTD adjusted to 60 Hz
7:30 AM to 7:40 AM	VTD adjusted to 50 Hz
7:40 AM to 7:50 AM	VTD adjusted to 40 Hz
7:50 AM to 8:00 AM	VTD adjusted to 30 Hz
8:00 AM to 8:10 AM	VTD adjusted to 20 Hz
8:10 AM to 8:20 AM	VTD adjusted to 10 Hz
8:20 AM to 8:30 AM	VTD adjusted to 5 Hz
8:30 AM to 8:32 AM	VTD adjusted to 20 Hz
8:32 AM to 8:34 AM	VTD adjusted to 30 Hz
8:34 AM to 8:36 AM	VTD adjusted to 40 Hz
8:36 AM to 8:38 AM	VTD adjusted to 50 Hz
8:38 AM to 8:40 AM	VTD adjusted to 58 Hz
8:40 AM to 8:43 AM	VTD adjusted to 60 Hz



**Figure 20:** The apparent power consumed for the wet-leg drag running under a no-load condition at various output frequencies from the VTD. Frequency adjustments to the VTD were made on-the-clock ten minute intervals from 60 Hz down at 7:20 m to 5 Hz, and back up to 60 Hz. See Table 3 for time intervals and frequency settings.



**Figure 21:** Data for the same test documented in Table 3, but the data are averaged over 20 data points, or averaged over 5 second intervals. This averaging helps show that below 40 Hz (at the 7:50 AM time mark) the power consumed actually goes up slightly, and even the 20-point averages become noisy. The most signal noise is observed between 20 Hz down to 5 Hz and then back to 20 Hz.

## 6) Discussion and Recommendations:

The MAC Marlette facility consumes energy in three primary areas. The first is in the area of electric motors used to operate fans for stored grain aeration (and for grain in temporary piles to secure tarpaulins). The second is related to motors that operate drags and legs, which are bulk conveyors. The third area is with their grain drier that consumes large amounts of natural gas, and also electricity for the large fans in these units, for drying wet or moist gran. Natural gas usage in drying grain will not be discussed here.

### 6.1) Fans:

Based on efforts of this project, it is believed that the greatest opportunity for energy savings at the Marlette facility is with fans and fan control using VFDs. There are between forty and fifty fans used extensively throughout the year at Marlette, with many running continuously for weeks at a time. There are dozens of 50 HP fans and 35 to 40 smaller fans, all used for aeration in Marlette, and can operate for thousands of hours a year. Leg and drag motors are large and do consume significant energy when in operation, but they do not have the operational times that fans do in Marlette. For example, the front receiving leg at Marlette is rated for 10,000 to 20,000 bushels per hour. In 2012 Marlette received about 2.75 million bushels of grain. If 65% of this grain was received by the front receiving leg (the back receiving leg is also available for receiving grain) and the front leg was operated at its lower-end rate of 10,000 bushels per hour, and if we assume that it was on four times longer than its needed duty time, then this leg operated for approximately 715 hours  $((2,750,000 \text{ bushels} \times 0.65 \times 4) / (10,000 \text{ bushels/hour}) = 715 \text{ hours})$  for the year and at full motor load would have consumed about 32,000 kWh  $(715 \text{ hours} \times 60 \text{ HP} \times 0.7457 \text{ kW/HP} = 31,990 \text{ kWh})$ . Whereas one large bin with four 50 HP fans could easily run for that many hours in a year and would consume 106,635 kWh  $(715 \text{ hours} \times 4 \text{ fans} \times 50 \text{ HP} \times 0.7457 \text{ kW/HP} = 106,635$



kWh). Therefore, the focus for energy savings at Marlette should be with fans first, and then only on selected legs and drags.

Even the electric energy usage by the two large 125 HP Brock<sup>®</sup> dryer fans over a year is small compared to one set of four 50 HP large-bin fans. For example in 2012 Marlette received 1,429,766 bushels of wet-grain requiring drying. The Brock<sup>®</sup> dryer processes between 4,500 and 5,000 bushels per hour. Assuming an average of 4,750 bushels per hour the dryer ran for approximately 300 hours (1,429,766 bushels/4,750 bushels per hour = 301 hours). If we assume an additional 10% startup/shutdown time for 2012 then it is a reasonable assumption that the dryer ran 330 hours (300 hours x 1.10 = 330 hours). This equates to 61,520 kWh (125 HP/fan x 2 fans x 330 hours x 0.7457 kW/h = 61,520 kWh), or only 58% of the energy consumed by one set of large-bin fans (four 50 HP fans), which can easily consume 106,635 kWh over a year.

The Marlette facility can also have several temporary grain piles in use from mid-summer through early spring. Temporary pile fans are used for securing tarpaulins on the piles, for preventing spoilage, and to control temperature. Typical piles use six fans rated at either 7.5 HP or 10 HP. Wind data were reviewed from the Michigan Automated Weather Station Network (MAWN) for Sandusky, MI, (a location in Michigan near the Marlette facility) to help assess potential wind conditions and a histogram of those data were created. Assuming an average of one temporary pile is in use from July through April, and using the wind-control scenario employed by the MAC Marlette workers, and aeration to prevent grain spoilage in temporary piles caused by insects, fungi, mold, and grain metabolism using the carbon dioxide monitoring, as discussed by Maier<sup>(28)</sup>, et al, and for regulating pile temperatures, then a single temporary pile in use from the July 1st through April 30th time period could consume 171,914 kWh of energy.

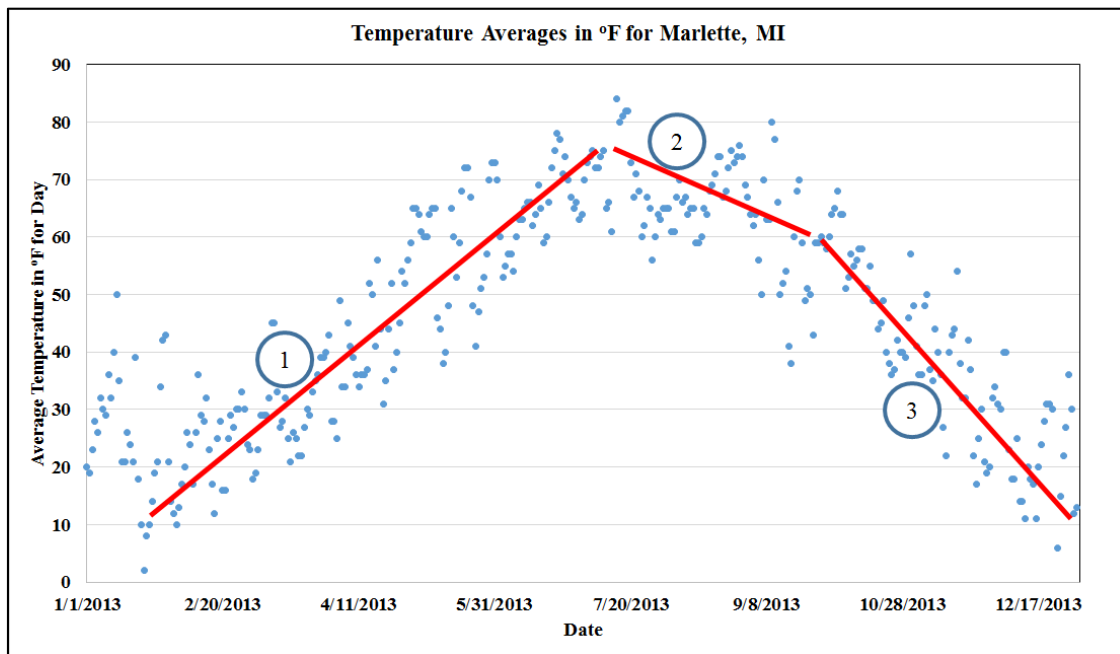
For large bins aeration is often described in terms of aeration cycles that are based on average daily ambient air temperatures. Aeration cycles provide the hours aeration fans must be kept on for a specific set of temperature storage conditions. McKenzie and Van Fossen have defined an aeration cycle as the period of time to equilibrate grain temperature when a daily average outside ambient temperature change of 10°F to 15°F occurs.<sup>(33)</sup> So in Marlette a 15°F average daily temperature change from mid-September to the end of October, which is quite common, would be defined as one aeration cycle within their grain storage bins. But note that there is no firm agreement on this, as some suggest the grain-to-outside temperature difference should be kept to 5°F to 10°F.<sup>(26)</sup>

The time required to complete an aeration cycle is dependent upon the air volumetric flow rate through the grain enabling heat exchange between the flowing air and the grain.<sup>(20-25)</sup> Wilcke has suggested the aeration of stored dry grains be carried out at 0.05 to 0.5 ft<sup>3</sup>/min/bushel (or cfm/bu).<sup>(34, 35)</sup> A quick review of the literature suggests that volumetric air flow rates in bins typically range from 0.05 to 0.2 cfm/bu. MAC personnel at the Marlette facility have indicated through personal correspondence that they typically try to operate at 0.1 cfm/bu in their permanent storage bins.

McKenzie and Van Fossen have provided simple equations for estimating aeration cycle times based on the season and on aeration in cfm/bu.<sup>(33)</sup> The computed times from these equations are based on 60-lb bushels, and also on 10°F-15°F temperature changes common in the Midwest of

the United States. Jones has provided a modified method of determining aeration cycle times that includes grain test weight.<sup>(27)</sup>

It is, therefore, possible to calculate the total hours that aeration fans might be running for a large permanent storage bin using average daily temperature data for Marlette, MI. Figure 22 below plots these average daily temperatures for Marlette, MI, for the year 2013 (note these data are provided by the Weather Underground [www.wunderground.com](http://www.wunderground.com)). As can be seen in Figure 38 there are approximately four 15°F temperature-change aeration cycles in the transition from winter to early summer (the red line labeled 1), only one aeration cycle in the summer (the red line labeled 2), and three aeration cycles in the fall (the red line labeled 3).



**Figure 22:** This graph plots the average daily temperature for Marlette, MI, for the year of 2013. These data are provided by Weather Underground. It shows approximately four 15°F temperature change aeration cycles in the transition from winter to early summer (red line 1), one aeration cycle in the summer (red line 2), and three in the fall (red line 3).

Using the McKenzie and Van Fossen aeration cycle equations and assuming a volumetric airflow value of 0.10 cfm/bu value (from MAC personnel) a reasonable estimate of fan operation time for a single 310,000 bushel bin (as for bin #30 in Marlette) can be calculated. If we assume the grain is received in the fall and is stored for seven months (three months in the fall, and four months in the winter), and that the grain is at 60 lb./bu (this would be slightly moist grain), then the aeration fan-hours are estimated as follows:

$$(\text{fall aeration hours}) = (3 \text{ cycles}) \times \left( \frac{15}{(0.10 \frac{\text{cfm}}{\text{bu}})} \right) = 450 \text{ hours}$$

$$(\text{winter aeration hours}) = (4 \text{ cycles}) \times \left( \frac{20}{(0.10 \frac{\text{cfm}}{\text{bu}})} \right) = 800 \text{ hours}$$

For four 50 HP (37.29 kW) aeration fans (as would be needed to keep air flowing in a large bin full of grain such as in Marlette) it can be seen 1,250 hours are required, and equates to 5,000 fan-hours (4 fans x 1,250 hours = 5,000 fan hours). This results in 186,425 kWh of energy needed for a seven month storage (5,000 hours x 50 HP x 0.7457 kW/HP = 186,425 kWh).

There are several references in the literature discussing fan controls using VFDs. For example, Teitel, et al, observed ~25% energy reduction in fan cooling of a poultry house and as much as 36% energy reduction, depending upon ambient air temperatures, in a greenhouse using VFD fan motor control compared to conventional on/off controls.<sup>(29, 30)</sup> It should be noted that Teitel, et al, found that they could not obtain the theoretical savings predicted by the affinity laws.

In addition, Al-Bassam and Alasseri obtained a 5.8% energy savings using VFDs for cooling tower fans over dual-speed motors in the hot weather environment of Kuwait.<sup>(31)</sup> Also, Du Plessis, Liebenberg, and Mathews found that in South African mine cooling systems they were able to obtain energy savings of approximately 29.9% from a pilot implementation of VFDs for controlling fans, chiller pumps and compressors.<sup>(32)</sup>

From data collected in this study, and also based in the technical literature, it is reasonable to assume that a conservative savings of at least 20% could be observed in temporary grain pile fan operation by using VFDs for ramping up at fan start and down at fan shutdown, and by operating fan at appropriate speeds based on a control plan using grain temperature, humidity, CO<sub>2</sub> levels, and volumetric air flow through the bin.

## **6.2) Legs and Drags:**

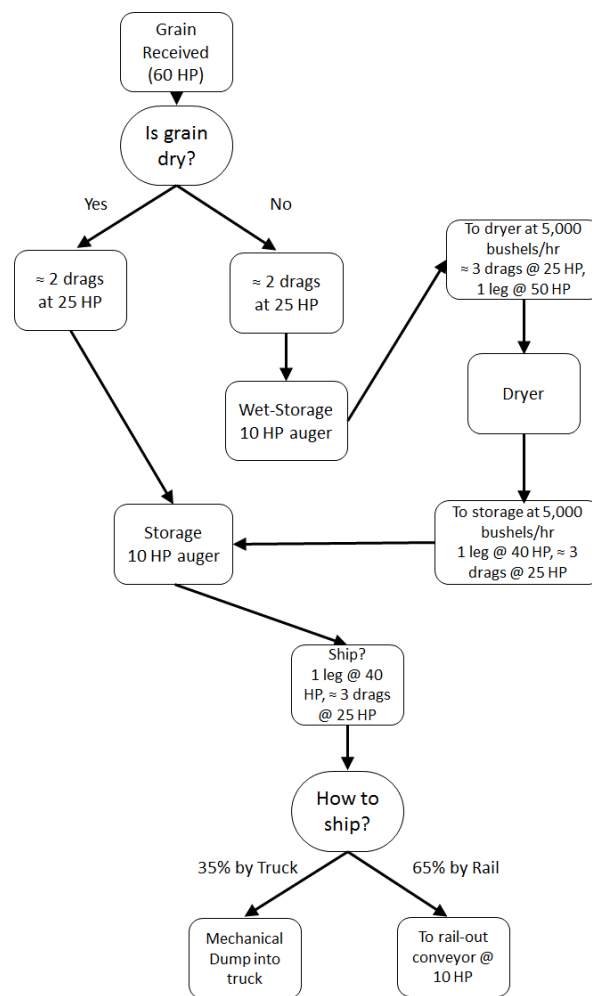
Because grain can take many different process routes in the Marlette facility before being sold, it was difficult to define a specific energy consumption for legs and drags using a convenient normalized value. The receiving leg which uses a 60 HP motor, the wet leg for drying uses a 50 HP motor, and other legs are 40 HP. The various drags range from 5 HP, to 30 HP, but most are 20 to 25 HP. After being carried by the receiving leg, grain can be transported to its storage location by one, two or three overhead drags. For shipping by rail a 10 HP “rail-out” conveyor moves grain to the rail loading station.

To clarify these various grain flow options, a flowchart was developed to define an “reference process” of grain flow using legs and lifts, and is illustrated in Figure 23. For simplicity it assumes no extra processes, such as blending or other handling, take place. It was assumed that after receiving, on average, grain is transported by two drags to a bin (the reality is that grain can be transported by one, two or three drags, but on average two drags are used). Also, the grain typically is transported to the dryer by one leg and three drags. From the dryer the grain is again typically transported to storage in a bin or a temporary pile by up to three drags.

When the grain is transported from a bin to its loading station for sale it will typically be moved by a 10 HP auger, a 40 HP leg and three 25 HP drags. If loaded to a truck there are no additional transporters. If rail loading is required the grain is transported to the rail loader by the 10 HP motor

on the rail-out conveyor. The benefit of the Figure 23 is that it helps establish some type of reference for energy usage for grain flow through the Marlette process.

Using the flow chart illustrated in Figure 23 above makes it possible to define a leg/drag baseline energy consumption for grain through the facility. Two estimated energy usages in kWh were computed. The first showed 100,063.6 kWh as a base estimate for all grain handled by leg and lifts in 2012. The second showed a calculated estimate using a worst-case correction factor of 150% to account for possible various side-operations, including mixing and blending (and other processes) to yield a value of 250,159.1 kWh. It is anticipated that legs and drags could require this high of a correction factor to accommodate the many extra activities done, as well as to address legs and drags left on during intermittent times. Even when using the 150% correction factor, legs and drags would only account for 22.8% of the total electrical energy used at the MAC Marlette facility.



**Figure 23:** This illustrates an optimum process flow of grain through the Marlette facility. It does not include possible side processes such as blending or separation. The purpose of this flow chart was to help establish a reference process for lift and drag energy consumption.

It must be emphasized that based on these estimates it is clear that legs and drags do not constitute the major energy usage at Marlette. The major electrical energy usage in Marlette is from aeration and drying fans.

The various demands and feed rates of process equipment can result in legs and drags running at speeds lower than their rated bushels per hour. Therefore, depending upon the process lifts and drags may need to run significantly below their designed bushels per hour rating. Because of the need for various speeds for legs and drags they lend themselves to an application opportunity for variable speed drives (VSDs), such as VFDs, and more appropriately variable torque drives (VTDs). Several examples are found in the literature describing the use of VSDs (either VFD or VTD) in conveyor applications documenting successful energy savings. A few are listed in the references section of this report for review.<sup>(36-38)</sup>

Assessing these data, and other reports show clear documented evidence of energy savings using VSDs of between 15% and 35%, with results dependent upon belt feed rates. However, using finely tuned VSDs (either VFD or VTD) in such processes as those found in Marlette could yield an estimated approximate savings of 15% to 20% kWh at  $\frac{1}{2}$  grain feed rates. Assuming the loading follows in line with the  $\frac{1}{2}$  feed rate, then at  $\frac{3}{4}$  grain feed rates an energy savings of 9% to 15% kWh is projected with VSD output frequencies of approximately 50 Hz. These are respectable possible energy savings. There is, however, a major point that needs to be stated and that is each drag and lift would require its own VFD/VTD. The installation of additional VSDs would need additional financial assessment to justify their installation.

## **7) Conclusions:**

The energy assessment of the Michigan Agricultural Commodities grain storage and transfer facility in Marlette, Michigan was a challenging, but also a rewarding project. It took place from mid-June 2012 through the late fall of 2013 for approximately eighteen months. Seven Lawrence Tech undergraduate engineering students and one faculty member worked on the project.

This report summarizes the major tasks, accomplishments and knowledge gained from these efforts. It must be stated that the findings documented in this report may not be applicable to other facilities or operations, and some recommendations made here may not be realized. Some important conclusions and recommendations can be drawn from the efforts of this project and are listed here.

- 1) Grain storage and transfer facilities such as the MAC facility in Marlette, MI, have many energy savings opportunities. A facility operations manager's primary job at such sites, however, is to receive, store and transfer grain. They may not be familiar with energy savings techniques or measurement systems available to them, and energy management is not their primary job function. It would be appropriate for site operations managers to be given staff support to collect, organize and analyze even basic energy usage data at their facility. Based on the observations made during this project the cost savings, especially at a large facility, could easily justify the added staff.

- 2) Operations personnel at facilities like the MAC Marlette facility need to communicate with their energy utility provider and learn about resources, support, rate options available to them. Even through some simple efforts working with the local utility representative, there may be opportunities to save money. The MAC Marlette personnel have been proactive and quite vocal about communicating with their DTE Energy representative and others at DTE Energy.
- 3) The activities of grain receiving and storage at the MAC Marlette facility tend to be done on large bulk quantities of grain. But there are also more nuanced and complex actions taken by the operations personnel there requiring great understanding of grain humidification and drying, bulk material handling to prevent physical damage, as well as blending and sorting. They also need to know the biology of the commodities they handle to prevent spoilage from mold and fungi. As a result of all of these issues they rely on equipment and technology such as fans, dryers and legs and drags to correctly process the grains to successfully deliver them to the customer. The broader engineering community needs to provide support and assistance to these individuals to help them connect to the agri-business objectives they have and the technological solutions available to them. This is where universities with engineering programs can step in and assist these efforts.
- 4) Specific examples of technologies that are available to the agri-business community are variable speed drives (VSDs), such as variable frequency drives (VFDs) and variable torque drives (VTDs). These systems can help save on energy usage. But the adoption of VSDs is not trivial and requires technical knowledge and background that may not be held by facility operations personnel.
- 5) The operations at the MAC Marlette facility use a number of different sized motors for fans, legs and drags. Most of these motors are possible candidates for using VSDs. Specific suggestions for how to approach these are made here regarding best possible candidates.
  - a) Aeration fans are used year round in Marlette. Some are run for days, and sometimes weeks. Two types of fan systems are most used. These are fans for temporary storage piles of grain and permanent bin grain aeration.
    - i) Volumetric air flow is a critical component in grain aeration but no volumetric airflow instrumentation is installed on any permanent storage bins at Marlette. It may be appropriate to develop an aeration fan control strategy based on temperature, humidity, CO<sub>2</sub> ppm, and volumetric air flow. Such an approach could properly regulate both the number of fans and the speed settings of aeration fans.
    - ii) Temporary grain piles require not only aeration but also suction to prevent the covering tarpaulins from blowing away in high winds. This is accomplished with either 7.5 HP or 10 HP axial fans. Some temporary pile suction fans are on the entire time a temporary pile is in use (which can be days to several weeks). These temporary pile fans are excellent candidates for VFD applications. A wind speed monitoring system feeding a signal back to a programmable logic controller (PLC) that also addresses temperature and CO<sub>2</sub> ppm buildup for controlling VFDs would be the best option.
    - iii) Proper control of aeration fans and temporary pile suction fans could result in an estimated overall fan related energy usage savings of approximately 20%.

- b) Motors powering legs and drags are also good candidates for VSDs, and specifically VTDs. Because of the many possible routings of grain using drags and legs within the Marlette facilities it would be best to focus on the major use legs and drags.
- i) The front receiving leg and the related overhead drags, however, would be the primary candidates for VTDs. This is because this section of the process is the most used, it deals with the greatest variability of incoming commodities, and is subject to the most amount of down-stream process variability. Motor speed control is needed here to properly run the process and can benefit from the energy savings from VTDs.
  - ii) The leg and drag systems feeding the dryer should also be considered as primary candidates for VSDs. In 2012 just over 52% of the grain received by Marlette was routed to the dryer. The drying system gets high usage and also forces drags and legs to operate at reduced speeds to accommodate the limited bushels per hour rating of the dryer. As a result legs and drags can operate at one-half to one-quarter their rated throughput. VSDs will help assure full or near full loading of the motor at these reduced speeds to assure maximum efficiency of the motor.
  - iii) Proper control of the appropriate legs and drags could reduce each of their individual energy consumption rates by an estimate 15%.
  - iv) There may be benefits in attempting to standardize motor sizes to minimize replacement inventory. An additional benefit to motor standardization may be if the utilization of VFDs (either VFDs or VTDs) were to become widespread at Marlette then the need to have so many different HP rated VFDs there could be reduced, and as a result VFD replacement costs and support could be reduced.
- 6) Some opportunities with suggestions for possible future exploration are listed here for consideration. There are several specific smaller testing projects that could and should be done. One is in the area of fan control and volumetric air flow rates. This is an understudied topic in the literature and could lead to sizable energy savings. The large bin fans may not need to run as frequently and at full-power speeds. The energy savings could be significant.

### **8) Summary of the educational gains made by student project team members:**

This project focused on understanding energy usage at the Michigan Agricultural Commodities, Inc. facility located in Marlette, Michigan. Seven Lawrence Technological University undergraduate engineering students served as team members supporting the project. Funding was provided by DTE Energy with students serving as paid Lawrence Tech research employees on the project. This author, a Lawrence Tech faculty member in the A. Leon Linton Department of Mechanical Engineering, served as the principle investigator and primary coordinator of the work. The project ran from June 2012 to December 2013. Numerous educational benefits for students were provided during this project. Some of these simply cannot be taught in the classroom and help prepare the student for eventual work in industry. The more prominent benefits gained by students on this project are listed below:

- Dealing with various levels of working professionals in an industrial agribusiness setting such as the Marlette facility
- Learning from others who may not have the same education level but have more extensive industry experience
- Dealing with contractors and the labor force

- Giving professional presentation preparation and delivery skills
- Having to collect data at times that were best for the process and not the most convenient for the students...especially 6:00 AM start times (after a 90 minute drive)
- Data collection and the selection of appropriate data collection systems, methods and approaches
- Complex data review, analysis and interpretation skills
- Experimental setup and the resulting sometimes failure and success
- A fundamental learning and applied knowledge of power electronics
- Scheduling of work over a long travel distance

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