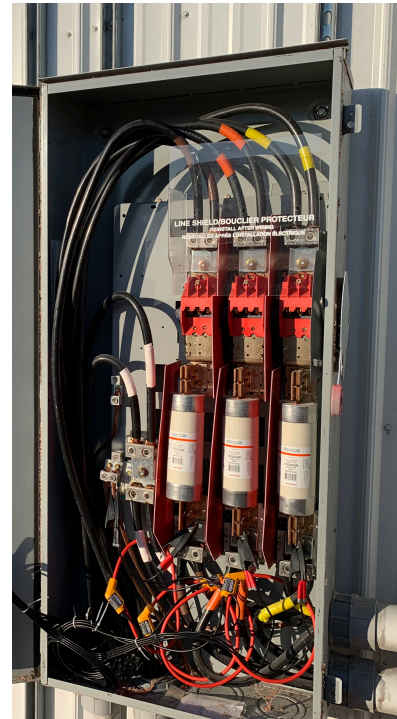


Energy Management in Agriculture

Understanding Implications of Power Factor in Grain Handling



OHIO SOYBEAN
COUNCIL



THE OHIO STATE UNIVERSITY

COLLEGE OF FOOD, AGRICULTURAL,
AND ENVIRONMENTAL SCIENCES

Eric Romich, Ohio State University Extension Farm

Energy Management Report # RFEM-102021

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TABLE OF CONTENTS

Acknowledgment	4
Introduction	5
Study Overview	6
On-Farm Critical Infrastructure Survey	8
What is Power Factor?	9
Electric Rate Structure	13
Case Study: RFEM Farms	16
Case Study: DFEM Farms	23
Power Factor Correction	29
Action Steps	33
Additional Resources	32



FIGURES, CHARTS, AND TABLES

Figures		Charts	
Figure A and B: Installing the Power Logger	7	Chart 1: RFEM Farms - Energy Usage	17
Figure C: Survey Response by County	6	Chart 2: RFEM Farms - True Power Factor	18
Figure D: On-Farm Critical Infrastructure Survey Results	8	Chart 3: RFEM Voltage THD%	19
Figure E: Key Terms and Power Factor Analogy	9	Chart 4: RFEM Current THD%	19
Figure F: Phase Angle of Lagging Current From Inductive Load	10	Chart 5: Average and Maximum Monthly Demand	20
Figure G: Power Triangle - Poor Power Factor (71%)	11	Chart 6: November 2020 Peak Demand	20
Figure H: Power Triangle - Acceptable Power Factor (90%)	11	Chart 7: RFEM Power Quality Logger Results	21
Figure I: Non-linear Current from Harmonic Distortion	12	Chart 8: DFEM Farms - Energy Usage	24
Figure J: Calculating Demand and Power Factor Correction	14	Chart 9: DFEM True Power Factor	25
Figure K: Fan Motor (20 HP)	16	Chart 10: DFEM Voltage THD%	26
Figure L: Auger Motor (20 HP)	16	Chart 11: DFEM Current THD%	26
Figure M: RFEM Farm Grain Bins	16	Chart 12: Average and Maximum Monthly Demand	27
Figure N: DFEM Farm Grain Bins	23	Chart 13: November 2020 Peak Demand	27
Figure O: Auger Motors	23	Chart 14: DFEM Power Quality Logger Results	28
Figure P: Example of Power Factor Correction Estimate	31	Tables	
Figure Q: Example of Power Factor Correction Estimate	32	Table 1: RFEM Case Study Analysis of Power Factor Fees	22
		Table 2: DFEM Case Study Analysis of Power Factor Fees	29
		Table 3: Multipliers to Determine Capacitor Size	30

Acknowledgments

CONTRIBUTORS

Contributing Authors:

- Eric Romich, Associate Professor, Field Specialist, Energy Education, Ohio State University Extension, Upper Sandusky, Ohio, romich.2@osu.edu

Peer Review Editors:

- David Civittolo, Associate Professor and Interim Assistant Director, OSU Extension Community Development
- John Hay, Extension Educator, Energy Department of Biological Systems Engineering, University of Nebraska

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OHIO SOYBEAN COUNCIL

As a land-grant university, Ohio State University is dedicated to solving societal challenges through community-engaged partnerships. This study was conducted with funding support from Ohio soybean farmers and their checkoff. Headquartered in Worthington, the Ohio Soybean Council (OSC) is governed by a volunteer farmer board, which directs the soybean promotion and research program. The program’s primary goal is to improve soybean profitability by targeting research, education, promotion, and development projects through the investment of farmer-contributed funds. For more information on the Ohio Soybean Council, visit soyohio.org.

ON FARM RESEARCH COLLABORATIONS

Special appreciation is expressed to the two farms who cooperated in this study by permitting the energy monitoring of their facilities, and by furnishing information on their farming operations. The names of farms collaborating in the on-farm research have been coded to protect their identity.



INTRODUCTION

As agricultural operations have become more sophisticated and automated, the electrical demands of many farms have increased, requiring enhanced needs for high quality power to operate electric motors and equipment. As of 2017 Ohio had over 540 million bushels of on-farm grain storage capacity, most of which use electricity to power large motors that run fans, move grain, and in some cases provide heat. Depending on the type of dryer, electricity accounts for 2 percent to 4 percent of the total energy required to dry grain.

Many dryers require three-phase electricity due to the high demand for electricity needed to power the large motors. In most cases, farms that install three-phase electricity are subject to commercial electricity rates. Unlike most residential electric rates which are based primarily on total energy usage, commercial accounts are often charged for both total energy usage and the peak amount of power, called demand, measured over a short time period (typically, the highest 15 or 30-minute peak during the month). One key variable that can significantly influence your monthly peak billing demand is power factor. In general, power factor is a ratio that indicates the percentage of electric current provided by the utility being used to produce useful work, compared to imaginary current used to sustain magnetic fields. A farm with a low power factor is not efficiently utilizing the electrical power delivered to their farm, often triggering additional fees that are combined with demand charges.

The demand for electricity in grain storage and drying operations is highly variable with long periods of low to medium activity and relatively short peaks of high activity. As a result, on some farms, the resulting demand charges represent 50% to 60% of the farms monthly electricity bill. Farmers have long explored alternative management techniques and equipment to provide energy savings associated with grain storage and drying. While there is an abundance of general information related to demand charges and power factor for the industrial sector, surprisingly few resources are available specific to the agricultural sector. Furthermore, there is a lack of energy usage and power quality data detailed enough to fully inform the scope of these impacts on grain storage facilities, suggesting an urgent need for additional research. The purpose of this bulletin is to introduce the main concepts of power factor, how correction fees are calculated, and review data from two case studies to assess the potential cost and introduce possible strategies for power factor correction.

STUDY OVERVIEW

Ohio State University Extension recently conducted a research project in collaboration with two Ohio Agricultural Research and Development farms and four private farms to investigate the current knowledge gap related to electricity usage and peak demand in swine and dairy livestock facilities. Specifically, the research team installed advanced multifunction energy meters capable of recording energy data for up to 24 critical operations on the farm. While our initial focus was on peak demand, the data indicated the farms had low power factor readings. Based on data collected, the power factor on the six test sites was commonly below 90 percent, including several sites with average monthly power factors around 70

percent. Power factor is a key element that can significantly influence the final billing demand. Based on the number of large electric motors and inductive loads on grain storage facilities, we anticipate many farms with on-farm grain storage also have poor power factor. However, additional data is needed to better understand the issue and cost saving potential. The primary focus of this study was to install energy meters at two on-farm grain storage facilities to collect energy usage and power quality data.

Goals and Objectives

The overall goal of the project was to generate empirical measures of data for peak demand and power factor on grain storage facilities. In addition, we evaluated how many farmers were aware of power factor issues, if they are charged for poor power factor, how the charges were calculated, and if they have installed power factor correction equipment, or not. The data will also allow us to assess the economic impact of power factor correction solutions and establish energy management best practice strategies.

To accomplish the overall goals of this project, we installed advanced energy metering systems on two grain storage facilities to track electric peak demand and monitor power quality to gain knowledge about energy usage, inform energy management strategies, and support decision making related to critical energy infrastructure projects in agriculture. The details of specific project objectives related to the research goals are summarized below.

1. Conduct a short survey to determine farmers level of knowledge of power factor requirements, power factor penalty fees, and if they have installed capacitors for power factor correction.
2. Install advanced energy metering equipment on two grain storage facilities to record electricity data on 5-minute intervals for electricity usage, peak demand, and power factor over a two-year period.
3. Conduct a comprehensive review of commercial electric rate structures in Ohio and examine power factor requirements and penalties and summarize the impact on the grain storage facilities overall electricity costs.

Equipment and data collection

To meet the research needs of this study, the project team selected the Fluke 1742 Three-Phase power quality logger (Figure A). The Fluke 1742 is capable of measuring all three voltage and current phases plus the neutral current while simultaneously logging up to 500 parameters and capturing key events such as intermittent power quality issues. The power loggers were IP65 compliant for both moisture and dirt ingress and were designed to withstand harsh installation environments commonly found on farms. The power logger which measures 9.1” (L) x 7.1” (W) x 2.1” (H) had a small footprint designed to fit in tight spaces. The magnetic hanger kit allowed the power loggers to be safely mounted inside the electric panels without



modifying the farms existing electric panel or adding additional safety enclosures. While the power logger can be configured with a network for real time data, it also had enough memory storage capacity to store up to 6 months of trending historical data-logs. However, the research team conducted a physical data download from the power logger every other month. To monitor the circuit, the Fluke 1742 uses flexible split core current probes that can loop around heavy gauge wires commonly found in crowded electric boxes. The other end of the current transformers connects directly to the power logger, displaying current measurements without error prone scaling factors (Figure B). The power logger profiles were set to collect readings for voltage, current, frequency, energy (kWh), active power (kW), reactive power (kVAR), apparent power (kVA) and power factor (PF) on 5-minute intervals over the averaging period.

The ability to hang the power logger inside the existing electric box along with the use for the flexible current probes greatly reduced the amount of time required for the installation. The equipment utilized for this research study was highly accurate with numerous advanced features contributing to a higher overall installation cost. However, there is a growing variety of cost-effective energy loggers available to interested farmers that can be purchased for under \$500. Many of these systems communicate directly with a local network and display real time energy usage statistics to a computer screen or smartphone device.

Timeline

The equipment was installed in of January 2020 and the average installation time was roughly one hour and twenty minutes. Following the installation, maintenance on a 138 kV transmission line caused the farms grain storage site to be without service for several months. As a result, the research team was not able to monitor and calibrate the equipment until August 2020. Data collection for both research sites officially started on September 1, 2020. The case study data presented in this report is a 6-month window from September 2020 to February 2021.

Figure A: Installing the Power Logger.

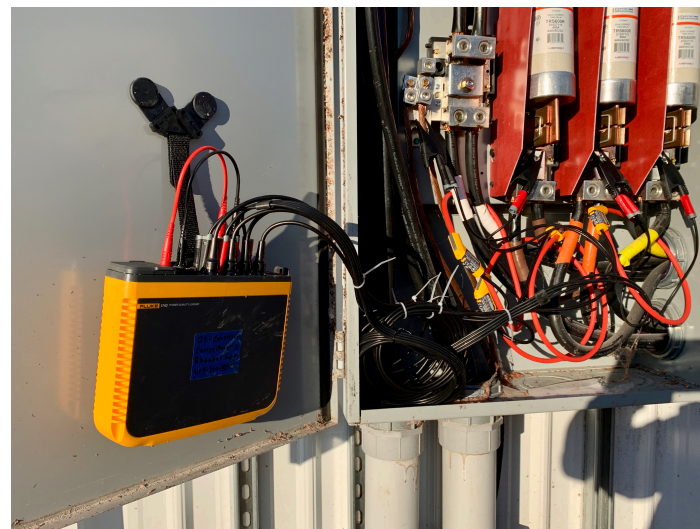


Figure B: Installing the Power Logger.



Photos by: Eric Romich, OSU Extension Field Specialist.

ON-FARM CRITICAL INFRASTRUCTURE SURVEY

In January of 2020, our research team conducted an electronic survey to determine farmers' overall level of interest of investing in energy management strategies on Ohio farms. In addition, we sought to identify individuals who had hands-on experience with energy efficiency, peak demand reduction, and power factor correction projects so we could summarize benefits and challenges. Using the Qualtrics survey software, the OSU research team designed the survey instrument and obtained the appropriate approval from the Ohio State University Office of Responsible Research Practices. This survey was shared amongst farmer groups in the Ohio Soybean Council and OSU Extension network. The study was voluntary, and the answers are shared in aggregate form. In total, 44 participants agreed to take the survey and 34 of the survey participants completed the entire survey.

The study respondents were geographically diverse representing 25 different Ohio counties (Figure C). The 25 counties represented in this study makeup 24% of Ohio's population, 29% of the state's land area, 39% of Ohio's grain farming employment, and 45% of the total economic output for Ohio's grain farming sector. In addition, the respondent's feedback was represented by 13 different electric utility providers in Ohio. When assessing the type of farmers that completed the survey, 100% of respondents identified as row crop farmers who grew corn and soybeans, while 20% of respondents also raised livestock. In total, 90% of respondents operated on-farm grain storage facilities with an average of 173,170 bushels of capacity. The study collected quantitative and categorical data to measure the current knowledge, interest, and experiences of farmers on investing in energy management strategies on their farm. A summary of key findings is illustrated in Figure D below.

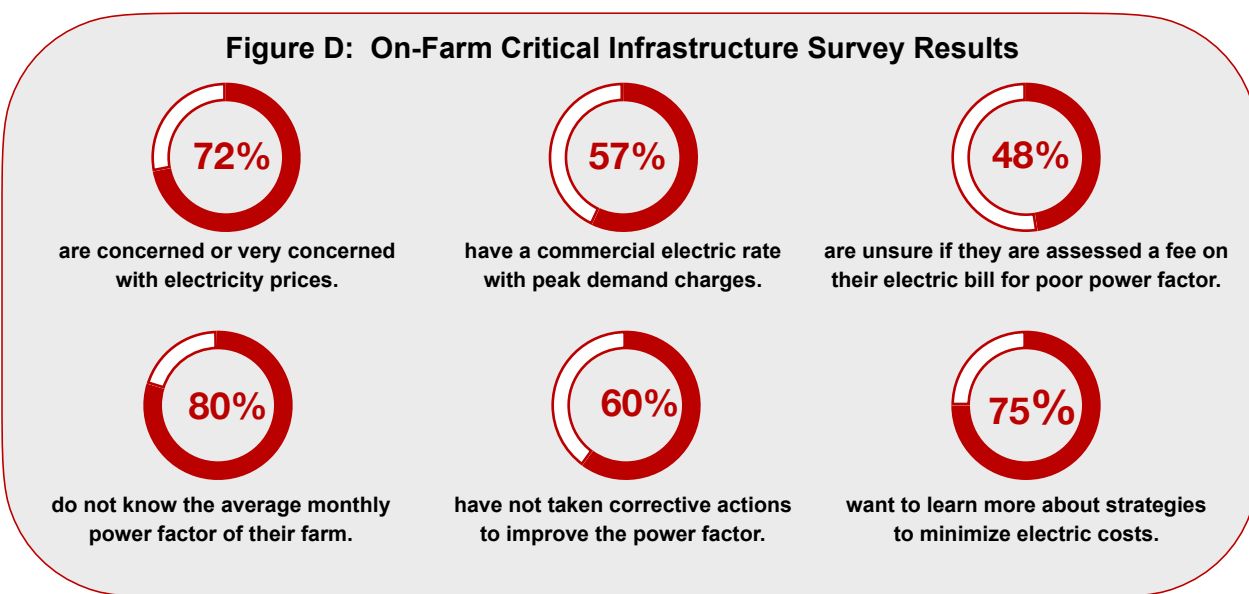
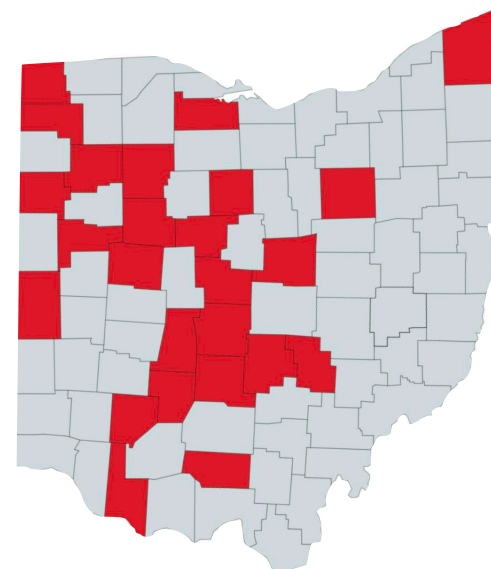


Figure C: Survey Response by County



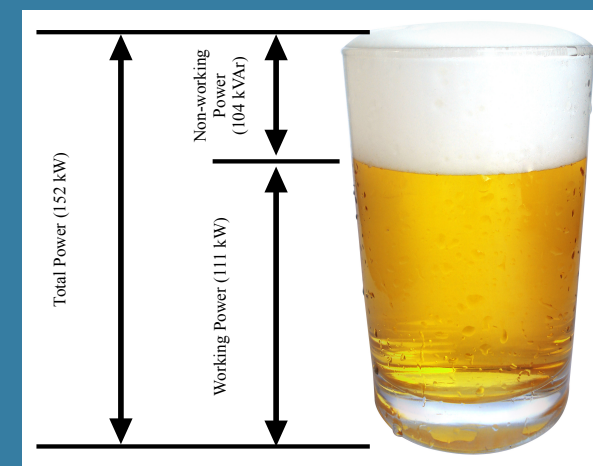
WHAT IS POWER FACTOR?

Power factor is a metric to measure how efficiently electricity is being used at your facility. To better understand the concept of power factor and how it is calculated, it is important to first understand some key electrical terminology (Figure E). First, active power, measured in kilowatts (kW), is the power that actually performs the useful work of creating heat, light, and motion. Active power is also referred to as **working power**, true power, actual power, real power, and useful power. For the purpose of this bulletin, we will refer to active power as **working power** because it is the power that actually does work. Next, reactive power which is measured in kilovolt-amps reactive (kVAR), is power that flows between the generator and load to sustain the magnetic field required in inductive loads such as electric motors. Reactive power is also referred to as **non-working power**, imaginary power, phantom power, and useless power. For the purpose of this bulletin, we will refer to reactive power as **non-working power** because although it takes up capacity in the distribution system and is required to magnetize inductive loads, it is power that does not preform useful work. Finally, apparent power, measured in kilovolt-amps (kVA), is the vectorial sum of working and non-working power. Apparent power is also referred to as **total power** or complex power. For the purpose of this bulletin, we will refer to apparent power as **total power** because it is made up of both working and non-working power.

As mentioned, the basic purpose of power factor is to quantify how efficiently a customer's electric load utilizes the current that it draws from a utility distribution power system. The lower the power factor at your farm, the more likely a utility will implement fees or surcharges that increase the overall electric bill. While each utility is unique, in Ohio many utilities tend to require consumers on commercial accounts to maintain a power factor of at least 90% to avoid additional fees. As the technology of power electronics has evolved over time, there are now additional variables that can significantly influence power factor. Many modern-day power electronics such as a variable frequency drive controllers can produce currents and voltages with frequencies higher than the fundamental frequency (60 Hz), which is effectively a type of electrical pollution known as harmonic distortion within the power system. As a result, today there are two primary components of power factor including displacement power factor and distortion power factor.

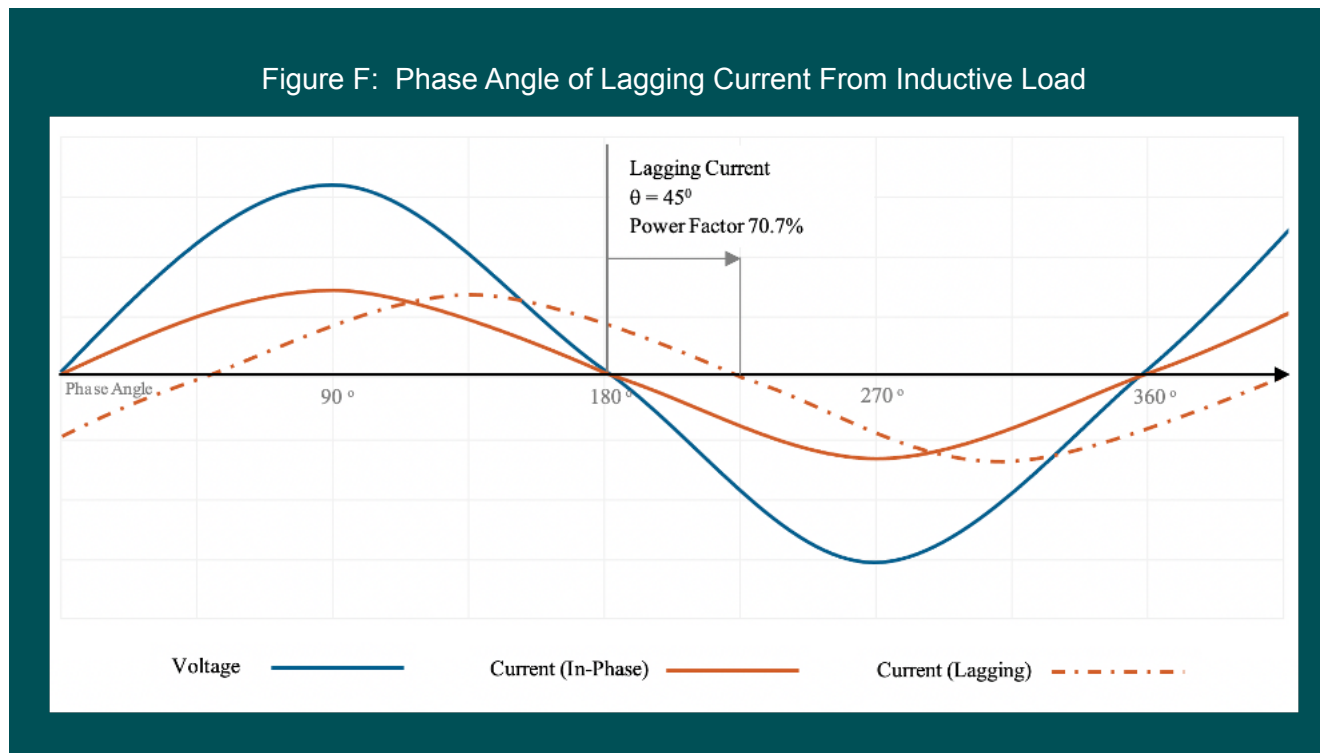
Figure E: Key Terms and Power Factor Analogy

- **Working Power (kW)** - Power that preforms useful work. This is represented as the liquid you drink in the schematic below.
- **Non-working Power (kVAR)** - Power that doesn't preform useful work but is required to sustain magnetic fields in induction loads. In the schematic below, this is represented as foam taking up space within the limited capacity of the cup that you do not drink.
- **Total Power (kVA)** - Power that is the vector sum of working and nonworking power. This is represented as everything that you pay for in the glass including both the liquid and foam in the schematic below.



Displacement Power Factor

The displacement power factor is the ratio of working power to apparent power (power factor = working power / non-working power) and is typically expressed as a percentage. A displacement power factor assumes there is no harmonic distortion present and is caused by inductive loads such as motors, which are considered linear loads. A linear load is a one where the input and output are linearly proportional, within a given range. These loads need non-working power to create and sustain a magnetic field, causing a phase shift between the current and voltage waveforms at the fundamental line frequency (60 Hz). When current and voltage are in-phase, the power factor is theoretically 100% indicating perfectly efficient use of energy and perfect unity of voltage and current in phase. However, induction loads from electric motors commonly utilized in on-farm grain storage facilities will cause the current to shift and lag voltage. The displacement angle between the current and voltage waves can be measured and is referred to as the phase angle. As illustrated in Figure F, the phase angle caused by the current lagging voltage is 45° and the power factor can be calculated as the cosine of the 45° phase angle, which is 71%.



The power triangle helps further describe the displacement power factor by visualizing relationships between working power (kW), non-working power (kVAR), and total power (kVA). Shown in figures G and H, working power (kW) remains constant, as the non-working power (kVAR) decreases, so does the total power (kVA) delivered to the system decrease. For example, to provide 111 kW of working power at a 71% power factor, it requires 156 kVA of total power to account for the 110 kVAR of non-working power used to sustain magnetic fields in induction motors. In comparison, to provide 111 kW of working power at a 90% power factor, it only requires 123 kVA of total power to account for the 54 kVAR of non-working power used to sustain magnetic fields in induction motors. In summary, for a system with a low power factor operating at a 71% power factor, it takes 27% more current to deliver the same amount of working power when compared to a system operating at a 90% power factor.

Distortion Power Factor

Non-linear devices are sources of harmonics, which leads to current and voltage distortion, giving rise to another component of power factor, which is known as distortion factor.¹ As described in the previous section, linear loads commonly caused by induction motors trigger an alteration in the phase angle as current waveform shifts and lag the voltage waveform. In comparison, non-linear loads commonly caused by power electronics such as variable frequency drive motor controllers and switching power supplies have a very different impact on the relationship between current and voltage. In a non-linear load, harmonic distortion causes the draw of current in the system to warp so that the current does not have the same waveform shape as the supply voltage, the relationship between current and voltage truly becomes, non-linear (Figure I). Harmonic currents in non-linear loads do not produce any useful work and therefore are reactive in nature.

Figure G: Power Triangle - Poor Power Factor (71%)

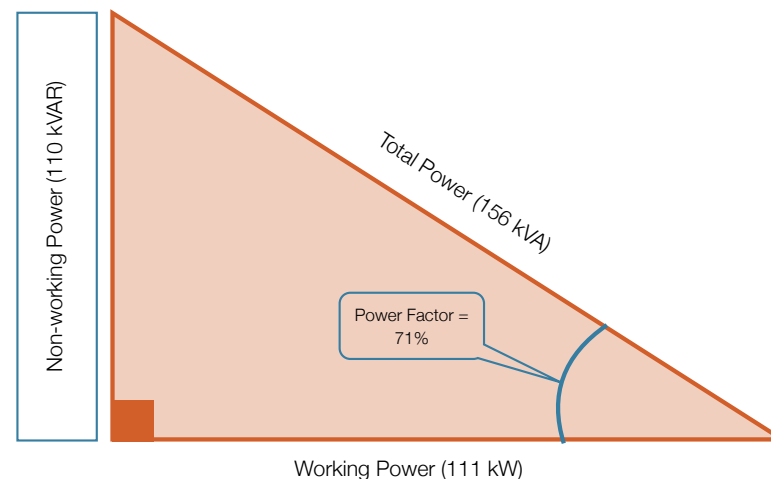
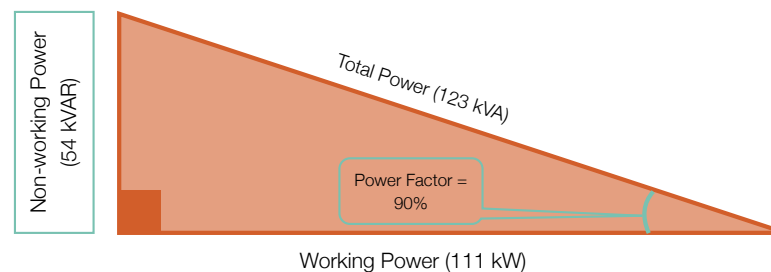
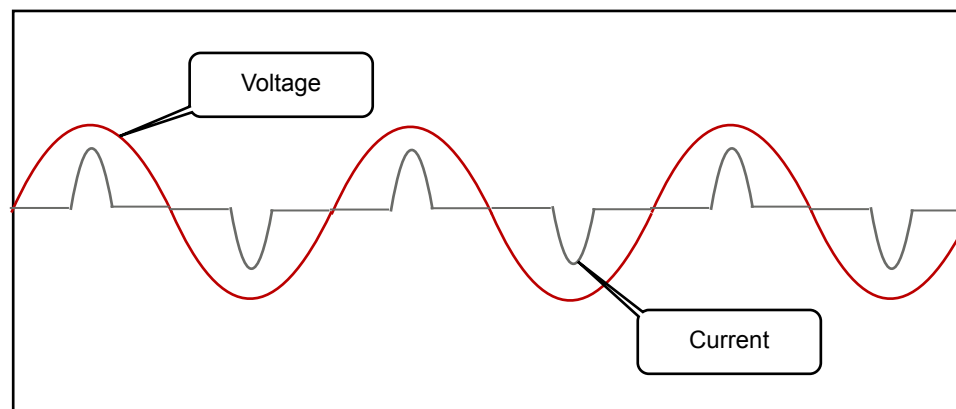


Figure H: Power Triangle - Acceptable Power Factor (90%)



A common measurement of quantifying the amount of harmonic distortion in a system is Total Harmonic Distortion (THD), sometimes referred to as distortion factor. The THD is a mathematical calculation that expresses the value of distortion current or voltage as a percentage of the fundamental levels. As a general guide the THD for voltage should not exceed 5 % and while THD for current will run considerably higher, it should generally be lower than 20%. Common non-linear loads from power electronic devices with harmonic distortion include variable frequency drive controllers, programmable logic controls, welding equipment, computers, fax machines, printers, refrigerators, televisions, and electronic lighting ballasts. In summary, wherever there are large numbers of non-linear loads, there will be some level of harmonic distortion in the distribution system that contributes to poor power factor.

Figure 1: Non-linear Current from Harmonic Distortion



True Power Factor

The lower the power factor at your farm, the more likely a utility will implement fees or surcharges that increase the overall electric bill. While each utility is unique, in Ohio many utilities tend to require consumers on commercial accounts to maintain a power factor of at least 90% to avoid additional fees. To account for both phase angle shifts and harmonic distortion, we use a metric referred to as true power factor. True power factor accounts for both the displacement power factor and the distortion power factor represented as: $\text{True Power Factor} = \text{Displacement Power Factor} \times \text{Distortion Factor (THD)}$.

While it is interesting, it is not necessarily essential to understand how to calculate your true power factor. Most utility meters will account for power factor plus the impacts of harmonics in the power factor they record on your account. However, conceptually it is important to understand the difference in displacement and distortion power factors. Before implementing corrective actions, it is critical to first understand if the poor power factor is caused by a phase angle shift from inductive loads or current distortion due to harmonics, or a combination of both. By better understanding the cause, you can accurately prescribe correction strategies that will effectively improve the power factor and reduce energy cost.



ELECTRIC RATE STRUCTURE

If your farm has a commercial rate with peak demand charges, it is extremely important to understand how the demand charges are calculated. In addition, it is important to analyze your load profile or usage patterns to understand when your facility is setting its peak demand and what equipment is causing the spike in usage. Some utilities have rate structures that include specific requirements for consumers on demand rates to maintain a minimum power factor. If the power factor falls below the minimum requirement, the utility can assess additional fees. While many utility providers consider the power factor of the facility when calculating the monthly billing demand charges, the resulting impact to the consumer is erratic. For example, in some cases there are no additional fees for poor power factor, or the fees are extremely low. However, there are some rate structures with significant power factor penalty fees and power factor correction strategies could offer long term cost savings.

Not all utilities will show the power factor on your bill, however if you see both peak kW and peak kVA stated on your bill, it is likely that power factor is considered when calculating your monthly billing demand. However, there are various methods that utilities use to calculate and apply fees for poor power factor. This bulletin is designed as a guide to help you understand common power factor billing methods and the possible implications. Please refer to your utility rate structure to review the details of how you may, or may not, be charged for poor power factor. Most state utility commission websites provide a list of the rate structures for investor-owned utilities, or you can request a copy of your rate structure from your utility provider. Several common methods of how to calculate demand charges while incorporating possible fees for poor power factor includes Base Demand Billing, Direct KVA Billing, Excess kVA Billing, and Power Factor Adjusted Billing. Each of these methods are described in further detail below.

Base Demand Billing

In most cases, farms that are on a general service commercial rate will pay a peak demand charge based on the peak usage of active power (kW) over a specific period in time. Most utilities will measure a peak demand as a rolling average over a specific time interval, typically 15, 30, or 60 minute intervals. The demand rate may include separate rates for distribution demand and transmission demand or combine them into one flat demand charge. Some utilities also have rate structures that include a seasonal and/or tiered demand rates structure. While it is not normally included on your monthly bill, commercial customers are often required to maintain a power factor above 90% to avoid additional fees or alternative methods of calculating the billing demand. Minimum power factor requirements are often not included on the monthly billing statement but are outlined in detail in the utility rate structure. Example 1 illustrates a basic monthly peak demand calculation on a grain dryer farm that maintained a power factor above 90% as outlined in the rate structure.

Figure J: Calculating Demand and Assessing Power Factor Correction

Utility Rate Assumptions & Abbreviations:

Minimum Power Factor (PF_{Min}): 90%

Base Demand Charge (Cost_{Demand}): \$13.50

Excess KVA Demand Charge (Cost_{Ex-kVA}): \$4.85

Total Demand Charge on Utility Bill (Total_{Charge})

Monthly Demand Assumptions & Abbreviations

Working Power (kW): 111

Nonworking Power (kVAR): 104

Total Power (kVA): 152

Recorded Power Factor (PF_{Rec}): 73%

Example #1: Base Demand Billing

$$\text{kW} \times \text{Cost}_{\text{Demand}} = \text{Total}_{\text{Charge}}$$

$$111 \times \$13.50 = \$1,499$$

Example #2: Direct KVA Billing

$$\text{kVA} = (\text{kW} / \text{PF}_{\text{Rec}}) \times \text{Cost}_{\text{Demand}} = \text{Total}_{\text{Charge}}$$

$$(111 / 0.73) \times \$13.50 = \$2,052$$

Example #3: Excess kVA Billing

$$[\text{kW} \times \text{Cost}_{\text{Demand}}] + [(\text{kVA} - \text{kW}) \times \text{Cost}_{\text{Ex-kVA}}] = \text{Total}$$

$$\text{Charge Base Demand Cost: } 111 \times \$13.50 = \$1,499$$

$$\text{Excess kVA Cost: } (152 - 111) \times \$4.85 = \$199$$

$$\text{Total Billing Amount} = \$1,499 + \$199 = \$1,698$$

Example #4: Power Factor Adjusted Billing

$$[(\text{PF}_{\text{Min}} / \text{PF}_{\text{Rec}}) \times \text{kW}] \times \text{Cost}_{\text{Demand}} = \text{Total}_{\text{Charge}}$$

$$[(0.90 / 0.73) \times 111] \times \$13.50 = \$1,847$$



Direct KVA Billing

If a consumer on a commercial account fails to maintain a power factor above the minimum standard outlined in the rate structure, some utilities will apply a Direct kVA Billing method. In a Direct kVA Billing method, the utility may measure and bill for every kilovolt-amp (kVA) of total power supplied, including reactive current. Example #2 demonstrates the calculation of Direct kVA Billing on a farm with a 111-kW measured demand and a power factor of 73% during the billing period.

Excess kVA Billing

The Excess kVA Billing method is like the standard Base Demand Billing method that is based on the peak usage of active power (kW) over the billing period and the demand charge rate. However, in addition to this base demand fee, consumers are charged a separate rate for any “excess kVA”, which is essentially the difference between the measured total power (kVA) and working power (kW) during the billing period. Example #3 outlines the formula and provides sample calculations for the Excess kVA Billing method.

Power Factor Adjusted Billing

The Power Factor Adjusted Billing method uses the base demand calculation at normal demand rates with a demand multiplier applied to account for low power factor. The multiplier is typically represented as a ratio of the minimum allowable power factor described in the rate structure over the recorded power factor over the billing period. Example 4 outlines the formula and provides sample calculations for the Power Factor Adjusted Billing method.

RFEM FARM CASE STUDY

As part of the research partnership between Ohio State University Extension and the Ohio Soybean Council, this case study report is specifically focused on data collected from the RFEM Farm research site. The RFEM farm participated in a two-year Ohio State University Extension on-farm research project to measure peak energy demand and power quality data. RFEM Farms is a family-owned farm located in Marion County, Ohio. The farm manages a total of 3,300 acres consisting primarily of corn and soybeans. Marion County is a strong agricultural county ranking 23rd in total agricultural receipts for the state of Ohio.

According to the Ohio Agricultural Statistics 2017-2018 Annual Bulletin Marion County ranked 19th in the state with 9,706,505 bushels of on-farm grain storage capacity. The RFEM Farms research site has a Meyer 1800 tower dryer and two Sukup storage bins with approximately 210,000 bushels of on-farm storage capacity. The primary motor loads on the grain storage facility include:

- 50 horsepower motors (2) - Tower Dryer Fan
- 40 horsepower motor - Receiving Elevator
- 15 horsepower motor - Dryer Elevator
- 20 horsepower motor - Pit Conveyor
- 20 horsepower motor (2) - Bin Aeration Fan
- 10 horsepower motor - Bin Fill Conveyor
- 5 horsepower motor - Reclaim Conveyor
- 3 horsepower motor - Dryer Reclaim Conveyor

Figure K: Fan Motor (20 HP)



Figure L: Auger Motor (20 HP)



Figure M: RFEM Farm Grain Bins

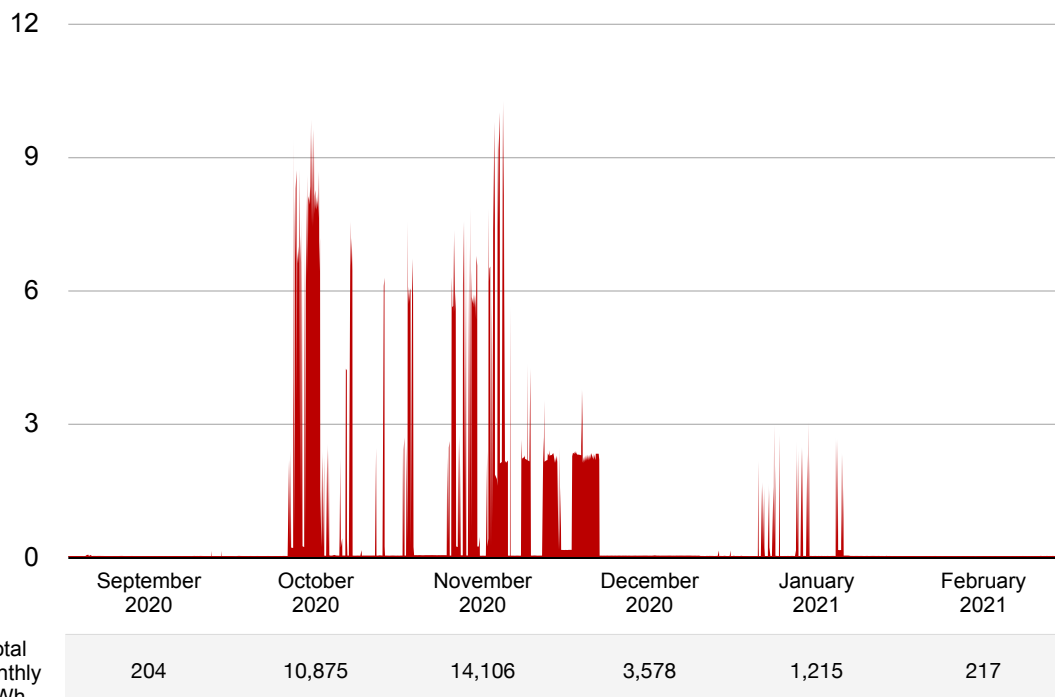


Photos by: Eric Romich, OSU Extension Field Specialist.



The site does not have any variable frequency drive equipment installed. The facility has 480 Volt three phase electric service and the split core current transformers were installed at the service entry point in the main disconnect box. Due to a transmission line upgrade of the utility's infrastructure, the RFEM on-farm grain storage facility was without grid power for the first half of 2020 and the facility was powered by a 200-kW backup generator to sustain the operation during the outage. During this time, our energy meters were not able to monitor the electric usage on the site, prohibiting our team from collecting a 12-month window of data. However, the data for the RFEM Farms was collected for the 2020 harvest season ranging from September 2020 to February 2021.

Chart 1: RFEM Farms - Energy Usage kWh (5-Minute Interval)



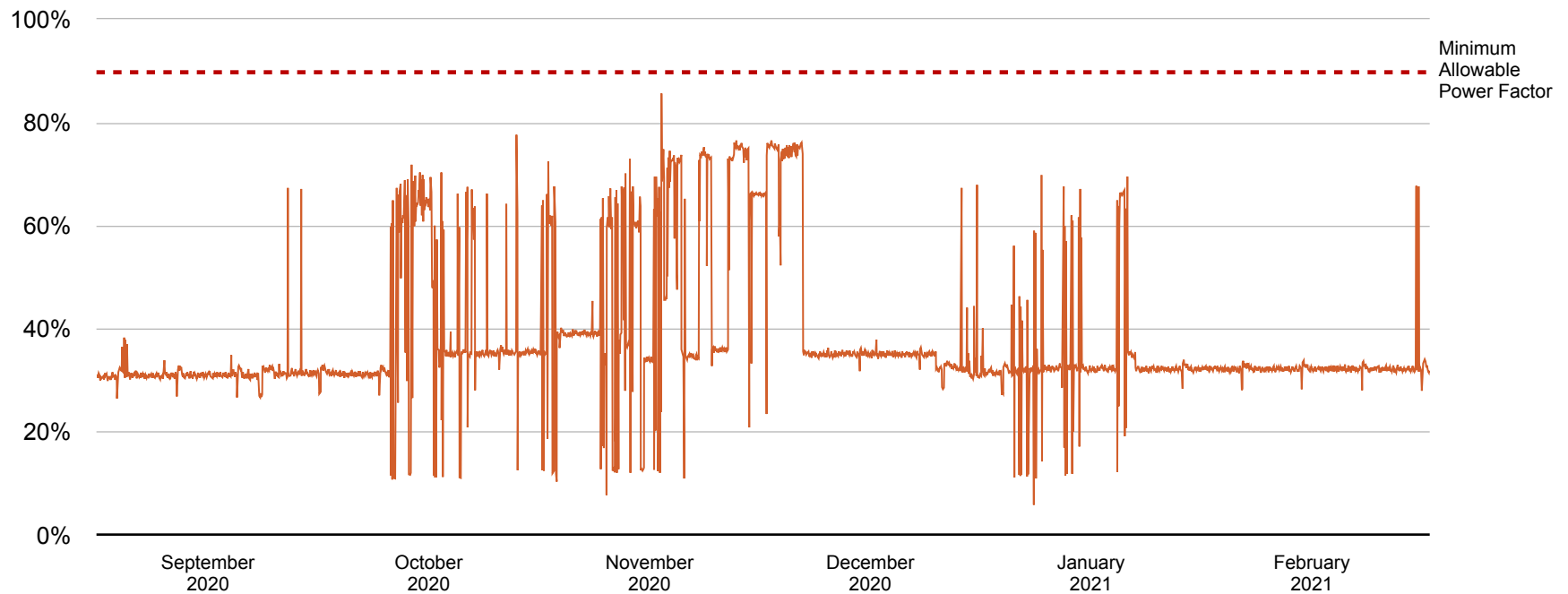
RFEM Energy Usage

Chart 1 Provides a visualization of the energy usage (kWh) on the RFEM farm in 5-minute intervals. Over the six-month analysis period, the RFEM farm used a total of 30,194 kWh of electricity for the on-farm grain storage facility. Over the six-month period the farm used an average of 5,032 kWh per month, including a minimum of 204 kWh used in September 2020 and a maximum of 14,106 kWh in November 2020. As shown in Chart 1, the energy usage is extremely seasonal with periods of very low usage before and after the harvest season.

RFEM Power Factor

Power factor is the ratio between working power and total power (Power Factor = Working Power / Total Power), typically expressed as a percentage. As described earlier, commercial electric rates are unique. For example, some utilities will consider the average power factor over the billing period while others will use the power factor recorded during the time window that the peak demand was established. While the RFEM farm's power factor is calculated as a monthly average, Chart 2 provides both the monthly average power factor and the power factor recorded at the time of the monthly peak demand to help understand the potential difference. In general, electric motors are most efficient when properly sized and operated full load, which will improve the power factor. Not operating a system at full load will cause the power factor to vary over time. The line graph in Chart 2 illustrates the

Chart 2: RFEM Farms - True Power Factor



Power Factor @ Peak Demand Event	67.4%	70.4%	73.4%	61.3%	67.2%	67.3%
Average Monthly Power Factor	31.1%	37.3%	47.7%	42.2%	33.4%	32.4%

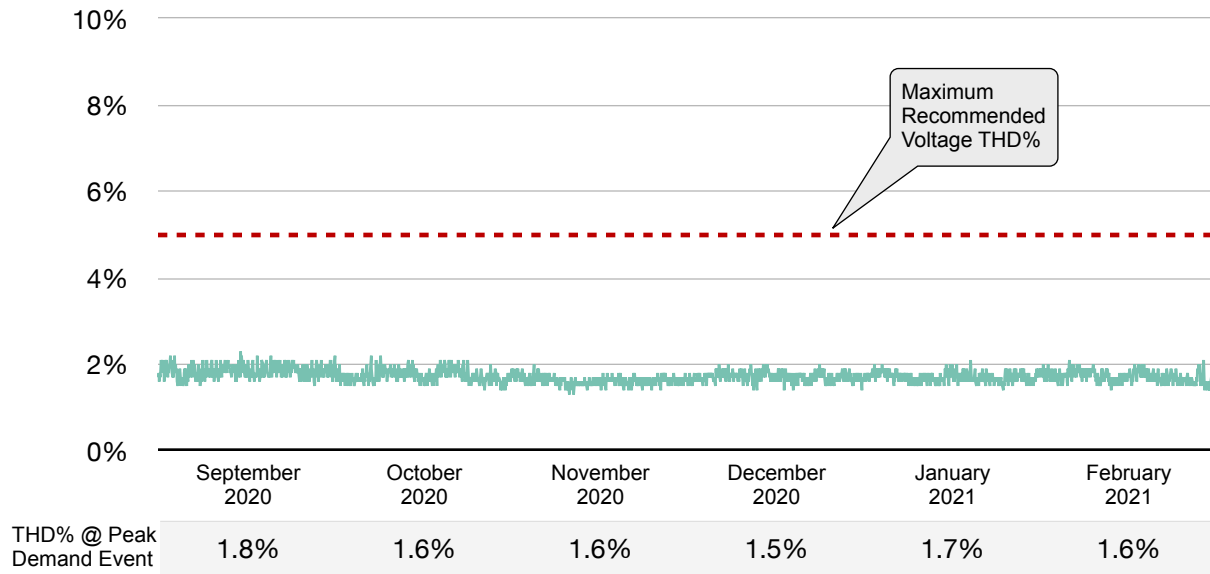
power factor data for the RFEM farm on 5-minute intervals. When assessing the six-month study period, the power factor ranged from a low of 6% to a high of 86% and an average of 38%. To avoid additional charges, the electric utility rate structure for the grain storage facility requires RFEM farm to maintain a power factor of 90% or greater, which is identified by the red dotted line in Chart 2. When assessing the average monthly power factor and the power factor at the time of the monthly peak demand, both metrics were well below the 90% minimum allowable power factor during the study period.

RFEM Harmonic Distortion

Harmonic distortion triggers an alteration or reshaping of the voltage and current waveforms causing the relationship between the two to become non-linear. We recorded the voltage and current THD in 5-minute intervals over the six-month study period from September 2020 to February 2021 and calculated the monthly average for both categories.

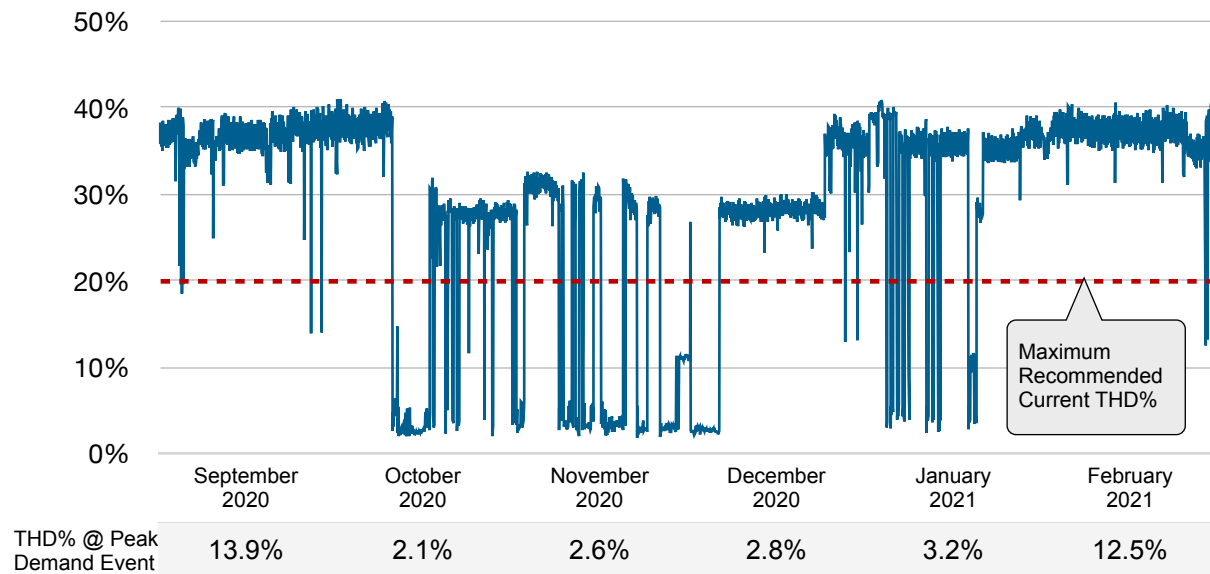


Chart 3: RFEM Voltage THD%



As shown in Chart 3, the voltage THD tends to produce a consistent trend pattern both from a daily and seasonal perspective. When considering the RFEM farm power logger 5-minute interval data recorded over the entire six-month study period the lowest recorded voltage THD was 1.3%, the highest was 2.3%, while the average voltage THD for the study period was 1.7%. When analyzing the monthly voltage THD recorded during the monthly peak demand window, all six months in the study period were under 2%. As illustrated by the red dotted line in the chart, a voltage THD under 5% is generally considered acceptable and likely not negatively impacting the overall power factor.

Chart 4: RFEM Current THD%



As shown in Chart 4, the current THD tends to produce fluctuating trend pattern that is less predictable. When considering the RFEM farm power logger 5-minute interval data recorded over the entire six-month study period there was a larger range as the lowest recorded current THD was 1.7%, the highest was 41.4%, and the average current THD for the study period was 28.7%. However, when analyzing the monthly current THD recorded during the monthly peak demand window, all six months in the study period were under 20%. As illustrated by the red dotted line in the chart, a current THD under 20% is generally considered acceptable and likely not negatively impacting the overall power factor.

RFEM Peak Demand

In this section we analyze the power quality logger results for working power, non-working power, total power, and power factor at the RFEM farm during the maximum monthly peak demand event. The data is filtered and presented based on a calendar month, which may vary slightly from the farms actual electric bill based on the service period days used to calculate their monthly bill.

When comparing the average monthly demand to the maximum monthly demand, there is a considerable difference (Chart 5). For example, as illustrated in Chart 5 the maximum 15-minute monthly demand of 125 kW was set in November 2020, which was the largest demand recorded at the RFEM farm during the six-month study period. However, when considering the 20 kW average monthly demand in November 2020, it is clear that most of the time the farm requires significantly less electrical demand to operate the facility than the energy actually used to set the monthly maximum demand. Chart 6 provides a more detailed daily perspective of the 15-minute demand profile for the RFEM farm in November 2020. As shown in Chart 6, even in the month with the greatest peak demand spike, the overall usage at the faculty was sporadic with very few spikes exceeding 100kW. In fact, 82% of the time, the demand at the RFEM farm in the month of November 2020 was under 35kW. This reenforces the impact of inconsistent seasonal usage from large motor loads and indicates that most of the time the farm requires significantly less electrical demand to operate the facility than the energy actually used to set the monthly maximum demand.

Chart 5: Average and Maximum Monthly Demand (kW)

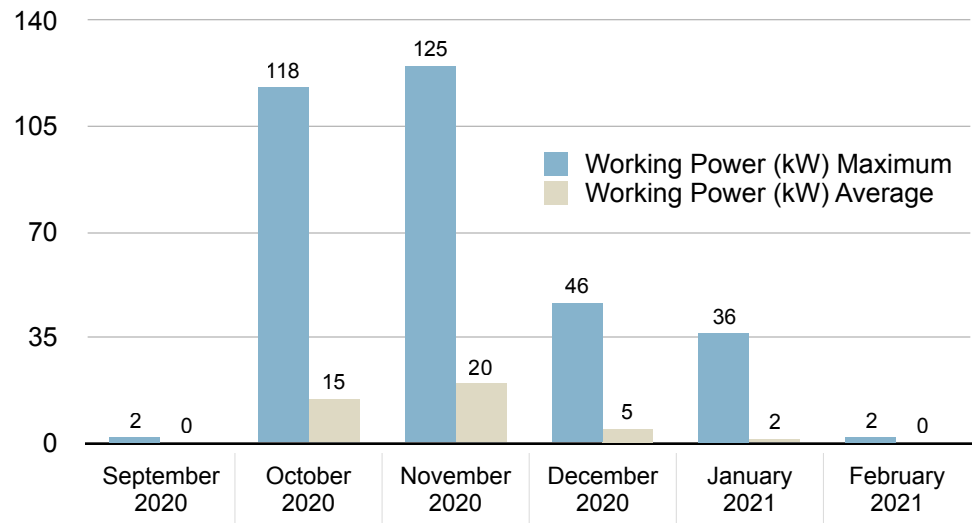
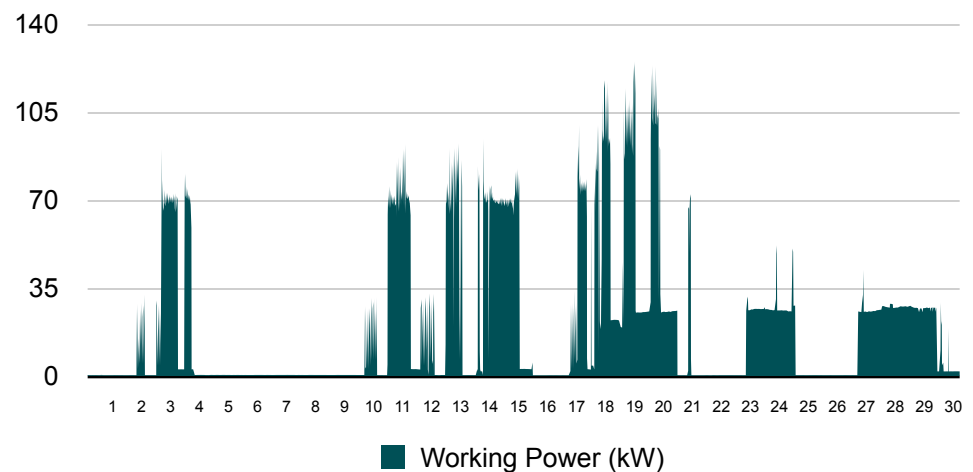


Chart 6: November 2020 Peak Demand (15-Minute Interval)



While understanding the peak demand trends is important, there are other considerations. As we described earlier, for commercial accounts there may be a difference between the actual measured monthly peak demand of working power (kW) and the billing demand that is applied to electric bill.

Many utility providers require commercial accounts to maintain a power factor above 90% to avoid additional charges. As discussed, there are various formulas used to apply additional charges for the impacts of poor power factor and most of the formulas consider the total power (kVA) in some manner. As a result, it is important to consider the interactions between the maximum monthly peak demand from working

power (kW), the power factor, non-working power (kVAR), and total power (kVA). As described earlier, the non-working power (kVAR) takes up capacity in the distribution system as it flows between the generator and load to sustain the magnetic field required for inductive loads, yet it does not preform useful work. Assuming working power (kW) remains constant, and the non-working power (kVAR) goes up, the total power (kVA) would increase, which would lower the overall power factor.

The scale, or size of the demand spike is important to the overall economic impact of poor power factor. This becomes evident when considering the monthly excess kVA, which is simply defined as the

Chart 7: RFEM Power Quality Logger Results @ 15 Min Peak Demand Event

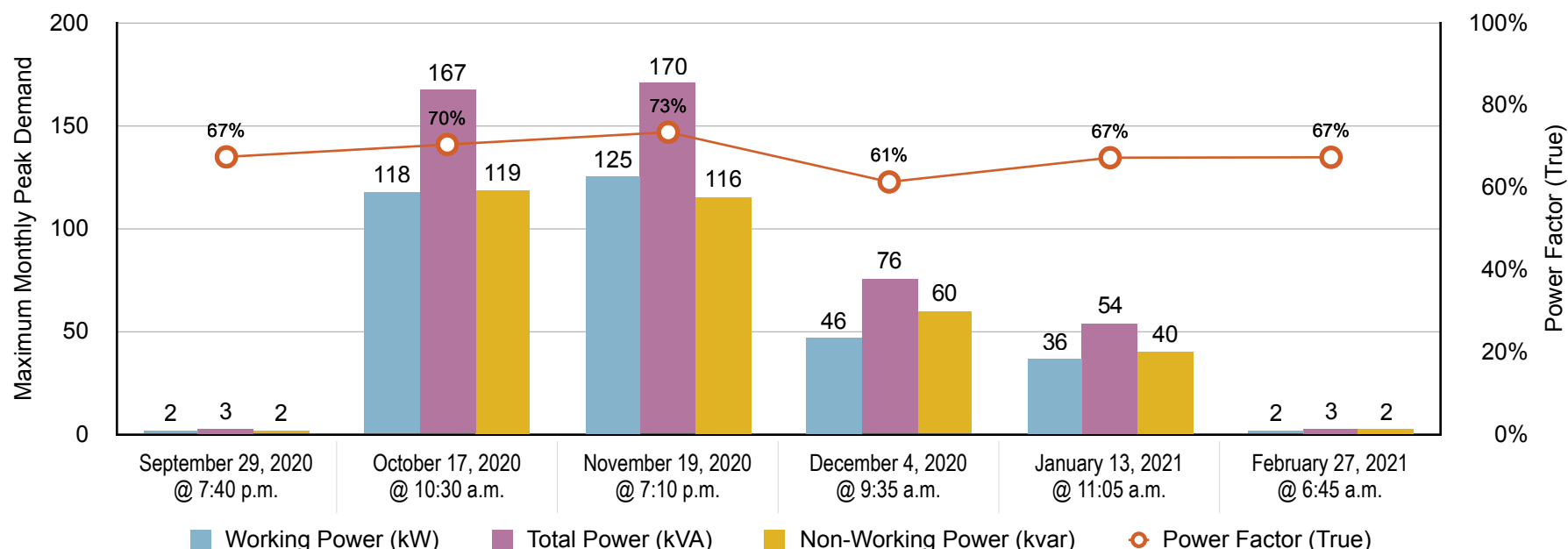


Table 1: RFEM Farm Case Study Analysis of Additional Power Factor Fees With Various Billing Methods

Month	Baseline - kW Demand Billing (PF above 90%)	Additional Power Factor Fees with Direct KVA Billing (PF below 90%)	Additional Power Factor Fees with Excess kVA Billing (PF below 90%)	Additional Fees with Power Factor Adjusted Billing (PF below 90%)
Sep 2020	\$23	\$11	\$4	\$8
Oct 2020	\$1,591	\$667	\$240	\$443
Nov 2020	\$1,688	\$611	\$219	\$382
Dec 2020	\$627	\$396	\$142	\$293
Jan 2021	\$491	\$239	\$86	\$167
Feb 2021	\$24	\$12	\$4	\$8
6 Month Total:	\$4,444	\$1,936	\$696	\$1301

Notes: Calculations are based on monthly power factor and demand data from Chart 7 assuming a monthly billing demand cost of \$13.50 per kW/kVA and an excess kVA demand cost of \$4.85 per kVA. Please refer to Figure J for additional information regarding the formulas used for each billing method.

difference between the total power (kVA) and the working power (kW). For example, as illustrated in Chart 7, the month with the lowest power factor was December 2020 at 61%, while the best power factor of 73% was recorded in November 2020. However, because the demand was significantly higher in November the excess kVA was 45 kVA, while in December the excess kVA was only 29 kVA. In summary even though the power factor in December was lower than the power factor in November, the impact was greater in November because there was a significantly higher peak demand.

Financial Implications

The financial impacts of poor power factor are difficult to quantify because many utilities have different rules. In fact, some utilities do not apply penalty fees for poor power factor, while others have very specific requirements and unique formulas that are applied to charge for poor power factor. To help better understand the range of possible cost associated with poor power factor, Table 1 used the power logger data from the RFEM farm and applied several common methods used to estimate demand charges and possible fees for poor power factor. The billing methods used includes Base Demand Billing, Direct KVA Billing, Excess kVA Billing, and Power Factor Adjusted Billing. Each of these methods and formulas are described in further detail in the electric rates section of this report. As illustrated in Table 1, the additional cost associated with poor power factor over the six-month study period ranged from zero under the baseline demand billing scenario, to \$1,936 with the direct kVA billing model. Please note that the costs in Table 1 are designed to provide the reader a range of possible outcomes and the actual cost applied to the RFEM farm electric bill was different due to a more complex power factor formula.



DFEM FARM CASE STUDY

As part of the research partnership between Ohio State University Extension and the Ohio Soybean Council, this case study report is specifically focused on data collected from the DFEM Farm research site. The DFEM farm participated in a two-year Ohio State University Extension on-farm research project to measure peak energy demand and power quality data. DFEM Farms is a family-owned farm located in Delaware County, Ohio. The farm manages a total of 3,100 acres consisting of roughly 1,400 acres of corn, 1,400 acres of soybeans, and 300 acres of wheat. Delaware County has a stable agricultural sector ranking 47th in total agricultural receipts for the state of Ohio.

According to the Ohio Agricultural Statistics 2017-2018 Annual Bulletin Delaware County ranked 37th in the state with 6,746,007 bushels of on-farm grain storage capacity. The DFEM Farms research site has a FFI/Zimmerman Series F tower dryer with a series of Brock storage bins totaling approximately 275,000 bushels of on-farm storage capacity. The primary motor loads on the grain storage facility include:

- 75 horsepower motor - Tower Dryer Fan
- 30 horsepower motor - Blower Air Pump
- 60 horsepower motor - Grain Leg (130ft)
- 5 horsepower motors (5) - Bin Unloads
- 10 horsepower motors (4) - Drag-Bin Unloads
- 7.5 horsepower motors (2) - On-Drags
- 15 horsepower motors (2) - Aeration Fans

Figure N: DFEM Farm Grain Bins



Figure O: Auger Motors

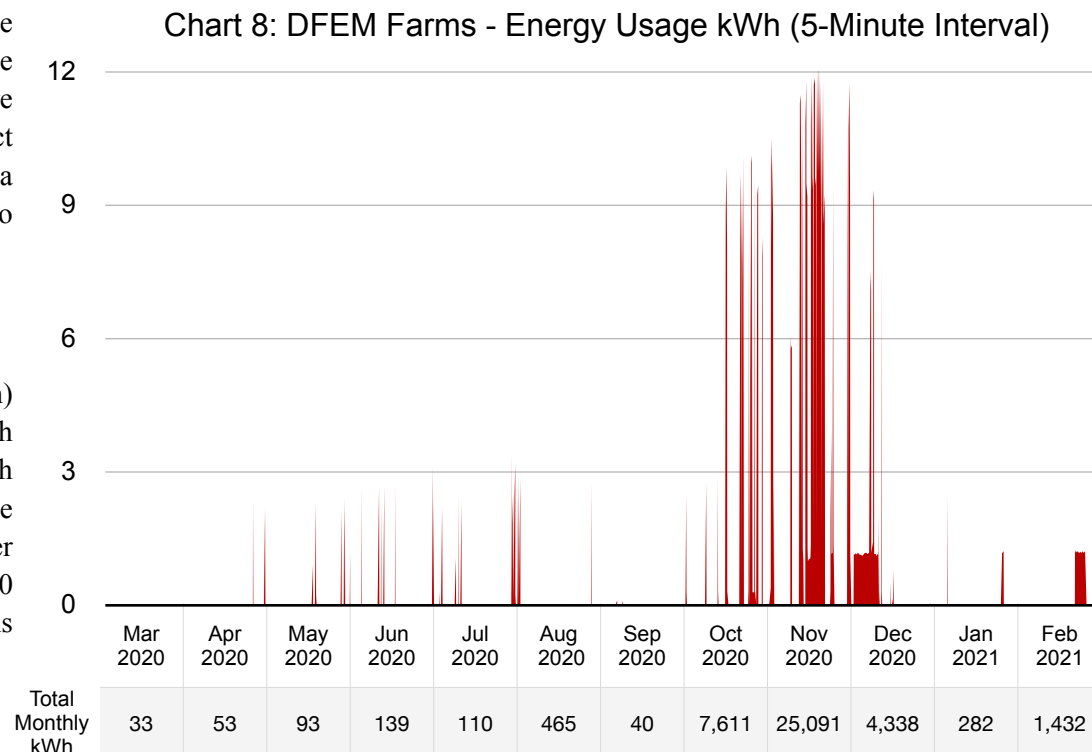


Photos by: Eric Romich, OSU Extension Field Specialist.

The site does not have any variable frequency drive equipment installed. The facility has 480 Volt three phase electric service and the split core current transformers were installed at the service entry point in the main disconnect box. Energy data for the DFEM Farm case study includes a 12-month window of data collected from March 2020 to February 2021.

RFEM Energy Usage

Chart 8 provides a visualization of the energy usage (kWh) on the DFEM farm in 5-minute intervals. Over the 12-month analysis period, the DFEM farm used a total of 39,688 kWh of electricity for the on-farm grain storage facility. Over the 12-month period the farm used an average of 3,307 kWh per month, including a minimum of 33 kWh used in March 2020 and a maximum of 25,091 kWh in November 2020. As shown in Chart 8, the usage is extremely seasonal with periods of very low usage before and after the harvest season.

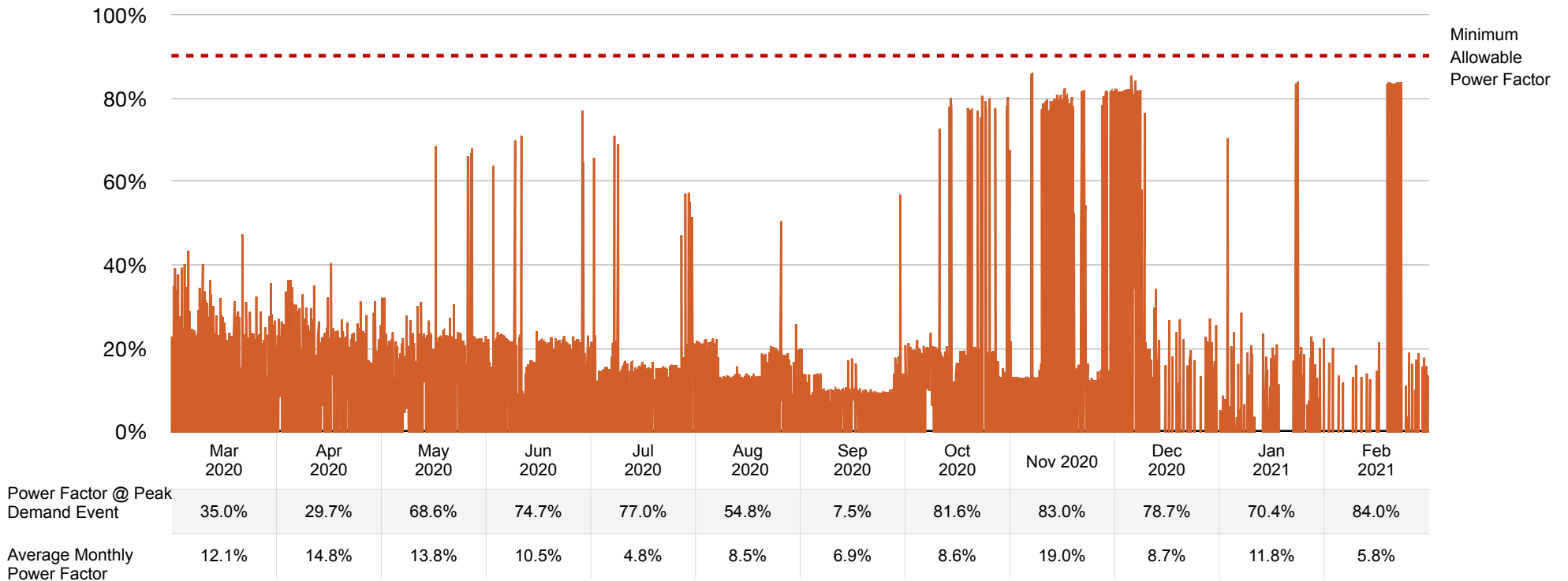


DFEM Power Factor

Power factor is the ratio between working power and total power (Power Factor = Working Power / Total Power), typically expressed as a percentage. As described earlier, commercial electric rates are unique. For example, some utilities will consider the average power factor over the billing period while others will use the power factor recorded during the time window that the peak demand was established. While the DFEM farm's power factor is calculated as a monthly average, Chart 9 provides both the monthly average power factor and the power factor recorded at the time of the monthly peak demand to help understand the potential difference. In general, electric motors are most efficient when properly sized and operated full load, which will improve the power factor. Not operating a system at full load will cause the power factor to vary over time. The line graph in Chart 9 illustrates the power factor data for the DFEM farm on 5-minute intervals. When assessing the 12-month study period, the power factor during the peak demand window ranged from a low of 7.5% to a high of 84% and an average of 62%. To avoid additional charges, the electric utility rate structure for the grain storage facility requires DFEM farm to maintain a power factor of 90% or greater, which is identified by the red dotted line in Chart 9. When assessing



Chart 9: DFEM True Power Factor



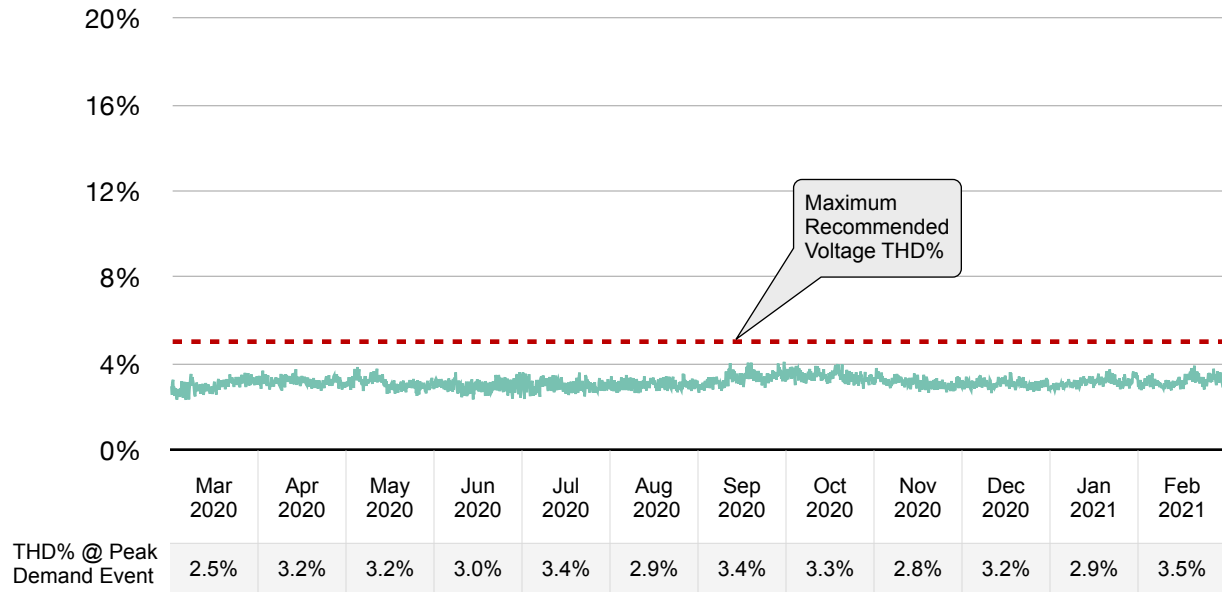
the average monthly power factor and the power factor at the time of the monthly peak demand, both metrics were below the 90% minimum allowable power factor during the study period.

RFEM Harmonic Distortion

Harmonic distortion triggers an alteration or reshaping of the voltage and current waveforms causing the relationship between the two to become non-linear. We recorded the voltage and current THD in 5-minute intervals over the 12-month study period from March 2020 to February 2021 and calculated the monthly average for both categories.

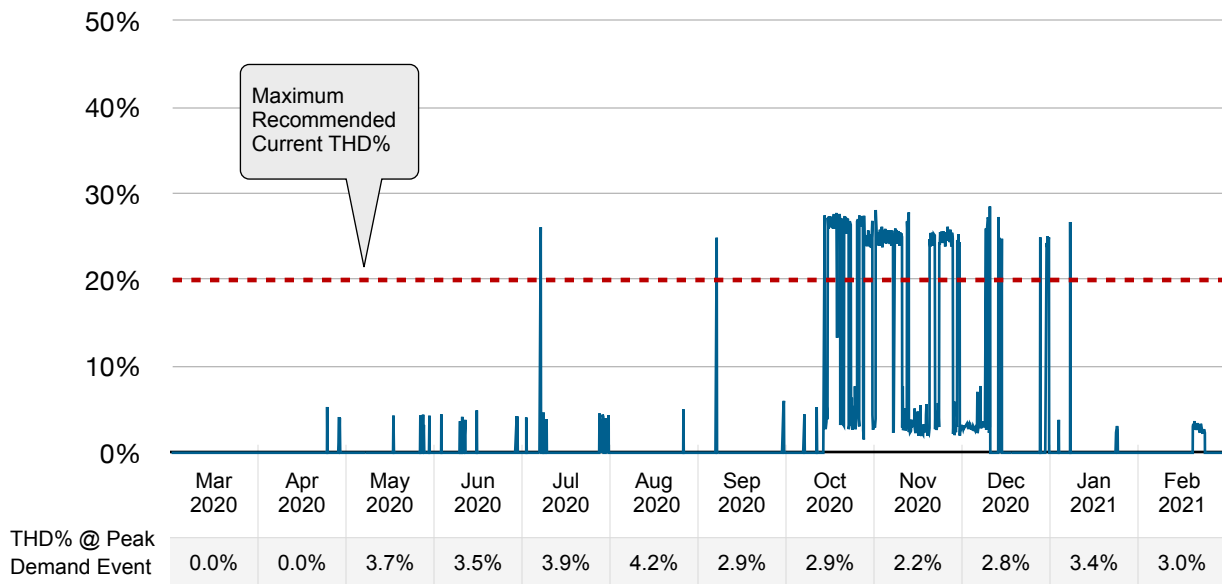
As shown in Chart 10, the voltage THD tends to produce a consistent trend pattern both from a daily and seasonal perspective. When considering the DFEM farm power logger 5-minute interval data recorded over the entire 12-month study period the lowest recorded voltage THD was 2.3%, the highest was 4.2%, while the average voltage THD for the study period was 3.1%. When analyzing the monthly voltage THD recorded during the monthly peak demand window, all 12 months in the study period were under 4%. As illustrated by the red dotted line in the chart, a voltage THD under 5% is generally considered acceptable and likely not negatively impacting the overall power factor.

Chart 10: DFEM Voltage THD%



As shown in Chart 11, the current THD tends to produce fluctuating trend pattern that is less predictable. When considering the DFEM farm power logger 5-minute interval data recorded over the entire 12-month study period there was a larger range as the lowest recorded current THD was 0%, the highest was 28.5%, and the average current THD for the study period was 2.45%. However, when analyzing the monthly current THD recorded during the monthly peak demand window, all 12 months in the study period were under 20%. As illustrated by the red dotted line in the chart, a current THD under 20% is generally considered acceptable and likely not negatively impacting the overall power factor.

Chart 11: DFEM Current THD%



RFEM Peak Demand

In this section we analyze the power quality logger results for working power, non-working power, total power, and power factor at the DFEM farm during the maximum monthly peak demand event. The data is filtered and presented based on a calendar month, which may vary slightly from the farms actual electric bill based on the service period days used to calculate their monthly bill.

When comparing the average monthly demand to the maximum monthly demand, there is a considerable difference (Chart 12). For example, as illustrated in Chart 12 the maximum 15-minute monthly demand of 148 kW was set in November 2020, which was the largest demand recorded at the



DFEM farm during the 12-month study period. However, when considering the average monthly demand in November 2020 of 35 kW, it is clear that most of the time the farm requires significantly less electricity to operate the facility. Chart 13 provides a more detailed daily perspective of the 15-minute demand profile for the RFEM farm in November 2020. As shown in the chart, even in the month with the greatest peak demand spike, the overall usage at the faculty was sporadic with nearly half of the days showing no electrical demand. In fact, 70% of the time, the demand at the RFEM farm in the month of November 2020 was under 35kW. This just reinforces the impact of inconsistent seasonal usage from large motor loads and indicates that most of the time the farm requires significantly less electrical demand to operate the facility than the energy actually used to set the monthly maximum demand.

While understanding the peak demand trends is important, there are other considerations. As we described earlier, for commercial accounts there may be a difference between the actual measured monthly peak demand of working power (kW) and the billing demand that is applied to electric bill.

Many utility providers require commercial accounts to maintain a power factor above 90% to avoid additional charges. As discussed, there are various formulas used to apply additional charges for the impacts of poor power factor and most of the formulas consider the total power (kVA) in some manner. As a result, it is important to consider the interactions between the maximum monthly peak demand from working power (kW), the power factor, non-working power (kVAR), and total power

Chart 12: Average and Maximum Monthly Demand (kW)

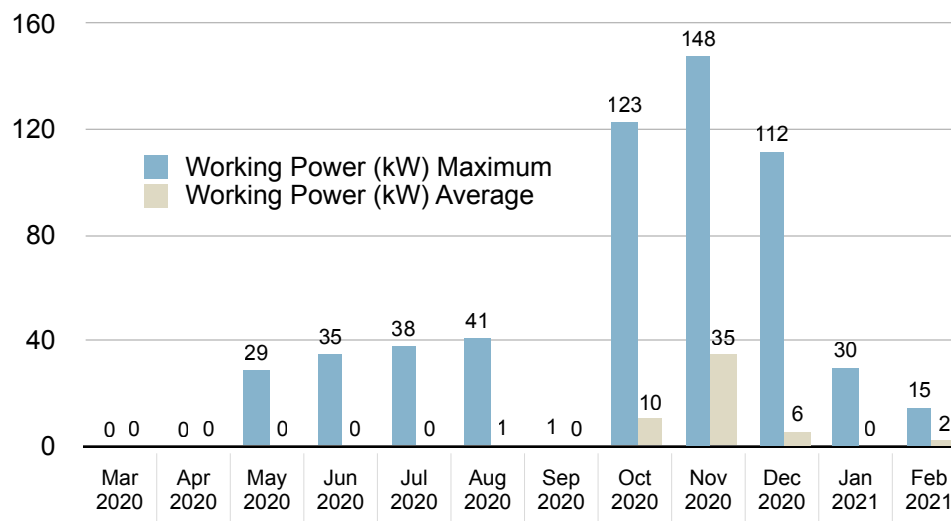
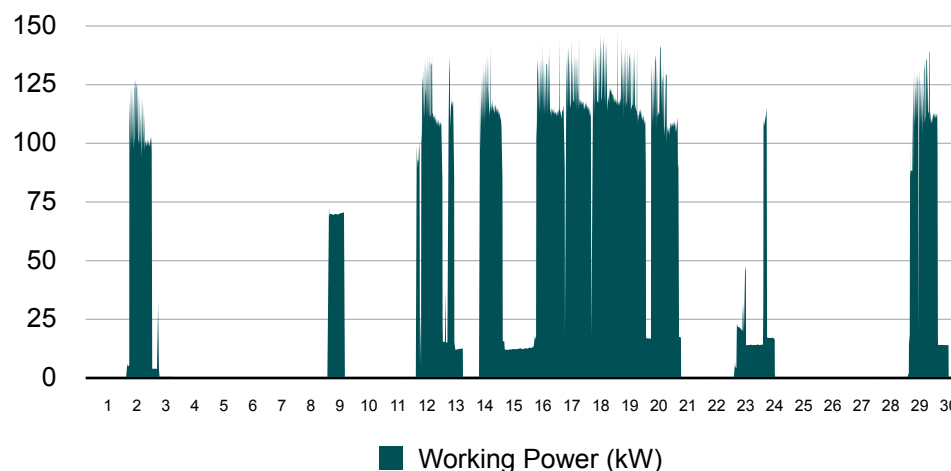


Chart 13: November 2020 Peak Demand (15-Minute Interval)



(kVA). As described earlier, the non-working power (kVAR) takes up capacity in the distribution system as it flows between the generator and load to sustain the magnetic field required for inductive loads, yet it does not perform useful work. Assuming working power (kW) remains constant, and the non-working power (kVAR) goes up, the total power (kVA) would increase, which would lower the overall power factor.

The scale, or size of the demand spike is important to the overall economic impact of poor power factor. This becomes evident when considering the monthly excess kVA, which is simply defined as the difference between the total power (kVA) and the working power (kW). For example, even though the power factor in September was lower than the power factor in November, the financial impact is likely greater in November because there was a significantly higher peak demand.

Chart 14: DFEM Power Quality Logger Results @ 15 Min Peak Demand Event

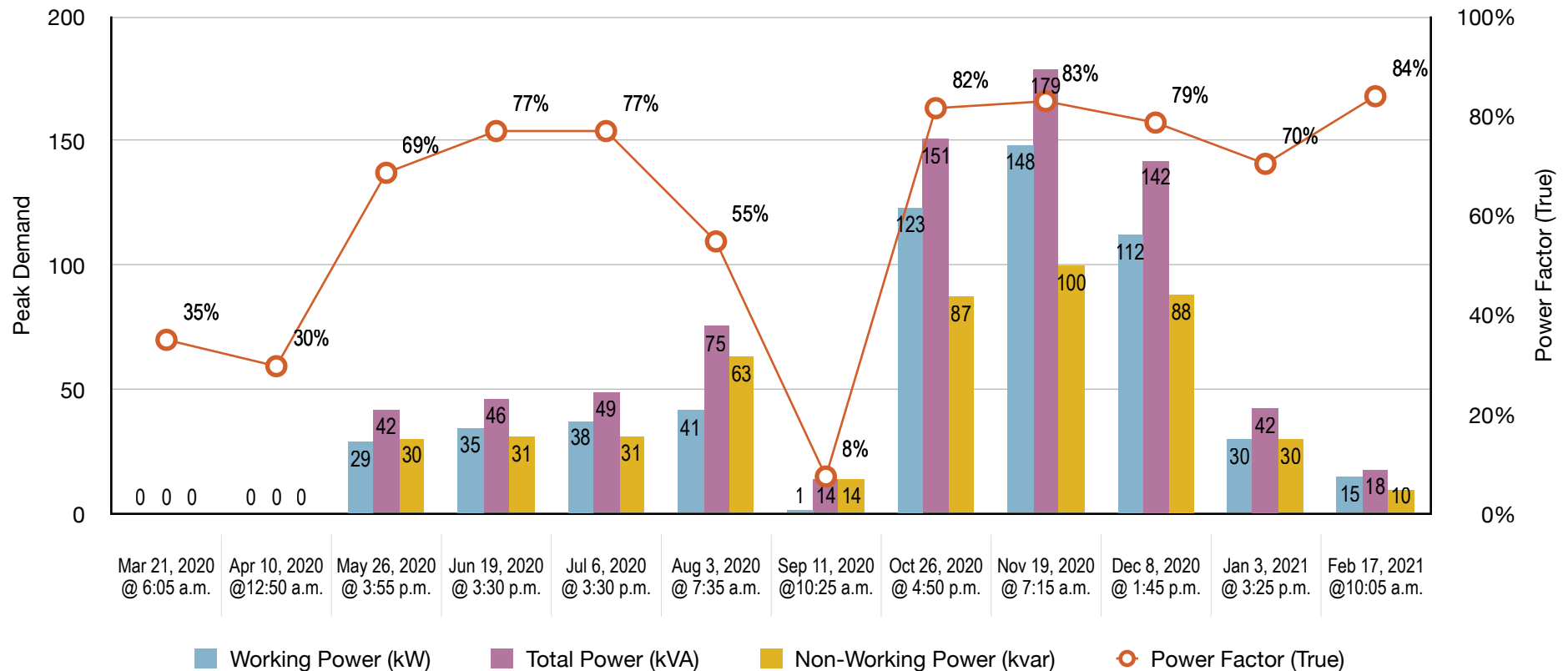


Table 2: DFEM Farm Case Study Analysis of Additional Power Factor Fees With Various Billing Methods

Month	Baseline - kW Demand Billing (PF above 90%)	Additional Power Factor Fees with Direct KVA Billing (PF below 90%)	Additional Power Factor Fees with Excess kVA Billing (PF below 90%)	Additional Fees with Power Factor Adjusted Billing (PF below 90%)
Mar 2020	\$2	\$3	\$1	\$2
Apr 2020	\$1	\$3	\$1	\$3
May 2020	\$388	\$177	\$64	\$121
Jun 2020	\$467	\$158	\$57	\$79
Jul 2020	\$507	\$152	\$54	\$86
Aug 2020	\$557	\$459	\$165	\$358
Sep 2020	\$14	\$174	\$63	\$155
Oct 2020	\$1,662	\$374	\$134	\$171
Nov 2020	\$2,002	\$410	\$147	\$169
Dec 2020	\$1,511	\$410	\$147	\$217
Jan 2021	\$401	\$168	\$60	\$112
Feb 2021	\$200	\$38	\$14	\$14
6 Month Total:	\$7,712	\$2,527	\$908	\$1486

Notes: Calculations are based on monthly power factor and demand data from Chart 14 assuming a monthly billing demand cost of \$13.50 per kW/kVA and an excess kVA demand cost of \$4.85 per kVA. Please refer to Figure J for additional information regarding the formulas used for each billing method.

Financial Implications

The financial impacts of poor power factor are difficult to quantify because most utilities have different rules. In fact, some utilities do not apply penalty fees for poor power factor, while others have very specific requirements and unique formulas that are applied to charge for poor power factor. To help better understand the range of possible cost associated with poor power factor, Table 2 used the power logger data from the DFEM farm and applied several common methods used to calculate demand charges and possible fees for poor power factor. The billing methods used includes Base Demand Billing, Direct KVA Billing, Excess kVA Billing, and Power Factor Adjusted Billing. Each of these methods and formulas are described in further detail in the electric rates section of this report. As illustrated in Table 2, the additional cost associated with poor power factor over the 12-month study period ranged from zero under the baseline demand billing scenario, to \$2,527 with the direct kVA billing model. Please note that the costs in Table 2 are designed to provide the reader a range of possible outcomes and the actual cost applied to the DFEM farm electric bill was different due to a more complex power factor formula.

POWER FACTOR CORRECTION

A primary goal of this bulletin is to help provide a better understanding of working power, non-working power, total power, and how they influence the power factor of a grain storage facility. In addition, this report has highlighted several common billing methods that are used to apply additional fees for poor power factor on your farm. While the technical aspects of power factor can be overwhelming, a general understanding of the key principles is essential to assessing the impact of additional

monthly power factor fees to your farms electric bill. This points to key questions of many grain farmers. Should I implement power factor correction measures? What is the cost of power factor correction equipment? How quick is the payback and how much will I save on my monthly electric bill? Obviously, every farm is unique so the required equipment and overall strategy to power factor correction will vary. In fact, as mentioned earlier depending on the rate structure of your electric bill, in some instances you may choose to ignore a poor power factor if you are not penalized or if the charges are minimal. However, to provide point of reference, we used the peak demand and power factor data from the RFEM Farm power logger to estimate the cost of power factor correction and the simple payback period.

In this example we are focused on the primary cause of poor power factor which was power factor displacement due to the large number and size of electric motors used at the grain storage facility. As a result, the power factor correction strategy we are evaluating includes the installation of capacitors to offset the inductive motor loads. In this example, we did not account for harmonic distortion in our correction measures as the levels were generally low during the farms peak demand window. However, as we discussed earlier you may also need to consider harmonic filtering if the total harmonic distortion at the farm is above the recommended levels.

To estimate the power factor correction cost, we first needed to determine the proper size of capacitors to maintain a power factor above 90%. Table 3 provides multipliers to estimate the proper capacitor size based on the current power factor and desired level of correction.

Table 3: Multipliers to Determine Capacitor Size (kVAR) for Power Factor Correction

Uncorrected Power Factor	Desired Corrected Power Factor										
	85%	86%	87%	88%	89%	90%	91%	92%	93%	94%	95%
60%	0.714	0.740	0.767	0.794	0.821	0.849	0.878	0.907	0.938	0.970	1.005
61%	0.679	0.706	0.732	0.759	0.787	0.815	0.843	0.873	0.904	0.936	0.970
62%	0.646	0.672	0.699	0.726	0.753	0.781	0.810	0.839	0.870	0.903	0.937
63%	0.613	0.639	0.666	0.693	0.720	0.748	0.777	0.807	0.837	0.870	0.904
64%	0.581	0.607	0.634	0.661	0.688	0.716	0.745	0.775	0.805	0.838	0.872
65%	0.549	0.576	0.602	0.629	0.657	0.685	0.714	0.743	0.774	0.806	0.840
66%	0.519	0.545	0.572	0.599	0.626	0.654	0.683	0.712	0.743	0.775	0.810
67%	0.488	0.515	0.541	0.568	0.596	0.624	0.652	0.682	0.713	0.745	0.779
68%	0.459	0.485	0.512	0.539	0.566	0.594	0.623	0.652	0.683	0.715	0.750
69%	0.429	0.456	0.482	0.509	0.537	0.565	0.593	0.623	0.654	0.686	0.720
70%	0.400	0.427	0.453	0.480	0.508	0.536	0.565	0.594	0.625	0.657	0.692
71%	0.372	0.398	0.425	0.452	0.480	0.508	0.536	0.566	0.597	0.629	0.663
72%	0.344	0.370	0.397	0.424	0.452	0.480	0.508	0.538	0.569	0.601	0.635
73%	0.316	0.343	0.370	0.396	0.424	0.452	0.481	0.510	0.541	0.573	0.608
74%	0.289	0.316	0.342	0.369	0.397	0.425	0.453	0.483	0.514	0.546	0.580
75%	0.262	0.289	0.315	0.342	0.370	0.398	0.426	0.456	0.487	0.519	0.553
76%	0.235	0.262	0.288	0.315	0.343	0.371	0.400	0.429	0.460	0.492	0.526
77%	0.209	0.235	0.262	0.289	0.316	0.344	0.373	0.403	0.433	0.466	0.500
78%	0.183	0.209	0.236	0.263	0.290	0.318	0.347	0.376	0.407	0.439	0.474
79%	0.156	0.183	0.209	0.236	0.264	0.292	0.320	0.350	0.381	0.413	0.447
80%	0.130	0.157	0.183	0.210	0.238	0.266	0.294	0.324	0.355	0.387	0.421
81%	0.104	0.131	0.157	0.184	0.212	0.240	0.268	0.298	0.329	0.361	0.395
82%	0.078	0.105	0.131	0.158	0.186	0.214	0.242	0.272	0.303	0.335	0.369
83%	0.052	0.079	0.105	0.132	0.160	0.188	0.216	0.246	0.277	0.309	0.343
84%	0.026	0.053	0.079	0.106	0.134	0.162	0.190	0.220	0.251	0.283	0.317
85%	0.000	0.026	0.053	0.080	0.107	0.135	0.164	0.194	0.225	0.257	0.291
86%		0.000	0.027	0.054	0.081	0.109	0.138	0.167	0.198	0.230	0.265
87%			0.000	0.027	0.054	0.082	0.111	0.141	0.172	0.204	0.238
88%				0.000	0.027	0.055	0.084	0.114	0.145	0.177	0.211
89%					0.000	0.028	0.057	0.086	0.117	0.149	0.184
90%						0.000	0.029	0.058	0.089	0.121	0.156
91%							0.000	0.030	0.060	0.093	0.127
92%								0.000	0.031	0.063	0.097
93%									0.000	0.032	0.067
94%										0.000	0.034
95%											0.000

Table Data Source: Siemens (2021) - *Power Factor Correction Capacitor - Sizing for Motors*
<https://new.siemens.com/us/en/products/energy/techtopics/techtopics-20.html>



Figure P: Example of Power Factor Correction Estimate

Step 1: Estimating Required kVAR to Operate the RFEM Farm at 90% Power Factor

Month	Power Factor (True)	Multipliers to Determine Capacitor Size (kVAR)	Peak Demand (kW)	kVAR to required bring farm to 90% power factor
Sep 2020	67%	0.624	2	1
Oct 2020	70%	0.536	118	63
Nov 2020	73%	0.452	125	57
Dec 2020	61%	0.815	46	38
Jan 2021	67%	0.624	36	23
Feb 2021	67%	0.624	2	1

- Example of Calculation for October 2020:
Multiplier (0.536) x Peak Demand (118 kW) = Estimated Capacitor Size (63 kVAR)
- Note: Working power and power factor data was from the RFEM farm power logger and the kVAR multipliers are from Table 3.

Step 2: Estimating Power Factor Correction Cost for 63 kVAR Capacitor

63 kVAR is required to maintain a 90% power factor in October 2020

- Minimum Correction Cost (\$15 per kVAR): 63 kVAR x \$15 = \$945
- Average Correction Cost (\$28 per kVAR): 63 kVAR x \$28 = \$1,764
- Maximum Correction Cost (\$47 per kVAR): 63 kVAR x \$47 = \$2,961

To identify the proper multiplier, you first identify the current power factor of your farm in the first (left) column, then select your target level of power factor correction from the top row. Once you identify the multiplier, you will apply it to the measured peak demand to determine the required kVAR capacity to achieve power factor correction.

In Figure P and Q, we outlined the steps to estimate the proper capacitor size, cost of correction, amount of penalty payments, and estimated project payback. In Step 1 of Figure P, we identified the proper multiplier based on the recorded monthly power factor during the peak demand window. Next, we applied the multiplier from Table 3 to the corresponding peak demand to determine the capacitor size (kVAR) required to maintain a power factor above 90% for the farm. Because it was the month that required the greatest amount of correction (63 kVAR), we selected October 2020 as the month to establish our capacitor size as we continue the cost analysis.

Next, in Step 2 we had to determine an appropriate cost for the 63 kVAR capacitor(s). The type of capacitor that will work best for your grain storage system will depend on the facility design variables such as the size of the load, usage patterns, and the use of variable frequency drives. In addition, there are a variety of capacitors and features available and you will need to evaluate the cost and benefits to determine what works best for your farm. To establish cost estimates we evaluated the retail cost of 13 different capacitors ranging in size from 25 kVAR to 150 kVAR. We filtered the cost down to a dollar amount per kVAR so we could accurately compare the costs. Of the 13 capacitors considered, the minimum cost was \$15 per kVAR, the maximum cost was \$47 per kVAR, while the average cost was \$28 per kVAR. As illustrated in Step 2, we then multiplied the minimum, maximum, and average cost times 63 kVAR to estimate a range of cost for the capacitor equipment. The equipment cost of

correcting the power factor from 70% to 90% on the RFEM farm in October 2020 ranged from a low cost of \$945, to a high of \$2,961 with an average cost of \$1,764. It should be noted that this estimate only includes the equipment cost and the labor and installation is an additional cost that should be considered.

Step 3 of Figure Q summarizes the estimated monthly power factor penalty fees over the 6-month analysis period for each of the three common billing methods. In summary the combined (6 month) penalty fees under the Direct KVA Billing method were \$1,936, while it was \$696 for the Excess kVA Billing method, and \$1,301 for the Power Factor Adjusted Billing method. It is important to recognize that the penalty fees summarized in Step 3 also represent possible savings that would offset the cost of installing power factor correction equipment.

In Step 4 of Figure Q, we applied the potential savings under each billing method to each cost scenario for installing the correction equipment to estimate the simple payback period in years. As illustrated in the Step 4 table, under the Direct kVA billing model the investment in power factor correction is expected to pay for itself in 1.5 years or less, compared to the Power Factor Adjusted billing method with an estimated payback of 2.3 years or less, and the Excess kVA billing method which estimated the longest payback of 4.3 years.

This example used measured data from the RFEM farm data logger compared to several cost scenarios for power factor correction equipment and is intended to help farmers determine if there is potential for energy cost savings on their grain storage facility. Farmers interested in power factor correction are encouraged to contact an energy specialists to explore solutions and costs specific to their farm.

Figure Q: Example of Power Factor Correction Estimate

**Step 3: Penalty Fee for Power Factor (below 90%)
Estimated for Each Billing Method**

Month	Direct KVA Billing Method	Excess kVA Billing	Power Factor Adjusted Billing method
Sep 2020	\$11	\$4	\$8
Oct 2020	\$667	\$240	\$443
Nov 2020	\$611	\$219	\$382
Dec 2020	\$396	\$142	\$293
Jan 2021	\$239	\$86	\$167
Feb 2021	\$12	\$4	\$8
6 Month Total	\$1,936	\$696	\$1,301

**Step 4: Estimated Simple Payback in Years
Based on Correction Cost and Billing Method**

Power Factor Correction Cost for 63 kVAR	Direct KVA Billing Method	Excess kVA Billing	Power Factor Adjusted Billing method
Minimum Correction Cost Scenario \$945	0.5	1.4	0.7
Average Correction Cost Scenario \$1,764	0.9	2.5	1.4
Maximum Correction Cost Scenario \$2,961	1.5	4.3	2.3



ACTION STEPS

Depending on the farm size, energy consumption can contribute significantly to total operating costs. This study examined how power factor correction may provide cost savings opportunities by reducing fees associated with poor power factor. Electric utilities apply power factor expenses to commercial customers in a variety of different ways, which can make it challenging to determine if your farm is charged, or not. Examining your monthly electric bills for key words such as power factor, power factor demand, kVAR or VAR billing can be helpful indicators of power factor charges.

Farm operations interested in investigating energy consumption and costs savings strategies should get started by first investigating your electric rate schedule, or tariffs, to understand how you are billed for electricity. It is critical to identify the methods used to measure and calculate the core components of your bill, and which variables will influence the calculations. This step will require dedicating time to locating and reading your rate sheet and discussing questions with your utility provider. Next, organize the most recent 12 months historical electric bills to locate the energy usage, peak demand, power factor, and associated charges. Finally, using the information from the electric rate schedule and the historical electric bills, download and complete the On-Farm Energy Analyzer Tool from OSU Extension Energize Ohio website (go.osu.edu/farmenergy). The On-Farm Energy Analyzer Tool will automatically create historical trend charts for monthly energy usage (kWh), peak demand (kW), and power factor to help you visualize the farms usage patterns and the associated cost.

Using the historical energy trends data from the On-Farm Energy Analyzer Tool, you can gain a clearer understanding of which farm operations and electric charge type is costing you the most money. This assessment process will help clarify the level of urgency for the farms energy cost and help prioritize the farms energy management projects that will produce the greatest energy cost savings.

ADDITIONAL READINGS



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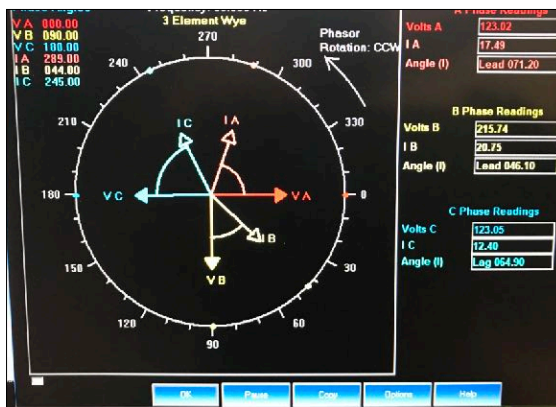
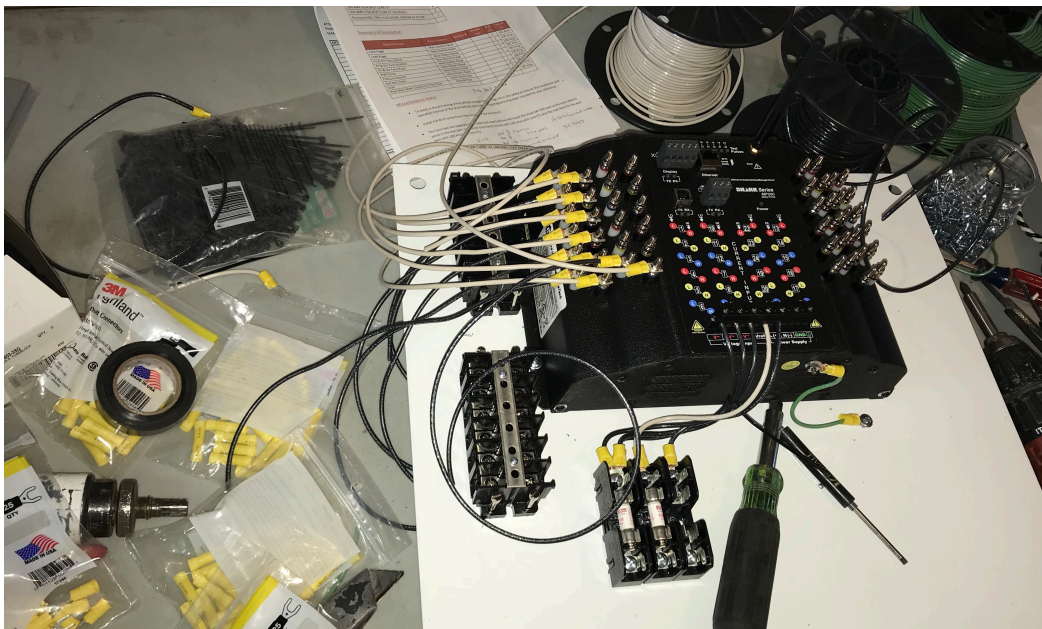
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For More Information From the OSU Extension Farm Energy Program.
Visit the Energize Ohio Website: www.go.osu.edu/farmenergy.



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