WELCOME

Basic Pump Efficiency and VFDs- UC Cooperative Extension- Monterey County

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Pump Efficiency: Goal and Objectives

Overall Goal: Minimize ENERGY and WATER Use

Objectives:

1. Pumping systems (<u>hardware</u>) in the field do not use excess energy or water
2. All systems are <u>managed</u> correctly

Mobile Education Center Tour (MEC video)

Review of Basic Pump Efficiency

Input Horsepower Equation

$$HPin = \frac{Flow \times TDH}{(3960 \times OPE)}$$

Where:

- HPin = required input horsepower
- Flow = pump flow rate (gpm)
- TDH = pressure in system – total lift in ft or psi x 2.31
- 3960 = constant
- OPE = overall pump efficiency (%)

Let’s take it step by step!

Input Horsepower Equation: OPE

$$HPin = \frac{Flow \times TDH}{(3960 \times OPE)}$$

Where:

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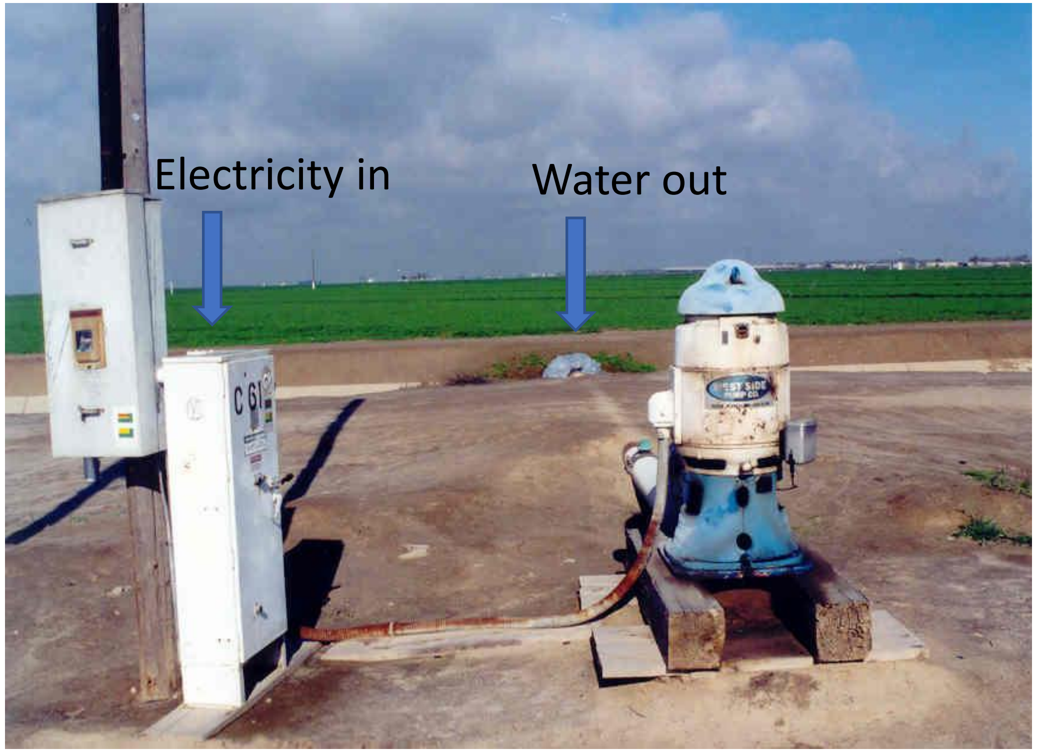
- 3960 = constant
- **OPE = overall pump efficiency (%) – three components**

Overall Pumping Efficiency

What is Overall Pumping Efficiency?

1. Input Horsepower Equation - HPin/ HPout
2. Wire to water efficiency
3. Energy in/ Energy out
   a. Electric energy in
   b. Water energy out



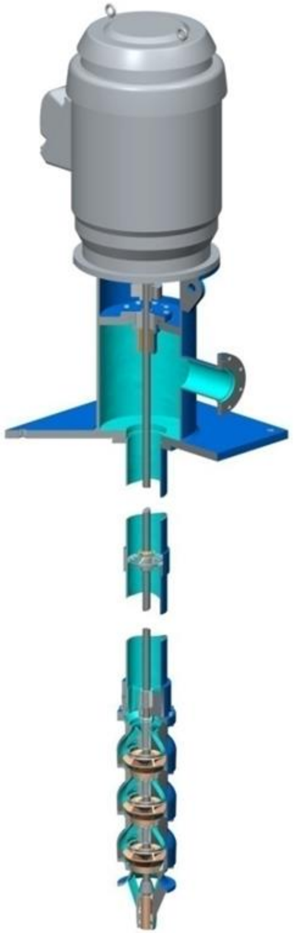
OPE (Overall Pump Efficiency)

Bowl or impeller efficiency (the pump itself) is only one aspect of Overall Pumping Plant Efficiency- OPE

Must also consider:

1. Transmission efficiency - losses through, shafts, bearings, pulleys, V-belts
2. Driver efficiency or the efficiency of the power source (motor, engine, etc.).

For electric pumps, OPE is often referred to as wire to water efficiency.



The “Operating Condition” of a pump

- HPin or “energy in” depends in part on the combination of flow and pressure or TDH (Total Dynamic Head/ Total Lift) developed.

- The combination of flow and pressure is termed the <u>“Operating Condition”.</u>

- Every pump has a combination of flow and pressure as it operates.

- kW (kilowatts) in / 0.746 = HPin or HPin x 0.746 = kWin

Input Horsepower Equation: Flow

$$HPin = \frac{Flow \times TDH}{(3960 \times OPE)}$$

Where:

- HPin = required input horsepower
- Flow = pump flow rate (gpm)
- TDH = pressure in system – total lift in ft or psi x 2.31
- 3960 = constant
- **OPE = overall pump efficiency (%) – three components**

What is Flow?

- Flow is the volume of water pumped measured in gallons per minute or gpm
- Flow can also be measured in cubic feet/second or cfs

Input Horsepower Equation: TDH

$$HPin = \frac{Flow \times TDH}{(3960 \times OPE)}$$

Where:

- HPin = required input horsepower
- Flow = pump flow rate (gpm)
- TDH = pressure in system – total lift in ft or psi x 2.31
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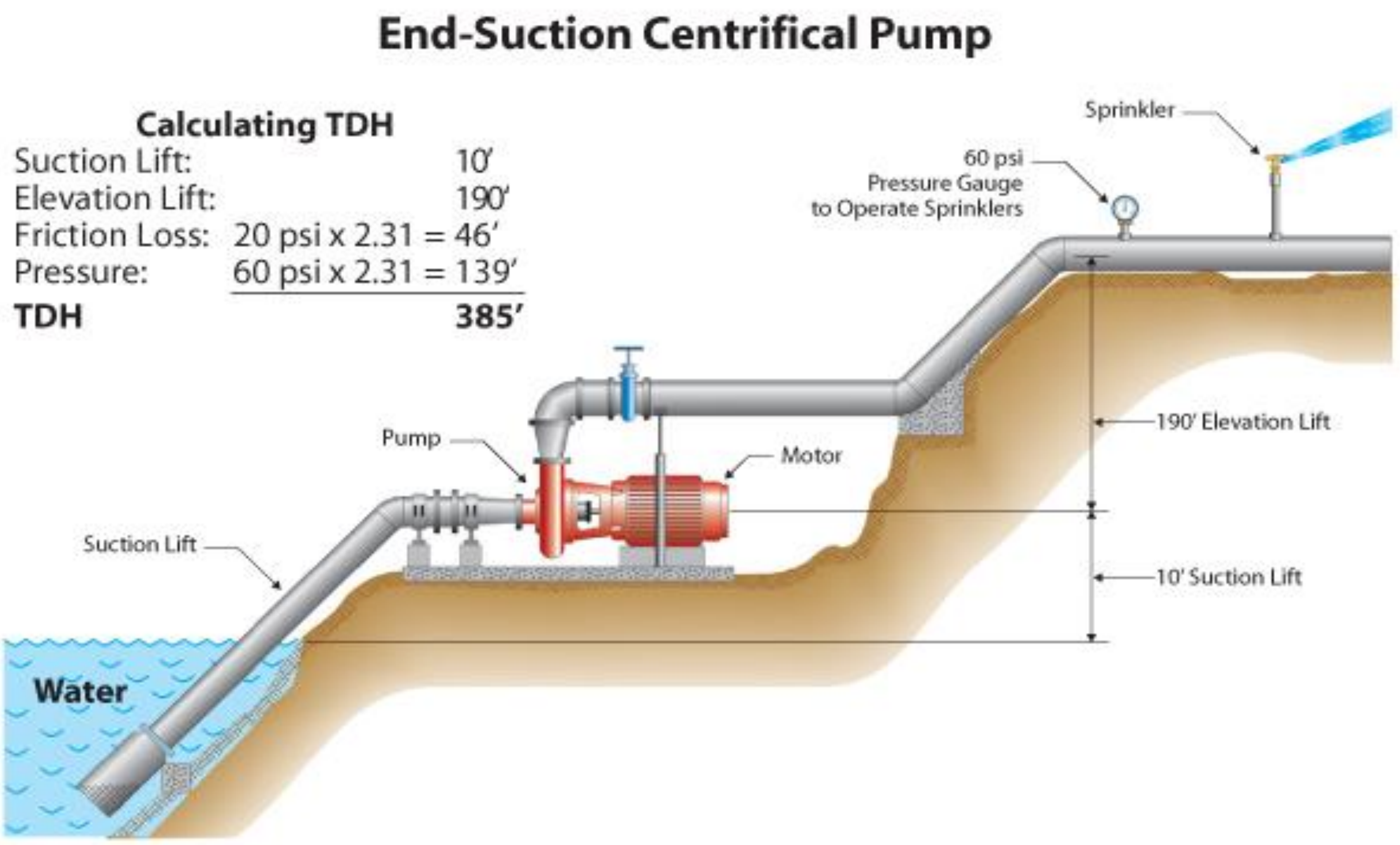
- **OPE = overall pump efficiency (%) – three components**

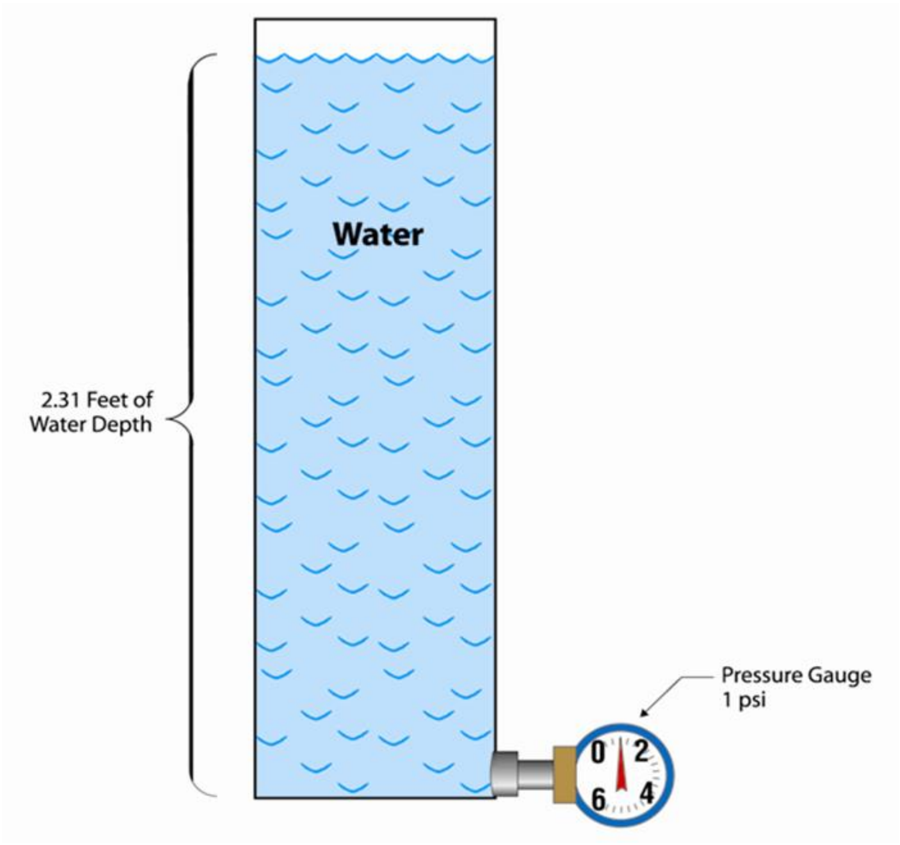
What is Pressure? TDH example

Total lift from the water source level (PWL) to the field level + the pressure to operate the irrigation system



The Constant to Convert psi to feet of Head

Every 2.31 feet of water depth equals 1 psi. If you dive into a swimming pool you notice the pressure on your ears increases the deeper you go. Every 2.31 feet deeper you dive increases the pressure by 1 psi.



Review of HPin Equation

$$HPin = \frac{Flow \times TDH}{(3960 \times OPE)}$$

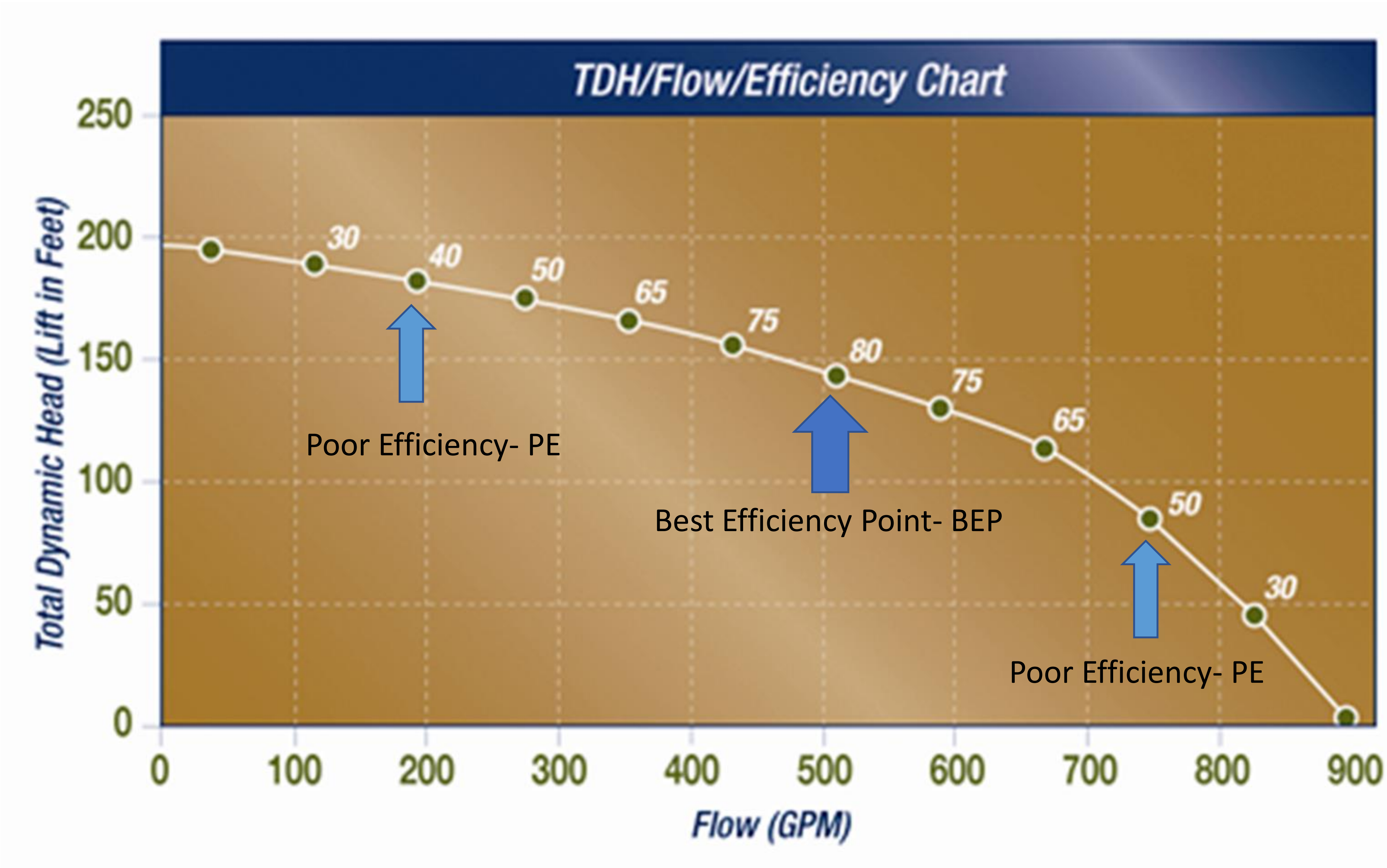
Example:

- Flow = 900 gpm
- TDH = 350 ft
- 3960 = constant
- OPE = 0.55 (55%)

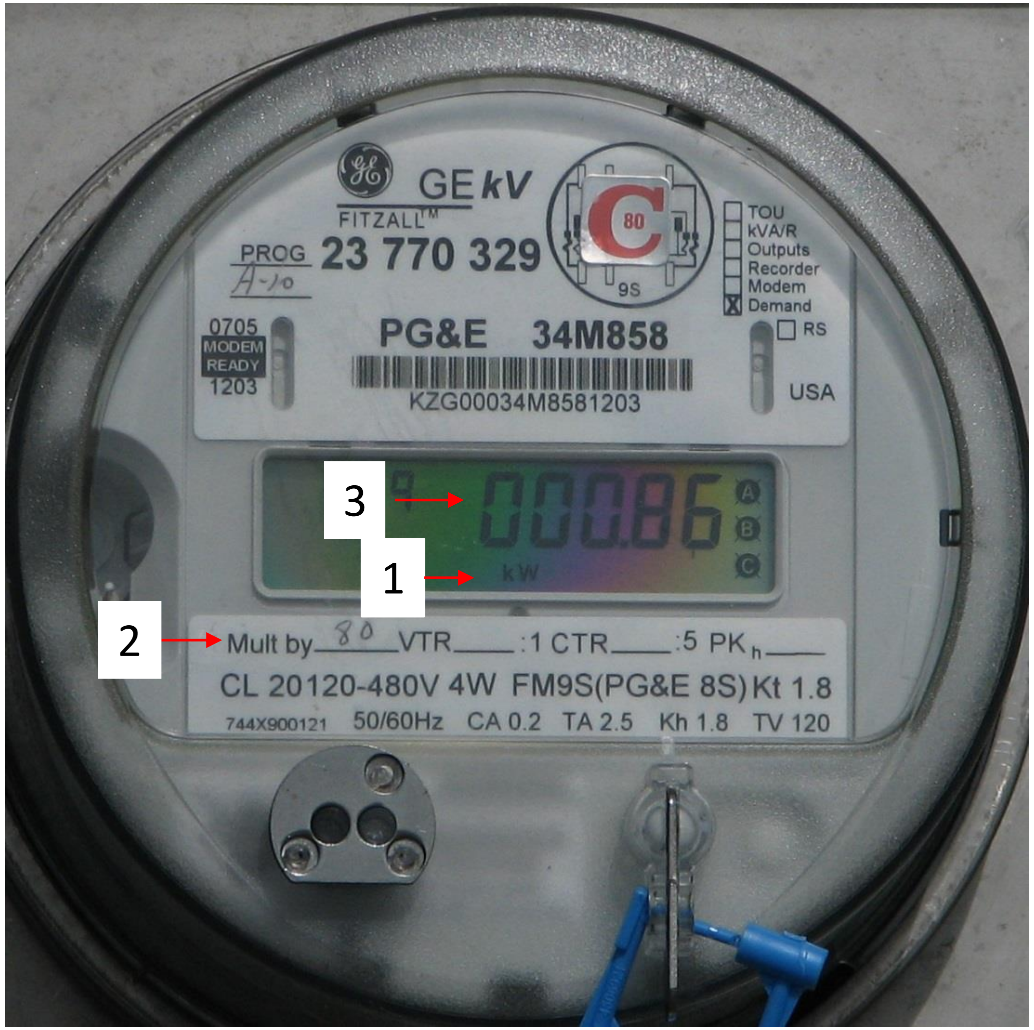
$$HPin = \frac{900 \times 350}{3960 \times 0.55} = 145 \text{ HP}$$

kWin = HPin x 0.746 = 145 x 0.746 = 108 kW

Bowl Efficiency Numbers on the Curve



Energy In – from SmartMeter, Pump Panel and/or VFD



HPin = kWin off the Smart Meter/0.746)

With this example smart meter on the left, identify the following to get HPin:

1. kW screen as the smart meter scrolls
2. Mult by number (80 in this case)
3. Real time reading, in this case 000.86

Next multiply 80 x 000.86 = 68.8 kWin

68.8 kWin / 0.746 = 92.23 HPin

With some smart meters, the "mult by" number is 1 or not listed. This means the number for kW as the meter scrolls is the actual kWin

Takeaway

$$HPin = \frac{Flow \times TDH}{(3960 \times OPE)}$$

$$OPE = \frac{Flow \times TDH}{(3960 \times HPin)}$$

- The HPin equation is used to calculate the power required to operate a pump at a given operating condition.
- The equation can be rearranged to calculate the OPE of an already installed pump.

MEC exaples – #2 Basic pump efficiency and smart meter ex

1. Flow from flowmeter
2. TDH from pressure gauge X 2.31
3. Energy in off Smart meter

Basics of VFDs

What is a Variable Frequency Drive?

A VFD changes the rotational speed of shaft which affects system output, energy consumption, and efficiency.

Various Names:

- VSD – Variable Speed Drive
- VFD – Variable Frequency Drive
- ASD – Adjustable Speed Drive

When full speed isn't required the VFD throttles the speed (rpms) of the pump, reducing energy costs.

Introduction to Variable Frequency Drives

A VFD allows you to (automatically) throttle an electric motor – just as you would a diesel or natural gas engine.

Benefits:

- Energy savings and reduced costs
- Machinery longevity due to gentle starts

Tradeoffs:

- Cost- initial investment in VFD
- Power Quality: uneven voltages and power surges
- Physical Constraints:
  - ✓ Cooling needed above 100 degrees
  - ✓ Filtration may be needed for the fan intake because of dust and dirt

How does a VFD affect Overall Pump Efficiency?

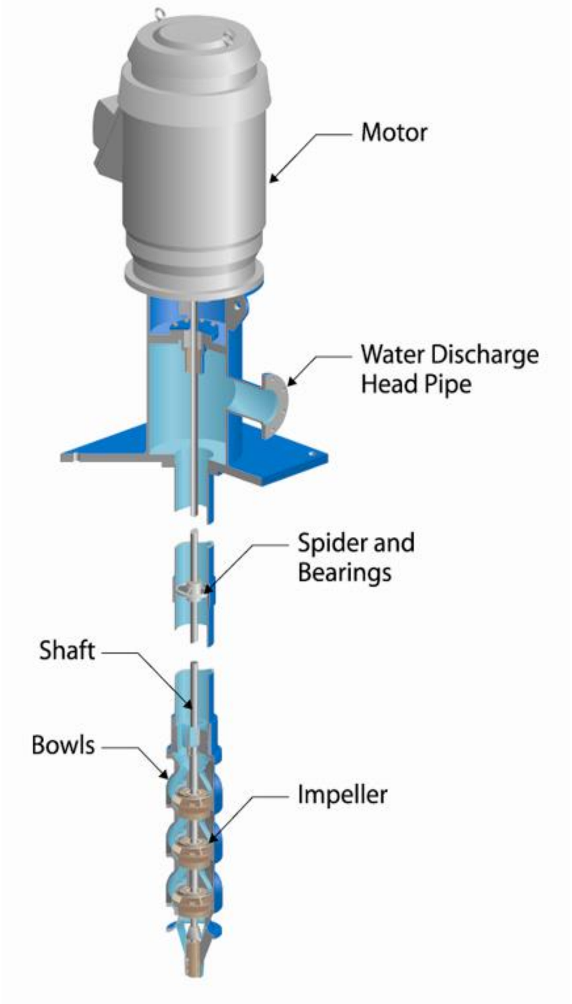
Efficiency Factors:

- **Motor Efficiency** – 88-96% (submersibles: 10% lower).
- **Transmission Efficiency** – 90-97%.
- **Bowl Efficiency** – 60s-mid 80s.
- **VFD Efficiency** – 94-97%.

OPE = ME x TE x BE x VFDE

Example of Good OPE:

- 0.93 ME x 0.95 TE x 0.76 BE OPE = 0.67 or 67%
- 0.93 ME x 0.95 TE x 0.76 BE x 0.96 VFDE OPE = 0.64 or 64%



How VFDs Save Energy

The Affinity Laws:

- Set of theoretical relationships
- Applicable to turbine pumps exclusively
- Connect pump speed, flow, and horsepower

Affinity Law Formula:
Brake HP (BHP) drops by power of 3 with pump speed reduction

- $BHPa / BHPb = (RPMa / RPMb)^3$
- $BHPb = BHPa / (RPMa / RPMb)^3$

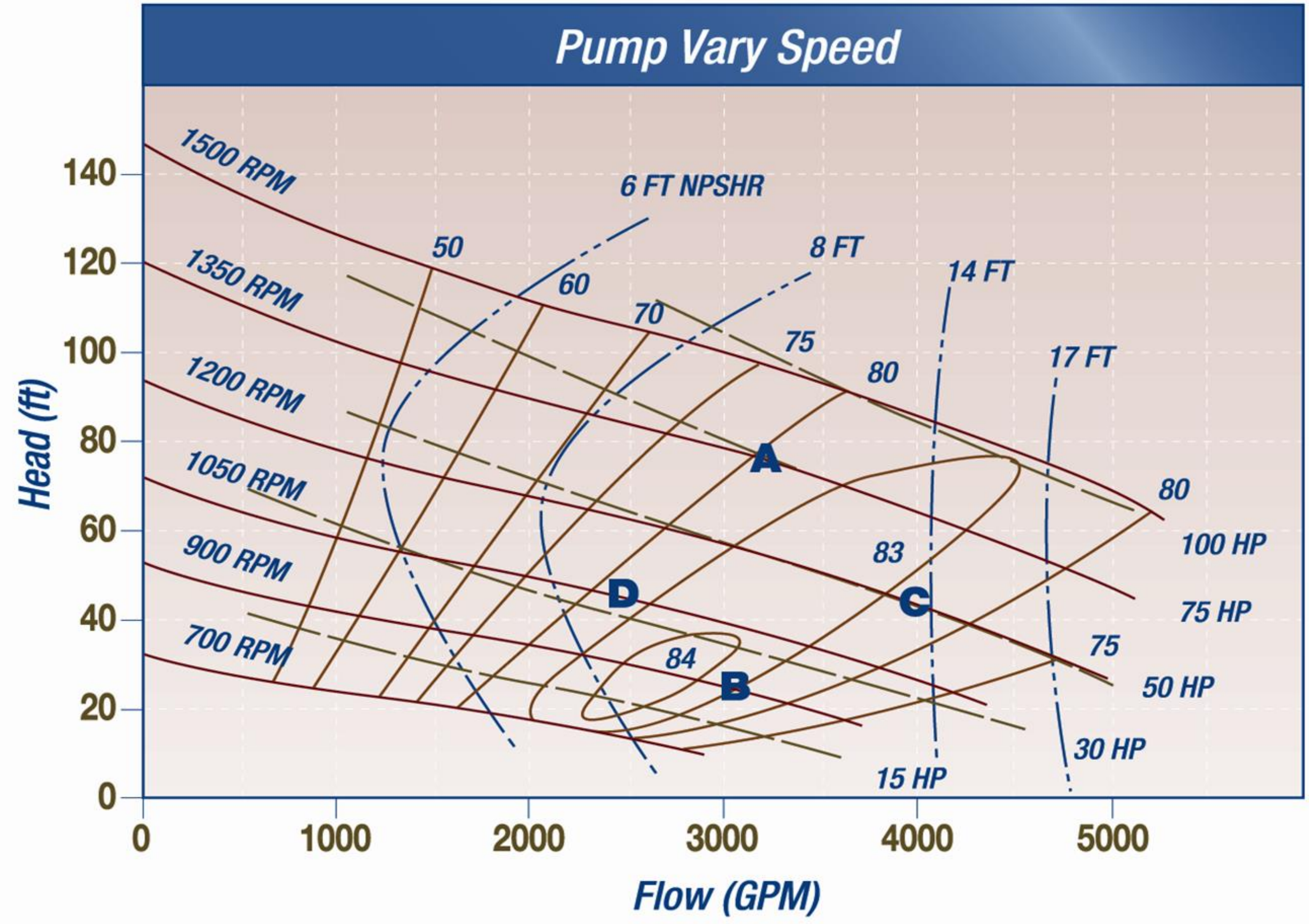
Example Calculation:

- Initial BHPa – 100
- Speed reduction – 1800 rpm to 1500 rpm

BHPb = <u>**100**</u> / $(1800 / 1500)^3$ = <u>**58**</u> BHP)

If I reduce the motor/pump speed from 1800 rpm to 1500 rpm (20%), then theoretically I should see HP go from 100 to 58 – **cut energy cost by more than 40%**

Pump Curves at Different Speeds – RPMs



Irrigation System Control

VFDs are often used where different flows and pressures are required:

1. Multiple systems
2. Emission devices
3. Irrigation sets
4. Field elevation changes
5. Changes in acreage, plant area being irrigated

What Other Things can VFDs do?

1. Reduce water hammer- soft start
2. Reduce cavitation- soft start
3. Reduce well sanding- soft start or reducing RPM to reduce sand pumping or continuous pumping reduce sanding when the pump is shut off completely
4. Allow oversizing the pump HP to accommodate a variable or fluctuating water table, changing pumping water level
5. Adapt to different operating conditions required for different irrigation system sets, emission devices, acreages or elevations
6. Maintain system pressure or pre-set RPMs to create proper flows and pressures
7. Assist with backflush of filtration systems

Agricultural VFD Applications

Application: Variable or Fluctuating Water Levels

Static or Standing Water Level (SWL):

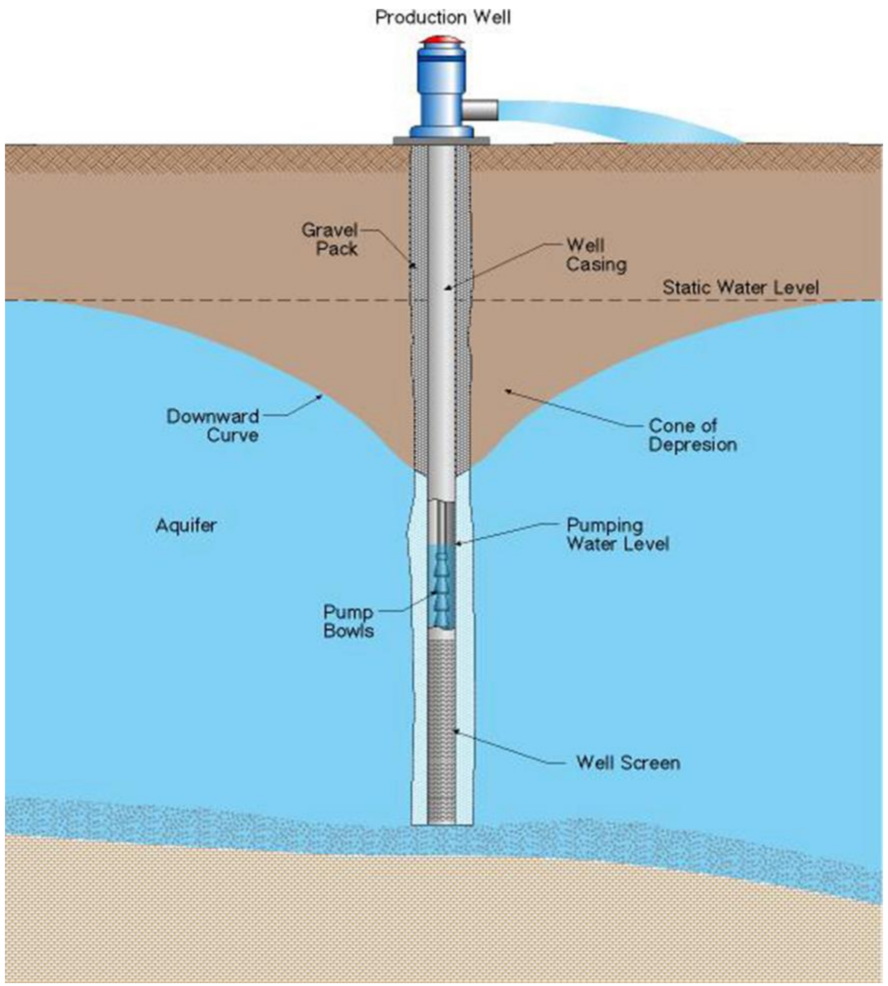
- Water level before pumping
- Varies with seasonal changes and drought
- Typically drops during summer due to decreased water table.

Drawdown:

- Difference between standing water level and pumping water level

Pumping Water Level (PWL):

- Water level while pumping
- Subject to fluctuation based on pumping activity



Example Pumping Cost Comparison 2026

HPin = Flow x TDH / (3960 x OPE)

Cost to pump water:
kWh per acre foot = 1.0241 x TDH/ OPE
Cost per acre foot = kWh per acre foot x cost per kWh ($0.24)

VFD

- Flow = 1,000 gpm
- TDH = 389.3 ft ft
- 3960 = constant
- OPE = 0.62 or 62%

HPin = 159 (119 kW)

kWh/ac ft = 643

Pumping cost = $154.33 per ac ft

Annual pumping cost:

480 ac ft x $154.33 = $74,078

Pressure Regulating Valve

- Flow = 1,000 gpm
- TDH = 519.3 ft
- 3960 = constant
- OPE = 0.65 or 65%

HPin = 202 (151 kW)

kWh/ac ft = 818

Pumping cost = $196.36 per ac ft

Annual pumping cost:

480 ac ft x $196.36 = $94,253

Over $20,000 annual savings in pumping costs!

MEC example Variable or Fluctuating water table

“Load Profile” for Multiple Operating Conditions

A load profile identifies the different operating conditions needed and amount of time at those conditions. For example:

- 40% of water pumped at 1400 gpm and 80 psi (189.42 ft TDH)
- 20% of water pumped at 1000 gpm and 70 psi (161.7 ft TDH)
- 20% of water pumped at 800 gpm and 50 psi (115.5 ft TDH)
- 20% of water pumped at 700 gpm and 40 psi (92.4 ft TDH)

Most manufacturer’s have software that can estimate energy savings, given a **load profile**.

Load Profile for the MEC

Identify your load profile:

1. 139 gpm 89 ft TDH
2. 114 gpm 62 ft TDH
3. 80 gpm 37 ft TDH

The load profile above is three different conditions we've included in the following video example. Based on these flow rates (gpm) and feet of lift (TDH) we will use the MEC to demonstrate pumping costs using a VFD versus a pressure regulating valve.

MEC example load profile

Application: Multiple Conditions

All these irrigation systems have different flow and pressure requirements - how can one pump supply multiple conditions?

MEC example multiple operating conditions

MEC example- Oversized pump for various operating conditions with VFD

MEC example- Use the original deep well pump and add a booster with VFD

Issues with VFD Installations

Operational Issues

VFDs don’t magically save energy. Many growers have installed expensive VFDs only to find out they didn’t save money on their power bill.

- VFDs only save energy when used to slow the pump down
- There’s a 4% efficiency loss through the VFD
- Often, it’s necessary to install a cooling unit, beyond a fan, that is costly to operate
- Operators in the field don’t understand how the VFD works and make mistakes that cost the grower money, training for the employees is key
- Pump companies install them but don’t set up operational parameters correctly
- VFD default settings are pre-set at the factory and can be too tight and cause faults and errors

Power Quality Issues

Many agricultural pumps are in rural areas. The grid can be greatly affected by large loads turning on and off, and voltage surges and spikes can occur. This can cause issues with a VFD installation, and it may be necessary to work with the power utility to correct these issues.

- Voltage surges and spikes can cause pumps to kick off or VFDs to trip and must be reset
- Large HP pumps turning on and off may cause these issues in rural areas. VFDs can deliver a slow ramp up to help with surges and spikes
- VFDs can cause harmonic distortion that affects the grid

Issues with VFD Installations

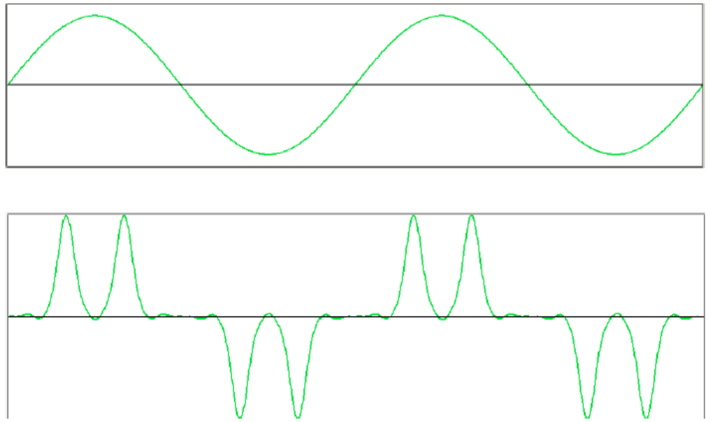
1. May need cooling - hot temps can cause issues, installed in an enclosure.
2. May have to be enclosed because of dirt and debris in the field.
3. Filter needs to be cleaned periodically with the enclosure or lack of ventilation and overheating can occur.
4. Power quality issues:
   - Voltage surges, spikes, and dips
   - Voltage and current imbalances
   - Overload/over current
   - Harmonic distortion

What is Harmonic Distortion?

Harmonics are one form of electrical pollution. They can be viewed as current sources with various frequencies that distort the normally clean voltage produced by the utility.

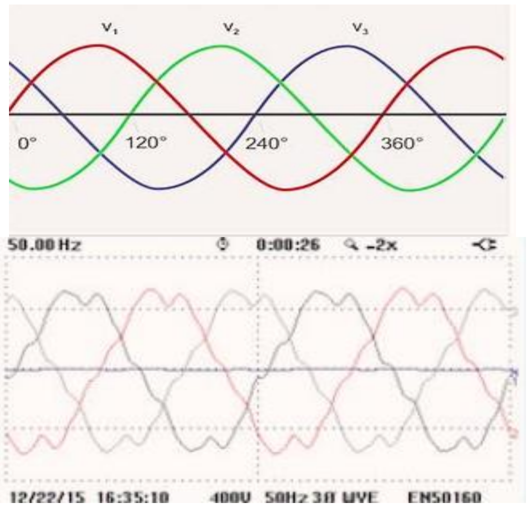
Normal voltage comes out of the utility substation looking like the clean fundamental 60Hz. Due to the fact that distorted currents flow through conductors and the power system, they distort the utility voltage and cause the voltage delivered to other customers to be distorted.

The left bottom plot shows a typical current waveform drawn by a three-phase VFD.



Linear current waveform

Non-linear current waveform



Where do Harmonics Come From?

Harmonics are usually injected into the power system by equipment owned and operated by customers.

If this polluting equipment is near equipment that is susceptible to the harmonic pollution, problems can and do occur.

Common sources of harmonics:

- Large industrial rectifiers - VFDs (also known as Adjustable Speed Drives)
- Solar PV inverters
- Welders and other arcing devices
- Modern converter-based appliances. For example: LED lights, computers, and electric vehicles

Variable Frequency Drive

What are the Impacts of Harmonics?

When the voltage is too distorted, equipment can operate incorrectly. For example, equipment that relies on the fundamental power system frequency, such as clocks can operate too fast. Irrigation equipment can go off track for the same reason.

Certain protection devices such as circuit breaker and relays can mis-operate.

Solar PV inverters and EV chargers may experience interference issues.

Other equipment can overheat, such as power factor capacitors, transformers and motors.

Because harmonics produce more heat than normal electricity, equipment life can be shortened if too much harmonic distortion is in the power system.

What can I do?

Utility customers can:

- Keep the power system clean and efficient for themselves and their neighbors.
- Keep their facility and equipment in compliance with harmonic standards. The standard for harmonics in North America is IEEE 519.

Best solution to avoid a harmonic problem for the owner of a large VFD or similar polluting device:

- Install a passive harmonic filter on the VFD.
- Select a VFD with built-in low harmonics output.

The passive harmonic filter can often be sized and ordered by the same company that sells the VFD.

Smaller VFDs can sometimes get by with simple series inductor or “chokes” as filters.

VFD Troubleshooting

- What is the problem? What are the symptoms?
- Install power quality monitor.
- AC Line Voltage measurements when motor is both ON/OFF
- AC Line Current measurements when motor is ON
- Check VFD alarm/error codes and look up in the VFD manual under troubleshooting section.

Summary and Resources

Summary

- The HPin equation is used to calculate the amount of power necessary to operate a pump at a given operating conditions.
- VFDs can develop a variety of operating conditions by changing the RPM of the pump shaft.
- Affinity laws describe how changes in the RPM of the pump shaft change the amount of power required to operate the pump.
- VFDs can improve irrigation system control by regulating pressure and flow and can also adapt to a variety of operating conditions such as falling water table.
- Another advantage of a VFD is that it can reduce water hammer and cavitation through soft starts.
- There can be issues in the field with VFDs including heat, dirt and debris, and plugging of cooling fan filters.
- VFDs can cause harmonic distortion which can affect operation of nearby equipment and the grid.
- Other power quality issues such as a voltage in-balance or current inrush can affect VFD operation.

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