Applications for Variable Frequency Drives (VFDs) at Water Treatment Plants

March 14, 2023

Providing effective energy strategies for buildings and communities
Smart Energy Design Assistance Center (SEDAC)

We assist buildings and communities in achieving energy efficiency, saving money, and becoming more sustainable.

We are an applied research program at University of Illinois.

Our goal: Reduce the energy footprint of Illinois and beyond.
ISTC Mission

To encourage and assist citizens, businesses and government to prevent pollution, to conserve natural resources, and to reduce waste to protect human health and the environment in Illinois and beyond.
IEPA WWTP Energy Assessment Program

Providing effective energy strategies for buildings and communities
About the Program

The Illinois EPA Public Water Infrastructure Program helps municipalities reduce the cost of water and wastewater treatment.

- NO-COST energy assessment for publicly-owned water and wastewater facilities
  - Similar assessments: $6,000-$12,000

- Comprehensive report listing:
  - Cost of upgrades
  - Estimated payback period
  - Any applicable incentives or available funding opportunities

- 160 total assessments since 2018
- $3,400,000 in total cost savings identified
Applying for the Program

**Step 1: Initial Application – Pre-Qualification**
- Be located in Illinois & a publicly-owned plant
- Allow SEDAC/ISTC to visit the site
- Be willing to share facility information with SEDAC and ISTC
- Share final assessment report with Illinois EPA Office of Energy

**Step 2: Data Collection**
- Facility information – energy use, maintenance reports, process flow, etc.
- 2 years of utility bills and DMRs

**Step 3: Site Visit Scheduled**
Site Visit Overview and Project Timeline

• Site visit on-site or conducted virtually

• Receive short list of energy efficient opportunities 1 week after site visit

• Receive assessment report
  • ~6-8 weeks after site visit

• Project leader & IEPA Office follows up
  ~two weeks after report sent
  • Ask about potential to complete projects
  • Assist in locating and applying for grant, incentive, and loan funding opportunities.
Site Visit Process

Before Assessment Begins:
- Utility Benchmarking
- General process overview
- Review known issues
- Review desired changes

Below is the table for data source:

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Electric Use Intensity (kWh/MG/year)</th>
<th>Energy Use Intensity (kBtu/MG/year)</th>
<th>Energy Cost Intensity ($) (MG)</th>
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</thead>
<tbody>
<tr>
<td>YOUR Water Plant</td>
<td>9,999</td>
<td>99,999</td>
<td>$999</td>
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<tr>
<td>Nat’l Avg (surface water)</td>
<td>1,406(^1)</td>
<td>6,223(^2)</td>
<td>N/A</td>
</tr>
<tr>
<td>IL Mean (surface water)</td>
<td>2,019(^3)</td>
<td>6,889(^2)</td>
<td>$586(^3)</td>
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<tr>
<td>Nat’l Avg (ground water)</td>
<td>1,824(^1)</td>
<td>6,223(^2)</td>
<td>N/A</td>
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<tr>
<td>IL Mean (ground water)</td>
<td>2,844(^3)</td>
<td>9,704(^2)</td>
<td>$239(^3)</td>
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</table>

During the Assessment:
- Walk-through
  - Process flow
  - Equipment
  - SCADA
- Detailed process questions and overview during walkthrough
- Usually request equipment run hours, any process tracking to assist with calculations
Energy Efficiency Assessment Report

City Facility
Water Treatment Plant

Facility Contact
John Doe, Public Works Director
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Assessment Date
May 3, 2023

Report Publish Date
August 5, 2023

Table 1: Measure Analysis Summary

<table>
<thead>
<tr>
<th>Measure #</th>
<th>Description</th>
<th>Potential Energy Savings</th>
<th>Estimated Project Cost</th>
<th>Potential Incentive</th>
<th>SPB w/o Incentive (years)</th>
<th>SPB w/ Incentive (years)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>LED Lighting Upgrades</td>
<td>5</td>
<td>$1,200</td>
<td>$5,600</td>
<td>4.6</td>
<td>4.3</td>
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<tr>
<td>2</td>
<td>Automatic Filter Backwash</td>
<td>0</td>
<td>$600</td>
<td>$5,000</td>
<td>8.6</td>
<td>5.4</td>
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<tr>
<td>3</td>
<td>Heat Pump HVAC</td>
<td>(8)</td>
<td>$1,400</td>
<td>$15,600</td>
<td>11.3</td>
<td>6.0</td>
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<tr>
<td>4</td>
<td>Well Pump UPDs</td>
<td>4</td>
<td>$600</td>
<td>$43,700</td>
<td>50</td>
<td>76</td>
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<td>5</td>
<td>Extreme Efficiency Motors</td>
<td>1</td>
<td>$250</td>
<td>$68,900</td>
<td>30</td>
<td>234</td>
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<tr>
<td>6</td>
<td>Heat Pump Water Heater</td>
<td>(1)</td>
<td>$2,500</td>
<td>$600</td>
<td>10</td>
<td>7.4</td>
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<tr>
<td>PKG 1</td>
<td>Measures 1 - 3</td>
<td>(3)</td>
<td>$3,100</td>
<td>$26,200</td>
<td>8.3</td>
<td>5.2</td>
</tr>
</tbody>
</table>

6.1 Measure 1 – Upgrade Interior & Exterior Lighting to LEDs

Current Issues and Observations:

Project Cost

- Investment ($) $5,600
- Incentives ($) $400
- Total ($) $5,200

Annual Savings

- Electricity (kWh) 13,000
- Natural Gas (Therms) 0
- Savings ($) $1,200
- CO2e (MT) 6

Economic Data w/ Incentives

- Simple Payback yrs 4.3
- Internal Rate of Return (%) 19%
- Net Present Value ($) $4,100
VFD Applications at Water Treatment Plants

Shawn Maurer, P.E., C.E.M.
SEDAC
Technical Director

Matt Johnson, P.E.
Xylem
Sr. Applications Engineer

Don Jensen
Highland Park WTP
Superintendent
Pump Affinity Laws – Simple Right?

\[ \frac{RPM_1}{RPM_2} = \frac{GPM_1}{GPM_2} \]

\[ \left( \frac{RPM_1}{RPM_2} \right)^2 = \frac{\Delta P_1}{\Delta P_2} \]

\[ \left( \frac{RPM_1}{RPM_2} \right)^3 = \frac{\bar{P}_1}{\bar{P}_2} \]

These laws are why VFDs on centrifugal systems are highly promoted!

- 20% reduction in speed is about 51% reduction in power.

So, we can put a VFD on any centrifugal pump, right?
Understanding VFD Potential

System curve impacts operation, too!
- Flat curves not good for VFDs
- Steeper curves better for VFDs

*Generally, above applies.

Example to right

Same Design Condition:
- 400 GPM, 54 ft TDH
- Different system designs
Understanding VFD Potential

Match steep pump curves to flat system curves
• VFD may be applicable

Same Design Condition:
• 400 GPM, 54 ft TDH
• Different pump curves, same system design
Benefits for Raw Water Well Pumps

- Reduce well draw-down
  - Decreases static head
  - Extend well life between cleanings
- Vary flow to match process demand
- Reduce wear and tear on pumps and motors
- Match oversized pump/motor to demand
Benefits for High Service Pumps

• **Closed Loop**
  • Pressure modulation
  • Demand matching
  • Water hammer reduction

• **Water Tower/Gravity Pressure**
  • Tower Draw-down matching
  • Pressure transient reduction
Thank you!

Questions?

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Why are VFD used

There are several reasons why a VFD might be used, including:

- Correcting flow to meet current and/or future demands.
- Flow matching (maintain sump level)
- Soft start to limit in-rush currents
- Soft stop to limit transients like water hammer
- Phase inversion (1-phase to 3-phase)
- Voltage correction
- Power Factor Correction
- Maximizing system efficiency
- Lowering operational costs
- Maintaining sump and pipe cleanliness

Let’s look at one of the main reasons VFD’s are used.
Use VFD’s to Correct Flow – Example

As levels in the sump change so does the system curve because static head will also change with level

Original Duty Condition: 500 GPM @ 50’ w/25’ static head

However, with a higher level in the sump, the static head will drop causing the pump to operate at a different point

This is where we would like to be: 500 GPM @ 40’ w/15’ static head
Use VFD’s to Correct Flow – Example

With a VFD added to the system the flow can be held constant regardless of the sump level (aka flow matching)

With the proper control system, the pump can be automatically adjusted to maintain a fixed flow rate
Specific energy

\[ E_s = \frac{\text{energy}}{\text{volume}} \left( \frac{kWh}{m^3} \right) \left( \frac{kWh}{Mgal} \right) \]

\[ E_s = \frac{h \rho g}{\eta} \frac{1}{3600000} \left( kWh \right) \]

\[ E_s = \frac{h \rho g}{\eta} \frac{1}{639} \left( kWh \right) \left( Mgal \right) \]
Process control aspects
-Variable speed pump systems

Reducing the total pumping head

\[ E_z = \frac{h \rho g * 1}{\eta 3600000} \left[ \frac{kWh}{m^3} \right] \]

Maximizing pump efficiency
Pump sump level control

-Minimizing energy usage

Specific Energy = \frac{\text{Energy}}{\text{Volume}} \propto \frac{H}{\eta}
Internal Recirculation Pumps

- Design flow: 8.4 MGD (5,830 gpm) – 2 Pump operation 1 standby
- Flow range 2.3-8.4 MGD (1,550 – 5,830 gpm)
- Average flow 3,400 gpm
- Pump selection NT 3153 LT
- 10” inlet and outlet
WWTP Recirculation System
WWTP Recirculation System
One pump operation
WWTP Recirculation System
One pump operation
One pump operation evaluation
Evaluation of 1 pump vs 2 pump operation requires system curve information.
One Pump Operation Evaluation

One pump system curve

Two pump system curve

622 237 mm [Pump 1]
622 237 mm [Pump 1+2]

73.7% Eff.

5784.1 US g.p.m.

14.3 ft
Variable Speed Curves for 1 vs 2 Pump Duty

Operating Characteristics

<table>
<thead>
<tr>
<th>Pumps / Systems</th>
<th>Frequency</th>
<th>Flow</th>
<th>Head</th>
<th>Shaft power</th>
<th>Flow</th>
<th>Head</th>
<th>Shaft power</th>
<th>Hyd. eff.</th>
<th>Specific Energy</th>
<th>NPSH re</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 / 1</td>
<td>35 Hz</td>
<td>1680 US g.p.m</td>
<td>4.83 ft</td>
<td>2.86 hp</td>
<td>3370 US g.p.m</td>
<td>4.83 ft</td>
<td>5.73 hp</td>
<td>71.9 %</td>
<td>26.5 kWh/US N</td>
<td>10.8 ft</td>
</tr>
<tr>
<td>1 / 1</td>
<td>60 Hz</td>
<td>3270 US g.p.m</td>
<td>10.3 ft</td>
<td>13.9 hp</td>
<td>3270 US g.p.m</td>
<td>10.3 ft</td>
<td>13.9 hp</td>
<td>61.2 %</td>
<td>60.3 kWh/US N</td>
<td>25.5 ft</td>
</tr>
</tbody>
</table>
Specific Energy Definitions

\( E_s \) is needed energy to transport a liquid volume

\[
E_s = \frac{\text{Energy}}{\text{Volume}} = \frac{Pt}{Qt} = \frac{\rho g Q H}{\eta_{tot}} \frac{1}{Q} = \frac{H}{\eta_{tot}} \rho g
\]

\( \rho = \text{density} \)

\( g = \text{gravity constant} \)

Bring system pressure down and total efficiency up!!
Specific Energy Analysis

![Specific Energy Analysis Graph](image)

- **Specific Energy (kWh/MGD)**
- **FLOW (Usgpm)**

- **Es-2pumps**
- **Es-1pump**
Energy Cost

- Example
- Average flow 3,4000 gpm (4.9 MGD)

1 pump operation: Head=0.3’, Total efficiency=61.2%, ES=60kWh/MGD
2 pump operation: Head=4.8’, Total efficiency=71.9%, ES=26.5kWh/MGD
Energy Analysis

- To operate 1 pump at ~60Hz and 3,400 GPM (4.9 MGD) for 1 year (24/7) would require 107.3 MWh.
- 2 pumps at ~35 Hz and the flow would require 47.4 MWh,
- A difference of ~ 60 MWh.
Skip the one pump alternative Always try to operate as close to BEP!
Select Pump to the Right of BEP for VFDs

- From 202 kWh/MG to 99.3 kWh/MG
Questions?
VFD Application in Highland Park

Implementing VFDs for Drinking Water Plants - March 14, 2023

Don Jensen, Water Plant Superintendent
Highland Park

On Lake Michigan 25 miles North of Chicago

Incorporated in 1869

A ‘bedroom’ suburb – primarily residential and commercial

Population 30,176.

Serving another 30,000 in neighboring communities
Early water supply
Artesian Well

Artesian Well 1889

1893 Water Tower & City Hall
Early water supply
Steam Powered Pump Station 1893

In 1893-94 a steam powered lakefront pump station-settling basin with a 2,230 foot 16 inch Lake Michigan intake

In time, the citizens of Highland Park became dissatisfied with the quality of this water (referred to in the local paper as "liquid mud").
At that time, the population numbered 12,000 and required 840 million gallons of water per year.

The plant was designed to supply seven million gallons per day.

The tower is 125 feet high and features a unique ornamental brick enclosure.
Our New 4,160 Volt Pumps - 1929
Treatment Plant Expansion 1960

This expansion project doubled the plant's settling basin and filter capacity and converted all of the pumps to 440 volt operation.

‘State of the Art’ Controls

New Pumps & Generator
Plant Upgrade 1986

Multi-media filter media increased the plant's capacity to 21 million gallons per day.

This also included:

- Replacement of several pumps,
- New (liquid) chemical feed building addition,
- Up-dating of the plant’s laboratory,
- Early SCADA control system (upgraded in 2002)
Ultrafiltration 2013-14

This major upgrade replaced the conventional surface water treatment with 0.2 micron ultrafiltration fiber technology providing superior pathogen protection and increasing the Plant capacity to 30 MGD
Ultrafiltration conversion increased the kWh/MG approximately 30%.

Not surprising as this required a 3rd pumping stage, blowers and large air compressors.
Historical Water Production

Declining about 1% per year
Plant Stats

Electricity Budget $450,000 annually
Average Pressure 100 PSI at Plant

<table>
<thead>
<tr>
<th>2022</th>
<th>RAW MGD</th>
<th>FIN MGD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>5.74</td>
<td>5.41</td>
</tr>
<tr>
<td>Max</td>
<td>16.39</td>
<td>15.46</td>
</tr>
<tr>
<td>Avg</td>
<td>8.81</td>
<td>8.20</td>
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</table>
Complex Distribution System

PUMP PRESSURIZED SYSTEM (No ‘floating’ elevated storage)

50% of water production wholesaled to neighbors
Original Operation: Multiple pumps
CLOSED SYSTEM

Plant Operators matched delivery to demand by selecting combinations of various sized HLPs and ‘trimmed’ pressure by bleeding off water into reservoirs.

This required constant Operator attention (pre SCADA!) and frequent pump changes producing pressure spikes in the distribution system, especially in winter months when water use is lowest.
# High Service Pump Upgrades Over the Years

<table>
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<th></th>
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</thead>
<tbody>
<tr>
<td>HLP #1</td>
<td>4.5 MGD</td>
<td>8 MGD</td>
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<td>HLP #2</td>
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<td>6 MGD</td>
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<td>-</td>
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<td>HLP #3</td>
<td>6 MGD</td>
<td>8 MGD</td>
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<td>-</td>
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<tr>
<td>HLP #4</td>
<td>6 MGD</td>
<td>-</td>
<td>8 MGD+VFD</td>
<td>NEW VFD</td>
<td>-</td>
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<td>HLP #5</td>
<td>6 MGD</td>
<td>9 MGD+VFD</td>
<td>NEW VFD</td>
<td>-</td>
<td>-</td>
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<td>HLP #6</td>
<td>-</td>
<td>8 MGD</td>
<td>-</td>
<td>-</td>
<td>VFD</td>
</tr>
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<table>
<thead>
<tr>
<th>PRESENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>PUMP</td>
</tr>
<tr>
<td>8 MGD Fairbanks Morse, TDH 275 FT, 1775 RPM</td>
</tr>
<tr>
<td>6 MGD Peerless. TDH 250, 1770 RPM</td>
</tr>
<tr>
<td>8 MGD Fairbanks Morse, TDH 275 FT, 1775 RPM</td>
</tr>
<tr>
<td>8 MGD Aurora Mod. 41, TDH 280 FT, 1750 RPM</td>
</tr>
<tr>
<td>8 MGD Aurora Mod. 41, TDH 280 FT, 1750 RPM</td>
</tr>
<tr>
<td>8 MGD Fairbanks Morse, TDH 275 FT, 1775 RPM</td>
</tr>
</tbody>
</table>

![Pump Upgrades Over the Years](image1.jpg)
VFDs Get **ALL** of the Hours!

HLPs 4 & 5 have had VFDs since 1994.  
HLP #6 received a VFD in 2022.
How VFDs are used for control

Since our system is ‘closed’ VFDs are ideal for matching delivery to demand and controlling system pressure.

They also provide for smooth operation over a wide range of conditions. When demand exceeds capacity of a single VFD pump, a second one (both at lower Hz) can be added for fine incremental flow changes.

This also facilitates delivery to connected supplies’ reservoirs.
“Pressure Track” Mode

When engaged, adjusts Hz to maintain constant Plant discharge pressure
VFD Pump Curves

Operation Set Point is 98 PSI Plant discharge pressure.

Plant sits at foot of a 60 foot bluff along Lake Michigan requiring 25 PSI to overcome.
Affinity Curves

We learned about this the hard way!
Energy Conservation Efforts

INDUSTRIAL SYSTEMS STUDY APPLICATION FORM
January 1, 2019 – December 31, 2019

WILL YOU ACCEPT THE CHALLENGE?
Water Utility Energy Challenge (WUEC) is a competition between Great Lakes water utilities to reduce energy related pollution emission in their water distribution systems.

COMPREHENSIVE WASTEWATER TREATMENT/WATER SUPPLY PLANT STUDY WORKSHEET
January 1, 2018 – December 31, 2018
Questions?

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