Energy Savings of Variable Frequency Drives in Pumping Applications

Agenda

- I.   VFD Basic's
- II. How VFD's Save Energy in Pump Applications.
- III. Calculating Energy Savings
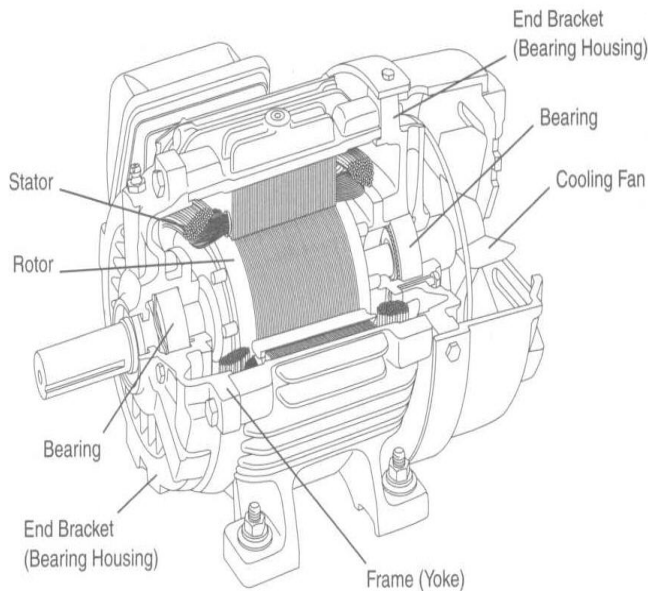- IV. Application Considerations
- V. Q & A

I. VFD Basics - Common Names

- **Adjustable Frequency Drives - AFD**
- **Variable Speed Drives - VSD**
- **AC Inverter**
- **AC Drives**
- **Drives**
- **Inverters**

Brief Snapshot of How a Motor Works

$$\text{Synchronous Speed} = \frac{120 * \text{frequency}}{\# \text{ poles}} = \frac{120 * 60 \text{ Hz}}{4} = 1800 \text{ rpm}$$

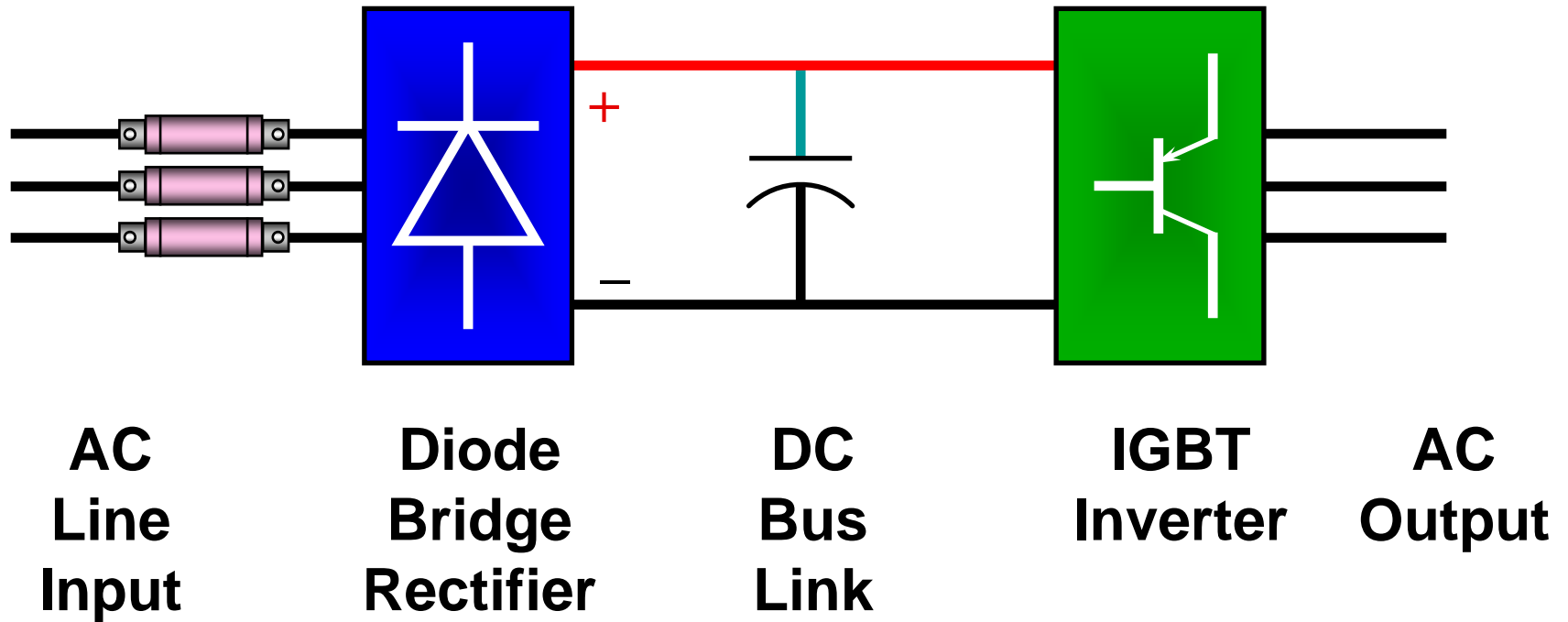**Rotor has fixed magnetic fields.**

Stator receives current from the drive which creates a magnetic field.

This rotating field moves the rotor.

The frequency is how often the current flows through the stator.

**Controlling the frequency to the stator controls the motor speed.**

End Bracket
(Bearing Housing)

Bearing

Cooling Fan

Stator

Rotor

Bearing

End Bracket
(Bearing Housing)

Frame (Yoke)

Basic Drive Design

| AC
Line
Input | Diode
Bridge
Rectifier | DC
Bus
Link | IGBT
Inverter | AC
Output |

DC voltage leaving converter is pulsing DC

And is smoothed to pure DC after going thru the DC buss

Once entering the inverter the DC is converted back to a waveform that will have varying pulse widths

AC Line
A
B
C

DC Bus

+

Typical 6-Pulse converter design

IGBT Inverter Bridge

Motor
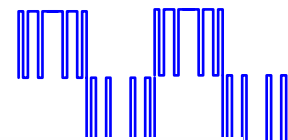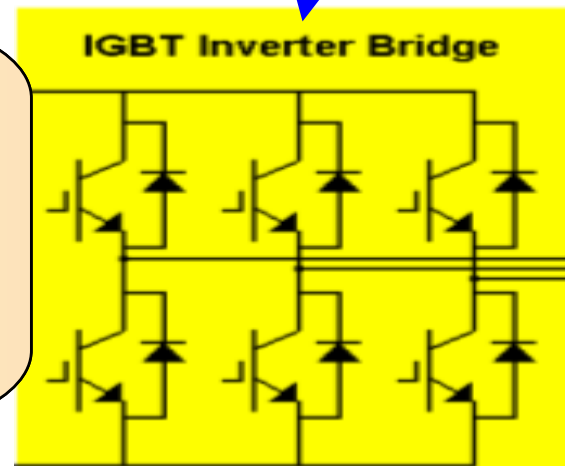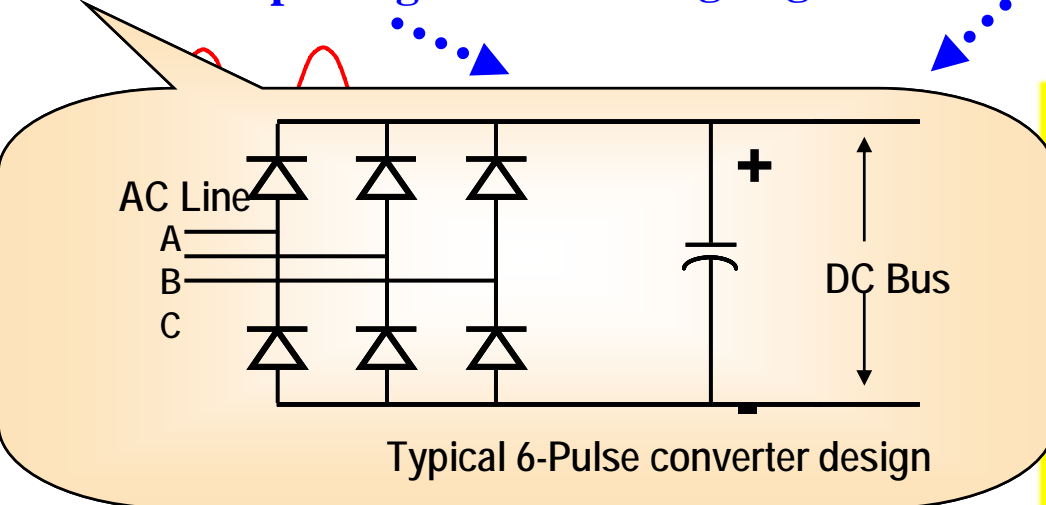
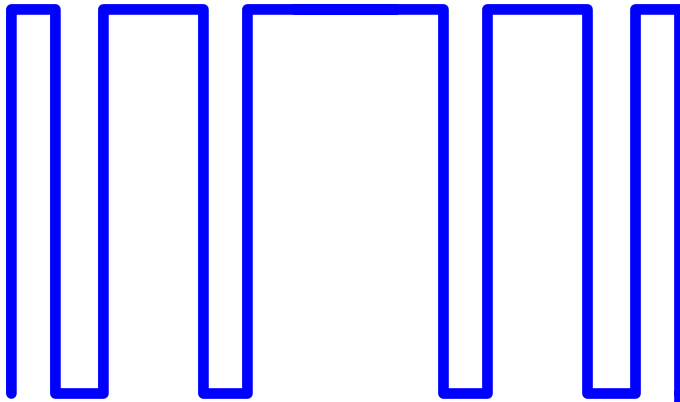| AC Line Input	Diode Bridge Converter	DC Bus Link	Transistor Inverter	AC Output

In a 480V unit the dc buss voltage reading will be @ 650-680 peakV

Pre-charge circuit limits the inrush of current while the capacitor is trying to charge

(rms x 1.414)

peak voltage or 480V x 1.414 is 678V

P_{ulse} W_{idth} $M_{odulation}$

*P*ulse *W*idth *M*odulation
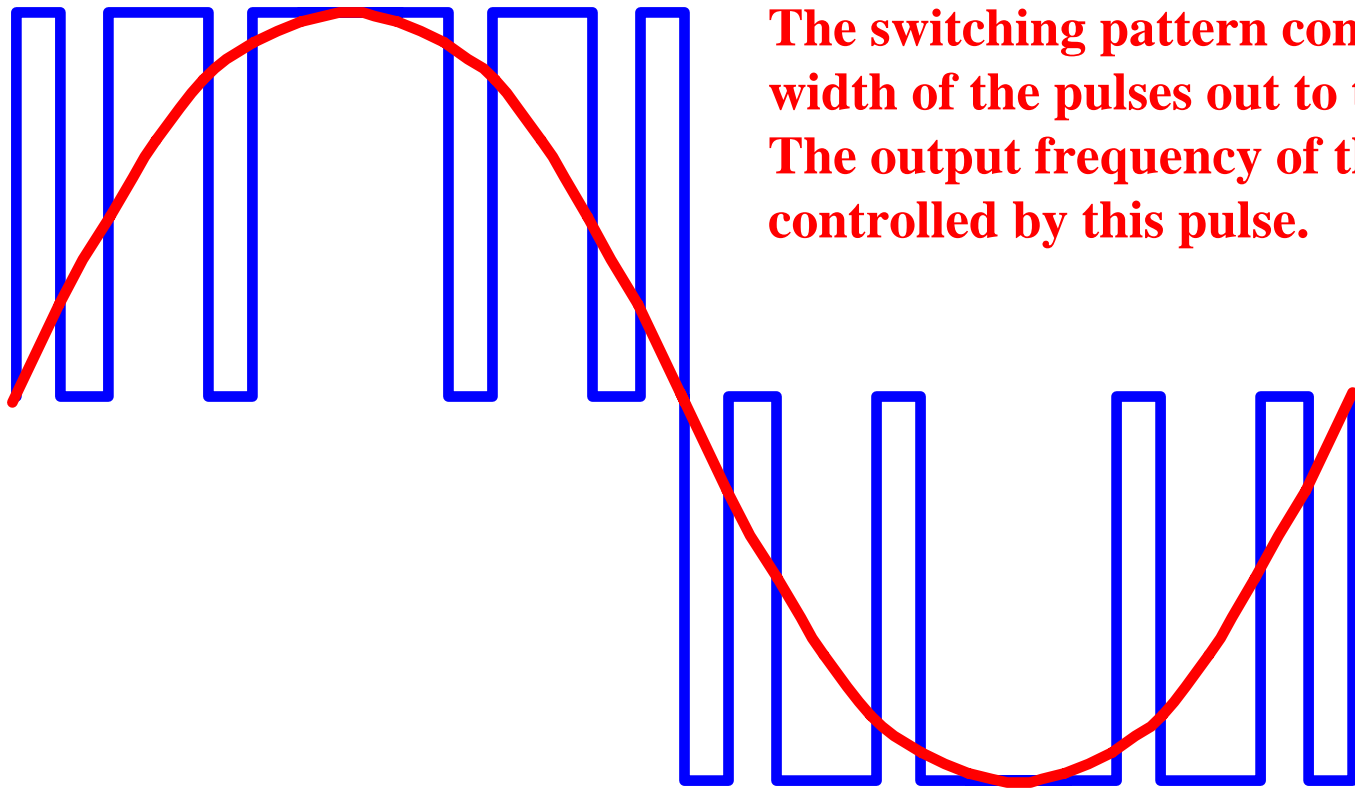
The switching pattern controls the width of the pulses out to the motor. The output frequency of the drive is controlled by this pulse.

*P*ulse *W*idth *M*odulation
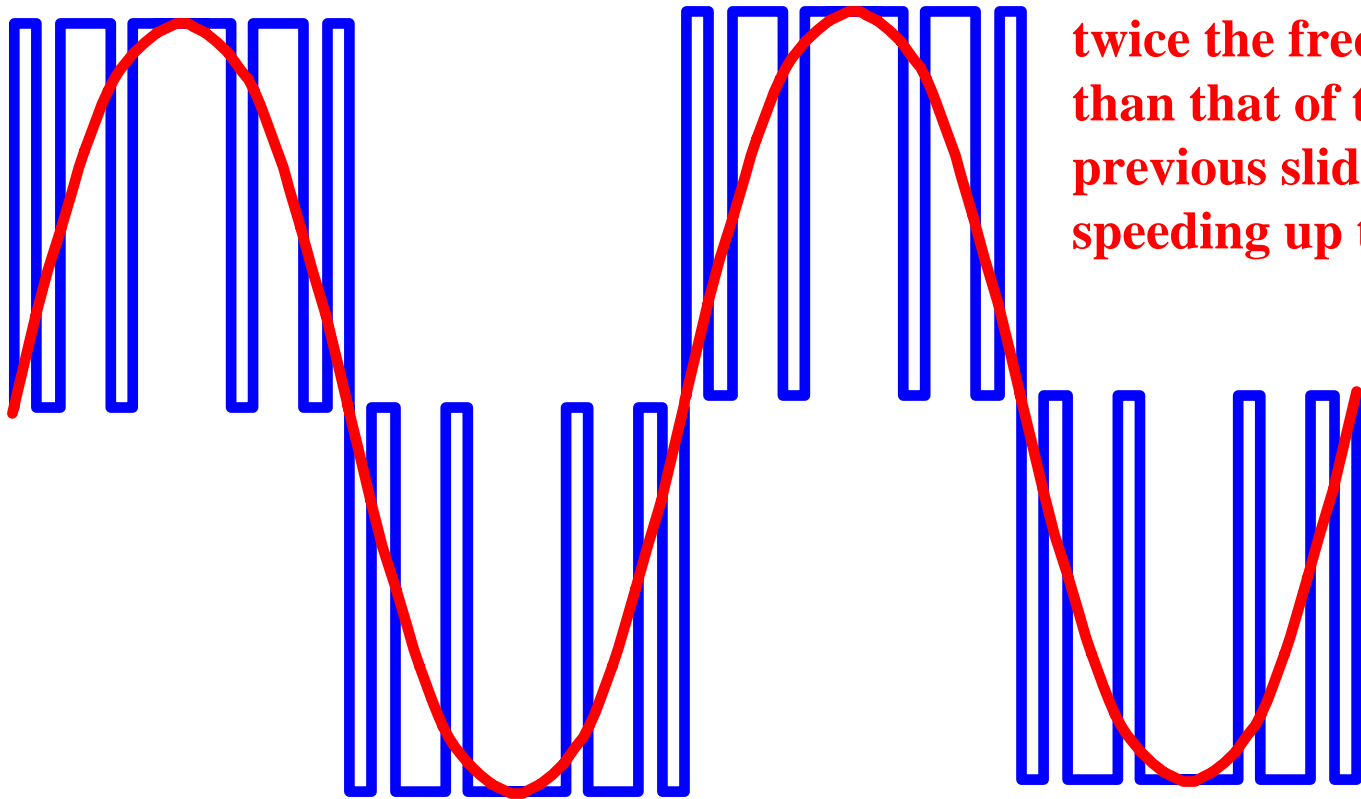
Here we are showing twice the frequency than that of the previous slide, therefore speeding up the motor

VFD's :

- Provide precise speed control of an AC Motor

- Can generate full torque from the motor at very low speed

- Allow simple setpoint control throughout the speed range

- Protects the motor and wiring from overload currents

- Provides built in Power factor correction – They are very efficient.

- Limits inrush current to providing soft-start, as well as, a soft stop

- Allows a simple connection to a communications network

- Provides ability for substantial energy savings on centrifigal pump & Fan applications.

How VFD's Save Energy in Centrifugal Pump Applications

Variable Frequency Drives can increase system energy efficiency by providing a means to reduce the motor speed of variable torque loads. The fact these centrifugal loads operate along the Laws of Affinity provide the opportunity for significant energy savings.

Affinity Laws of Centrifugal Loads

- **FLOW** is proportional to motor speed.

- **PRESSURE** is proportional to the motor speed squared.

- **POWER** is proportional to the motor speed cubed.

Affinity Laws for Centrifugal Equipment
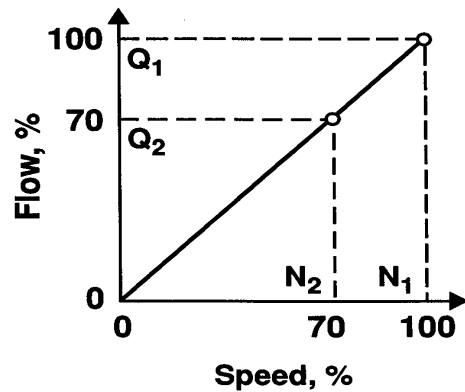
$$\frac{Q_2}{Q_1} = \frac{N_2}{N_1}$$
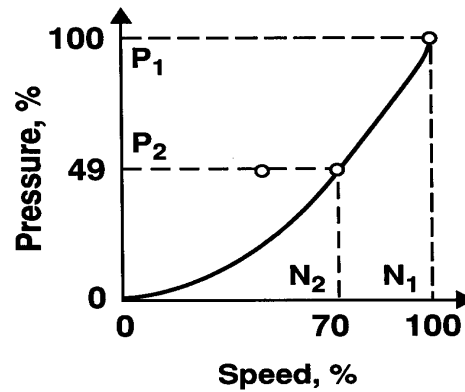
$$\frac{P_2}{P_1} = \left(\frac{N_2}{N_1}\right)^2$$
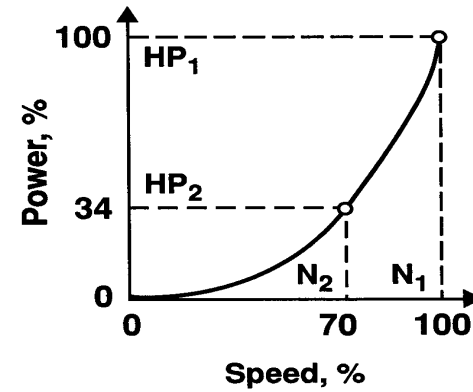
$$\frac{HP_2}{HP_1} = \left(\frac{N_2}{N_1}\right)^3$$

N = Speed
Q = Flow
P = Pressure
HP = Horsepower

Examples of Affinity Laws at Work

- **A motor running at 50% of full speed capacity has a motor torque of 25% of full speed.**

- **The electricity required to operate the motor at 50% of full speed is 12.5% of the amount of the electricity required if the motor was running at 100% full speed capacity.**

- **The electricity required to operate the motor at 80% of full speed is 55% of the amount of the electricity required if the motor was running at 100% full speed capacity.**

- **Thus, reducing the motor speed can significantly reduce the electrical energy consumption.**

III. Calculating Energy Savings

Example:

- **A 20 horsepower Centrifugal Pump operating**
- 10 hours a day
- 260 days a year
- Energy cost is of $0.10 cents per kilowatt-hour.

- **Cost of running full speed:**
- 20 hp x 0.746 kW/hp x 2600 hours x $0.10/kWhr = **$3879.20** per year

VFD Cost Savings Example

- **Assuming the Pump does not need to run at <u>full speed</u> all of the day, we will use an example of:**
- Running full speed (100%) for 25% of the day
- 80% speed for 50% of the day
- 60% speed for the remaining 25% of the day

- **Cost of running with an AC drive controlling the motor:**
  - 20 hp x (1)3   x 0.746 kW/hp x   650 hours x $0.10/kWhr = $969.80 per year
  - 20 hp x (0.8)3 x 0.746 kW/hp x 1300 hours x $0.10/kWhr = $993.08
  - 20 hp x (0.6)3 x 0.746 kW/hp x   650 hours x $0.10/kWhr = <u>$209.48</u>
- **Total = $2172.36** per year

- **Annual savings: $3879.20   - $2172.36   =   <u>$1706.84</u> per year**

- **<u>Payback for VFD Installations in VT Applications average 18 to 24 months</u>**

Tools Available

- Energy Savings Calculators/Tools are readily available from most major VFD Manufacturers.

- Visit Square D Lean Power website offers such a tool.

- www.squaredleantools.com

LEAN TOOLS

Create a new project   Logout

Welcome Andy Matthews   Your current projects: Drive Calculator - Harvey   Open   Edit   New

Square D Lean Tools - ENERGY SAVINGS - VFD vs MECHANICAL DAMPING

| Motor Horsepower ? | 30.0 |
| High or Std. Efficiency ? | Standard |

| Motor Efficiency | 0.91 |

Fan or Pump Load ?	Pump
If a Fan load :	
Inlet or Outlet Vanes?	Outlet
Utiity rate ($/kWh)?	0.1

| Full Load Input Power | 24.59 | kW |

| Load Designation? | annual use |

Usage Profile	
% Speed	Hours per Yr
100	520
90	390
80	910
70	1144
60	806
50	3068
40	1898
30	0
20	0

kWh/Year Saved	97096.57
Annual $ Savings	$ 9709.66
PAYBACK ESTIMATOR	
Drive Cost	$ 5264.40
Utility Rebate	$ 0
Months for payback	6.51

Annual Use Calculator   Save

TO CALCULATE SAVINGS:
1) Complete annual hourly useage using the "**Annual Use Calculator**".
2) Complete the information in above yellow highlighted areas.

SQUAREDLEANTOOLS.COM

a brand of
Schneider Electric   **SQUARE D**

LEAN TOOLS

Create a new project   **Logout**

Welcome Andy Matthews   Your current projects: Drive Calculator - Harvey   [Open] [Edit] [New]

ANNUAL USAGE PROFILE CALCULATOR (add % speed the drive would run by time, day and season)

Time Bracket		Winter Weekday	Winter Saturday	Winter Sunday	Spring Weekday	Spring Saturday	Spring Sunday	Summer Weekday	Summer Saturday	Summer Sunday	Fall Weekday	Fall Saturday	Fall Sunday
12:00 AM	2:00 AM	50	40	40	50	30	30	50	40	40	50	30	30
2:00 AM	4:00 AM	50	40	40	50	30	30	50	40	40	50	30	30
4:00 AM	6:00 AM	50	40	40	50	30	30	50	40	40	50	30	20
6:00 AM	8:00 AM	50	50	50	50	50	50	50	50	50	50	50	50
8:00 AM	10:00 AM	50	50	50	50	50	50	50	50	50	50	50	50
10:00 AM	12:00 PM	70	50	50	80	50	80	50	50	50	80	50	50
12:00 PM	2:00 PM	80	50	50	80	50	80	50	50	50	80	50	50
2:00 PM	4:00 PM	90	50	50	70	50	90	50	50	50	70	50	50
4:00 PM	6:00 PM	80	50	50	50	50	80	50	50	50	50	50	50
6:00 PM	8:00 PM	50	50	50	50	50	50	50	50	50	50	50	50
8:00 PM	10:00 PM	50	50	50	50	50	50	50	50	50	50	50	50
10:00 PM	12:00 AM	50	50	50	50	50	50	50	50	50	50	50	50

[Back] [Save]

% Speed	Hours per Yr
100	0

File   Edit   View   Favorites   Tools   Help

Back   Search   Favorites

Address http://www.squaredleantools.com/drives/index.cfm?projectid=2   Go   Links

LEAN TOOLS

Create a new project   Logout

Welcome Andy Matthews

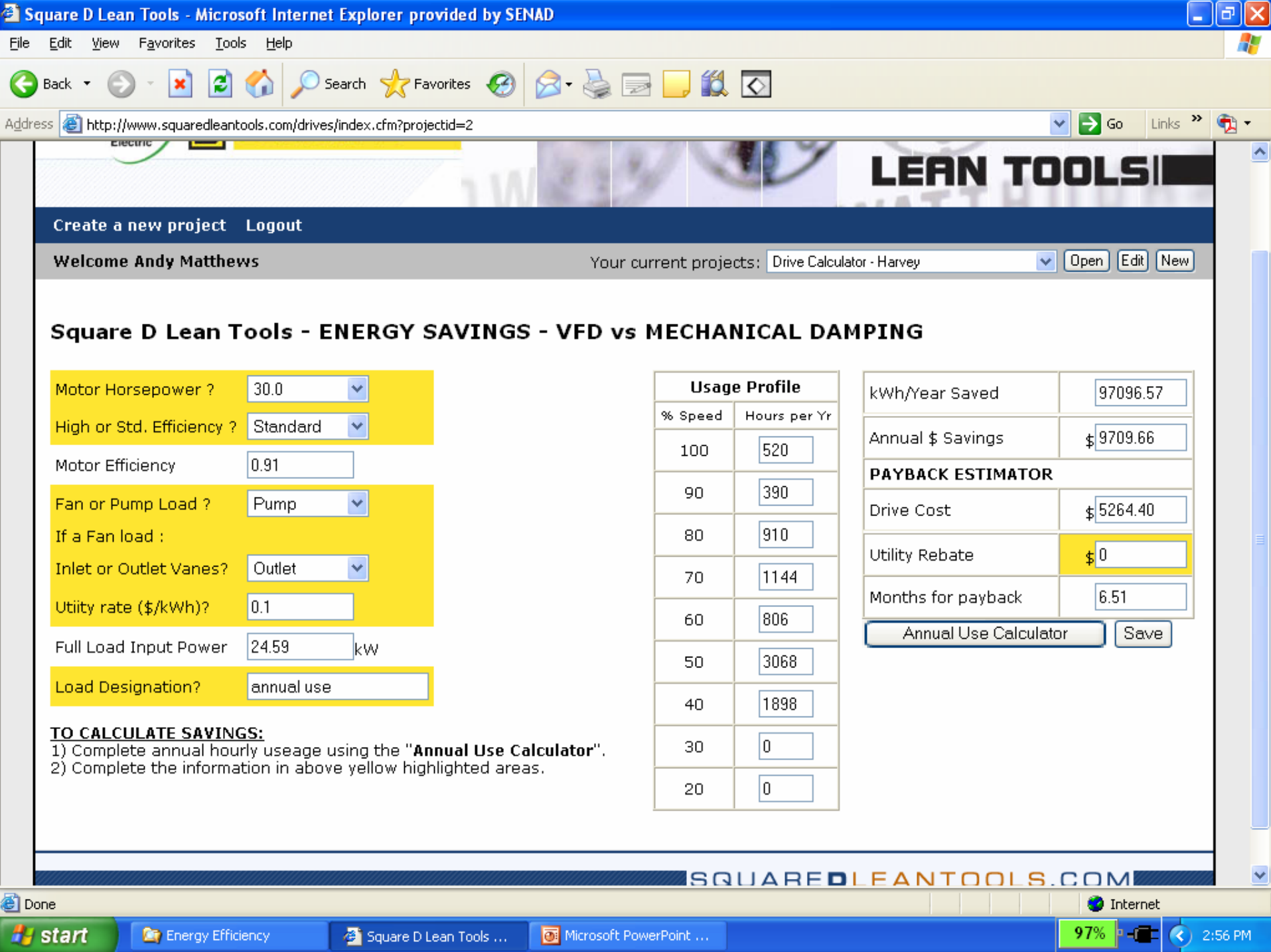Your current projects: Drive Calculator - Harvey   Open   Edit   New

Square D Lean Tools - ENERGY SAVINGS - VFD vs MECHANICAL DAMPING

Motor Horsepower ?   30.0

High or Std. Efficiency ?   Standard

Motor Efficiency   0.91

Fan or Pump Load ?   Pump

If a Fan load :

Inlet or Outlet Vanes?   Outlet

Utiity rate ($/kWh)?   0.1

Full Load Input Power   24.59 kW

Load Designation?   annual use

Usage Profile	
% Speed	Hours per Yr
100	520
90	390
80	910
70	1144
60	806
50	3068
40	1898
30	0
20	0

kWh/Year Saved	97096.57
Annual $ Savings	$ 9709.66
PAYBACK ESTIMATOR	
Drive Cost	$ 5264.40
Utility Rebate	$ 0
Months for payback	6.51

Annual Use Calculator   Save

TO CALCULATE SAVINGS:
1) Complete annual hourly useage using the "**Annual Use Calculator**".
2) Complete the information in above yellow highlighted areas.

SQUAREDLEANTOOLS.COM

Done   Internet

start   Energy Efficiency   Square D Lean Tools ...   Microsoft PowerPoint ...   97%   2:56 PM

Application Considerations

- Selecting VFD's
- Load Type
- Environmental Considerations
- Control/Communication
- Motor Requirements
- Cable lengths/harmonic mitigation

Selecting VFD's

Type H—Selection and Pricing

Input Line Voltage	Three Phase Motor Power (Horsepower)				Continuous Output Current (Amperes)				Catalog Number without Keypad	Price
	Constant Torque	Contant Torque Low Noise	Variable Torque	Variable Torque Low Noise	Constant Torque	Contant Torque Low Noise	Variable Torque	Variable Torque Low Noise		
208/230 Vac Single Phase	0.5	-	-	0.5	2.3	-	-	2.5	ATV58HU09M2ZU	$ 650.
	1	-	-	1	4.1	-	-	4.8	ATV58HU18M2ZU	790.
	2	-	-	2	7.8	-	-	7.8	ATV58HU29M2ZU	900.
	3	-	-	3	11	-	-	11	ATV58HU41M2ZU	1000.
	4	-	-	4	13.7	-	-	14.3	ATV58HU72M2ZU	1350.
	5	-	-	5	18.2	-	-	17.5	ATV58HU90M2ZU	1790.
	7.5	-	-	7.5	24.2	-	-	25.3	ATV58HD12M2ZU	2200.
208/230 Vac Three Phase	2	-	2	2	7.8	-	7.5	7.5	ATV58HU29M2ZU	900.
	3	-	3	3	11	-	10.6	10.6	ATV58HU41M2ZU	1000.
	4	-	4	4	13.7	-	14.3	14.3	ATV58HU54M2ZU	1175.
	5	-	5	5	18.2	-	16.7	16.7	ATV58HU72M2ZU	1350.
	7.5	-	7.5	7.5	24.2	-	24.2	24.2	ATV58HU90M2ZU	1790.
	10	-	10	10	31	-	30.8	30.8	ATV58HD12M2ZU	2200.
	15	10	15/20	15	47	31	46.2/60	46.2	ATV58HD16M2XZU	3413.
	20	15	25	20	60	47	75	60	ATV58HD23M2XZU	4191.
	25	20	30	25	75	60	88	75	ATV58HD28M2XZU	4388.
	30	25	40	30	88	75	116	88	ATV58HD33M2XZU	5038.
	40	30	50	40	116	88	143	116	ATV58HD46M2XZU	6597.
400/460 Vac Three Phase	1	-	1	1	2.3	-	2.1	2.1	ATV58HU18N4ZU	890.
	2	-	2	2	4.1	-	3.4	3.4	ATV58HU29N4ZU	1000.
	3	-	3	3	5.8	-	4.8	4.8	ATV58HU41N4ZU	1210.
	4	-	5	5	7.8	-	7.6	7.6	ATV58HU54N4XZU*	1405.
	5	-	7.5	7.5	10.5	-	11	11	ATV58HU72N4XZU*	1600.
	7.5	-	10	10	13	-	14	14	ATV58HU90N4XZU*	2050.
	10	-	15	15	17.6	-	21	21	ATV58HD12N4XZU*	2600.
	15	-	20	20	24.2	-	27	27	ATV58HD16N4XZU*	3200.
	20	-	25	25	33	-	34	34	ATV58HD23N4XZU*	4000.
	25	20	30	25	40.7	33	40	34	ATV58HD28N4XZU▲	4906.
	30	25	40	30	48.4	40.7	52	40	ATV58HD33N4XZU▲	5550.
	40	30	50	40	66	48.4	65	52	ATV58HD46N4XZU▲	6994.
	50	40	60	50	79.2	66	77	65	ATV58HD54N4XZU■	8978.
	60	50	75	60	93.5	79.2	96	77	ATV58HD64N4XZU■	10931.
	75	60	100	75	115.5	93.5	124	96	ATV58HD79N4XZU■	13271.

▲ If EMC filter to meet level A compliance is desired, delete the "X" from the catalog number and add $280. to the price.

- ✓ Size by Motor FLA and Base Speed whenever possible
- ✓ Typically picked from table based on Voltage, HP and Load Type
- ✓ It's also useful to know the motor base speed, service factor, enclosure type and insulation Class of the motor.

Load Types

- Variable Torque
- Constant Torque
- Constant Horsepower
- Impact Load

Depends on speed, may require different torques. Requires very little torque at starting or low speeds

Usually for high starting torque requirements. The torque loading is not a function of speed. As speed changes, load torque remains constant and horsepower changes linearly with speed.

When over speeding the motor is required, grinders, etc.

The torque loading is intermittent and is not a function of speed, punch presses, etc. which uses a large flywheel to deliver the energy needed for the load.

Temperature

- ✓ Environmental Issues – Ambient Temperature
  - ✓ Most drives are rated 0-40 degrees C
  - ✓ Derating is generally required above 40 degrees C
  - ✓ Heating is required below zero degrees C
  - ✓ Usually available in Nema 1, 12, 3R & other enclosures.

Altitude

✓ Environmental Issues – Altitude

  ✓ Most drives are rated up to 3300 feet above sea level

  ✓ De-rating is required above 3300' due to thinner air

  ✓ 1% for every 300'

Control Considerations

- How will VFD receive start/stop command and speed reference.

- Today's Technology provides the ability for VFD's to communicate on numerous communication platforms.

- Examples include:Ethernet, Modbus, Modbus Plus, DeviceNet, Profibus, BacNet, and many others.

Specifying Motors

- Standard Nema B motors with class F HPE insulation class or better with a 1.15 service factor are usually fine for most applications.

- Consider specifying NEMA MG1, Part 31 motors.
  NEMA MG1-1993, Revision 1, Part 31, Section IV –"Performance Standards Applying to All Machines", Part 31 – "Definite Purpose Inverter-Fed Motors"

- This will give you 1600 Peak Input Voltage Rating, better insulation, bearing protection and separation of the input and output leads to the motor.

Other Considerations

- Motor lead lengths – Is output or DV/DT filter required. VFD Manufacture can provide guidelines.

- Most major VFD manufacturers provide built in DC chokes & or line reactors to provide means to reduce harmonics.

- Alternates such as 12 or 18 pulse drive configurations &/or active/passive harmonics filters are available.

- Square D Lean Tools web site has harmonics calculator configurable for each one line to model whether installation meets IEEE519 requirements.

- Some estimates claim 68% of all energy is used in driving motors of which at least half run centrifugal pumps and fans.

- VFDs can run centrifugal pumps and fans more efficiently due to the Affinity Laws.

- The energy that can be saved is ENORMOUS!

- Most applications pay for themselves in less than two years.

- VFD's provide precise speed and torque control of AC motors.

- They provide built in softstart control protecting mechanical equipment and providing the ability to control water hammering in pump systems.

- They are efficient and can be integrated in most communication networks or facility automation systems.

- Determining if a given pump system can effectively operate at reduced speeds for a given period of time will provide the opportunity to analyze the cost/savings benefit of installing VFD's.

Questions & answers

Thanks for your attention !!!!