9. General Information

Section Contents:

Energy Efficient Electric Motors

Efficiency is an important factor to consider when buying a new electric motor. Once a particular motor is selected and installed, you are locked into the energy use characteristics for the life of the motor with no option for improvement.

The annual energy costs of running a motor is usually many times greater than the initial purchase price. For example a typical 20 hp motor running 18 hours a day at 12¢ per kWh, uses $11,700 worth of electricity annually, about 10 times its initial cost. Relatively small increases in efficiency can pay for the additional costs for higher efficiency motors quickly.

Motor efficiency is the ratio of mechanical power output to the electrical power input, usually expressed as a percentage. The National Electrical Manufacturers Association (NEMA) performs motor efficiency tests in accordance with standards developed by the Institute of Electrical and Electronics Engineers (IEEE). The "nominal efficiency" published by NEMA is an average value obtained through testing of a population of motors.

The Energy Policy Act of 1992 (EPACT) requires that most general purpose motors manufactured for sale in the United States after October 1997 meet minimum efficiency standards. Using these standards as a benchmark, the NEMA Premium Efficiency class of motors has been established. NEMA Premium Efficiency motors must equal or exceed a higher level of nominal efficiency to be considered energy efficient.

When To Select Energy-Efficient Motors

The selection of energy-efficient motors should be strongly considered in the following situations:

- For all new dairy complexes.
- When purchasing equipment packages, such as cooling and air compressors, water and vacuum pumps, air circulation equipment, etc.
- When major modifications or updates are made to dairy facilities.
- To replace oversized and under-loaded motors.

A general rule of thumb indicates a simple payback of two years or less for replacement of standard efficiency with Premium Efficiency motors that operate at least 4000 hour per year or slightly less than half time.

Energy-efficient motors offer other benefits. Because they are constructed with improved manufacturing techniques and superior materials, energy-efficient motors have higher service factors, higher quality insulation and longer bearing life, better power factor, operate more quietly, produce lower waste heat output, and less vibration, all of which increase reliability. Many of these motors are also rated for use with variable frequency drives, which offers further savings.

How Much Can An Energy-Efficient Motor Save?

To calculate actual Annual Energy Savings from selecting a more efficient motor, use the following formula in Table 9-1. To see the Annual Energy Savings Calculator, click on the following link: Calculators

Table 9-1. Annual Energy Savings

Savings =	Hp x (L/100) x 0.746 x hr x C x (Eee/100-Estd/100)		
	Hp	=	motor rated horsepower
	L	=	Load factor (percentage of full load)
	Hr	=	annual operating hours
	C	=	average energy costs ($/kWh)
	Eee	=	Energy-efficient motor efficiency rating, %
	Estd	=	standard motor efficiency rating, %
	0.746	=	conversion from horsepower to kW

The following Table 9-2 provides estimated savings for Premium Efficiency motors at 1 to 3% improvements in nominal efficiency:

Table 9-2. Annual value of efficiency gains for fully loaded motor operating 4,000 hours annually at an electric rate of $0.12 per kWh with a standard motor efficiency of 85%. Eee represents the energy-efficient motor efficiency rating.

Motor Horsepower	*Annual Savings*		
	1% Efficiency Gain (Eee = 86%)	2% Efficiency Gain (Eee = 87%)	3% Efficiency Gain (Eee = 88%)
5	$ 24	$ 48	$ 72
10	$ 49	$ 97	$144
20	$ 98	$194	$287
50	$245	$484	$718

Factor To Consider When Choosing A New Motor:

- **Motor size** – Motors should be sized to operate with a load factor between 65% and 100%. The common practice of over sizing results in less efficient operation. The first step is to verify if the old motor was correctly sized for the application. A larger, lightly loaded motor will be less efficient than a smaller, fully loaded motor. As well as more expensive to purchase.

- **Operating speed** – ensure the correct operating speed is selected and compare efficiencies for motors at the same speed.

- **Operating voltage** – make sure to select motor with correct voltage.

- **NEMA Frame Size –** match frame designation so replacement motor will have the same physical dimensions.

- **Enclosure Type** – match enclosure type to the environment the motor will be subjected to. Typical enclosures:

  Open Air Over ((OAO) or Open Drip Proof (OPDP)

  Enclosed – Either totally enclosed fan cooled (TEFC)
Total enclosed non-ventilated (TENV)
Total enclosed open air (TEOA)

  Hazardous Location – explosion proof (XP)

Although the perception that increases in efficiency between standard and Premium Efficiency motors is comparatively small (1-3%), the benefits in energy savings and operating costs can be significant. A motor will consume 50-60 times its initial price in electric expense during a typical 10-year life. The additional costs of a Premium Efficiency motor will be returned many times during that life in lower energy costs. Careful evaluation of all motors operating 12+ hours daily (4,000 hours annually) can yield substantial opportunities for energy savings.

A list of manufacturers that sell NEMA Premium motors is given in Table 9-3 along with the web site address.

Table 9-3. NEMA Premium™ Motor Manufacturers

NEMA Premium™
www.nema.org/premiummotors

COMPANY	WEB SITE
A.O. Smith Electrical Products	www.aosmithmotors.com
Baldor Electric Co.	www.baldor.com
Emerson Motors	www.emersonmotors.com
GE Motors	www.geindustrial.com
Leeson Electric	www.leeson.com
Lincoln Motors	www.lincolnmotors.com
Marathon Electric	www.marathonelectric.com
RAM Industries	www.ramusa.com
Rockwell Automation	www.reliance.com
Siemens	www.sea.siemens.com/motors
Sterling Electric	www.sterlingelectric.com
TECO-Westinghouse	www.tecowestinghouse.com
Toshiba International	www.tic.toshiba.com
WEG Electric Motors	www.wegelectric.com

Rev. 5/3/02

Motor management and Selection Software.

MotoMaster+ 4.0 - United States Department of Energy, Office of Industrial Technologies. - http://www.oit.doe.gov/bestpractices - Software to evaluate and select energy efficient motors and estimate potential savings.

The specifications of Premium efficiency for motor 1 to 200 hp is given in Table 9-4. This table is from the Consortium for Energy Efficiency [CEE]. The table gives specification for motors – open and enclosed and for 1,200, 1,800 and 3,600 rpm [theoretical speed].

Table 9-4. CEE Premium-Efficiency Motors Initiative

EFFICIENCY SPECIFICATIONS

CEE Specification aligned with NEMA PREMIUM™ on June 13, 2001

Nominal Full Load Efficiencies for EPAct – covered equipment 1-200 horsepower NEMA design A and B, three phase, integral horsepower, general purpose motors (1200, 1800, 3600 RPM).

	Open Drip-Proof (ODP)							Totally Enclosed Fan-Cooled (TEFC)					
	1200 RPMs		1800 RPMs		3600 RPMs			1200 RPMs		1800 RPMs		3600 RPMs	
	EPACT Efficiency Standard*	NEMA Premium Efficiency	EPACT Efficiency Standard*	NEMA Premium Efficiency	EPACT Efficiency Standard*	NEMA Premium Efficiency		EPACT Efficiency Standard*	NEMA Premium Efficiency	EPACT Efficiency Standard*	NEMA Premium Efficiency	EPACT Efficiency Standard*	NEMA Premium Efficiency
HP							**HP**						
1	80	**82.5**	82.5	**85.5**	N/A	**77.0**	**1**	80	**82.5**	82.5	**85.5**	75.5	**77.0**
1.5	84	**86.5**	84	**86.5**	82.5	**84.0**	**1.5**	85.5	**87.5**	84	**86.5**	82.5	**84.0**
2	85.5	**87.5**	84	**86.5**	84	**85.5**	**2**	86.5	**88.5**	84	**86.5**	84	**85.5**
3	86.5	**88.5**	86.5	**89.5**	84	**85.5**	**3**	87.5	**89.5**	87.5	**89.5**	85.5	**86.5**
5	87.5	**89.5**	87.5	**89.5**	85.5	**86.5**	**5**	87.5	**89.5**	87.5	**89.5**	87.5	**88.5**
7.5	88.5	**90.2**	88.5	**91**	87.5	**88.5**	**7.5**	89.5	**91.0**	89.5	**91.7**	88.5	**89.5**
10	90.2	**91.7**	89.5	**91.7**	88.5	**89.5**	**10**	89.5	**91.0**	89.5	**91.7**	89.5	**90.2**
15	90.2	**91.7**	91	**93**	89.5	**90.2**	**15**	90.2	**91.7**	91	**92.4**	90.2	**91.0**
20	91.0	**92.4**	91	**93**	90.2	**91.0**	**20**	90.2	**91.7**	91	**93**	90.2	**91.0**
25	91.7	**93.0**	91.7	**93.6**	91	**91.7**	**25**	91.7	**93.0**	92.4	**93.6**	91	**91.7**
30	92.4	**93.6**	92.4	**94.1**	91	**91.7**	**30**	91.7	**93.0**	92.4	**93.6**	91	**91.7**
40	93	**94.1**	93	**94.1**	91.7	**92.4**	**40**	93	**94.1**	93	**94.1**	91.7	**92.4**
50	93	**94.1**	93	**94.5**	92.4	**93.0**	**50**	93	**94.1**	93	**94.5**	92.4	**93.0**
60	93.6	**94.5**	93.6	**95**	93	**93.6**	**60**	93.6	**94.5**	93.6	**95**	93	**93.6**
75	93.6	**94.5**	94.1	**95**	93	**93.6**	**75**	93.6	**94.5**	94.1	**95.4**	93	**93.6**
100	94.1	**95.0**	94.1	**95.4**	93	**93.6**	**100**	94.1	**95.0**	94.5	**95.4**	93.6	**94.1**
125	94.1	**95.0**	94.5	**95.4**	93.6	**94.1**	**125**	94.1	**95.0**	94.5	**95.4**	94.5	**95.0**
150	94.5	**95.4**	95	**95.8**	93.6	**94.1**	**150**	95	**95.8**	95	**95.8**	94.5	**95.0**
200	94.5	**95.4**	95	**95.8**	94.5	**95.0**	**200**	95	**95.8**	95	**96.2**	95	**95.4**

*This standard, equivalent to NEMA Table 12-10, went into effect in October 1997. New motors manufactured and imported for the US market must meet or exceed these full load nominal efficiencies.

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Gas-Fired Absorption Heat Pumps

A potential future technology for water heating and space product cooling is the gas fired absorption heat pump. Primarily operating on natural gas (or bio-gas) this technology utilizes highly efficient heat pump cycles to provide both heating and cooling energy streams. The heating effect could be employed to heat water for dairy CIP washing and the cooling stream used to cool milk.

Absorption heat pumps are thermally driven, which means that heat rather than mechanical energy is supplied to drive the cycle. Mechanical energy is primarily limited to pumping. Absorption systems utilize the ability of liquids or salts to absorb the vapor of the refrigerant fluid. The most common working pairs for absorption systems are: water (refrigerant) and lithium bromide (absorbent), and ammonia (refrigerant) and water (absorbent). Figure 9-1 shows a schematic diagram of a gas-fired absorption heat pump.

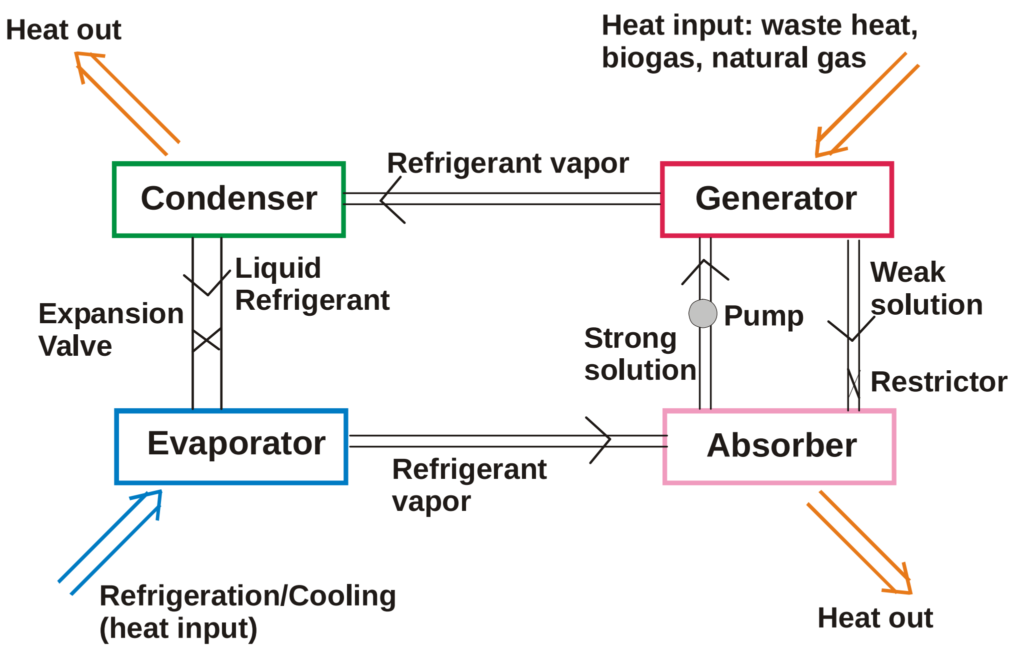

Figure 9-1. Schematic diagram of an absorption refrigeration system

Heat is added at the generator. The "generator" includes a rectifier and an analyzer. The refrigerant boils/vaporizes at a lower temperature than the absorbent. The vapor moves through the rectifier and analyzer on its way to the condenser. The absorbent [weak solution] remaining in the generator flows to the absorber. The refrigerant is condensed in the condenser by removing heat. The liquid flows through the expansion valve to the evaporator and evaporates - absorbing heat. The refrigerant vapor is drawn to the absorbent [weak solution] in the absorber. Heat is released as the refrigerant is absorbed by the absorbent. This heat must be removed to keep the temperature in the absorber low to maintain a high solubility. The strong solution is pumped back to the generator. The generator and condenser are at high pressure and the evaporator and absorber are at low pressure.

Using an ammonia-water system the temperature in the evaporator can be below freezing. The process starts as heat is applied to the generator and ammonia is vaporized – driven off to a condenser. The cooled ammonia liquid then passes through an expansion valve to the evaporator. Here the low-pressure ammonia liquid boils and vaporizes absorbing heat to provide cooling. The above portion of the absorption cycle, functions much like the standard vapor compression refrigeration cycle.

In the absorption cycle, however, there is a secondary circuit around which the liquid absorbent [water] flows. The low-pressure ammonia vapor is drawn to the absorber where the ammonia recombines with the water. This absorption process releases heat, which must be removed. The low-pressure liquid absorbent/refrigerant mixture is pumped to the generator [higher pressure] to start the process again. Useful heating energy is recovered from both absorber and condensing sections.

The major advantages of the absorption heat pump are:

- Ability to deliver more than one unit of output energy per unit of input energy (COP greater than 1)
- Delivers two useful energy streams (heating and cooling)
- Ability to use multiple sources of input energy (natural or biogas, waste heat, steam) in place of electricity.
- Few moving parts or mechanical components to wear out.
- Use of more environmentally friendly refrigeration/absorbent in place of standard CFC refrigerants

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Temperature Monitoring

Equipment operating temperature is one of the most powerful, yet underused status indicators available to monitor the health of equipment. Excessive heat build up indicates a problem with the equipment and causes many equipment failures. Many times, the cause of the heat build up can be remedied before heat damage occurs.

Excessive heat also indicates poor efficiency, as extra power is required to generate the heat. Devices that should have a periodic temperature check include motors and motor contactors, compressors, vacuum pumps, lighting ballasts, condenser coils, gearboxes, heat exchangers, water heaters and electrical panels. The equipment should be in the same portion of the operating cycle each time the temperatures are measured. The highest temperature typically occurs long after the equipment is started so the temperature measurement should be made near the end of the operating cycle.

Several different devices are available for measuring equipment temperature. Infrared thermometers are a very handy temperature measurement instrument for performing spot checks. These hand-held thermometers measure the surface temperature without contacting the surface. Measurements can be made on equipment that cannot be reached such as circulation fan motors and lighting ballasts. Many infrared thermometers feature a laser-aiming device to ensure that the invisible infrared beam is properly aimed at the desired target. This aiming feature becomes important as the distance to the target increases.

Infrared thermometers have a cone shaped field of view. An infrared thermometer with a distance specification of 12:1 means that at 12 feet the temperature reading will be the average temperature within a 1-foot diameter circle. Using such a thermometer to measure the temperature of a 6-inch fan motor 12 feet from the infrared thermometer, the reading would be average temperature of the motor and the background surfaces within the cone. More accurate temperatures would be read as the thermometer became closer the fan motor. At 6 feet of the motor the temperature would be the most accurate.

The emissivity of the surface being measured will make a difference in the temperature reading. Some infrared thermometers have an adjustment for emissivity, others have a preset emissivity generally at 0.95. Some of the apparent inaccuracies may not be a problem since the purpose is to make enough observations of the same object so that a “high” temperature can be identified.

Other devices useful for measuring temperature include self-adhesive temperature indicating strips that attach directly to the device being measured. These strips have several temperature zones that change color as the indicated temperature is reached. These strips are suitable for spot-checking temperatures as they indicate the current temperature of the device.

Intermittent equipment such as air compressors may never reach a steady operating temperature, making spot checks unreliable. Self-adhesive temperature indicating strips are available that will show the maximum temperature. These strips record the highest temperature reached since the strip was installed, ensuring that peak temperatures will not be missed. These strips should be replaced periodically in response to downward trends in maximum temperature, such as seasonal changes.

Another type of temperature measuring device is the thermocouple pipe clamp probe. Here a special pipe clamp holds a thermocouple firmly against a pipe surface for quick and uniform measurement of the temperature of a pipe surface.

High equipment temperatures do no need to exceed the manufacturer's temperature rating to indicate a problem. Regular temperature checks are needed to establish normal values so that irregularities can be identified.

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Understanding Pump Curves

Applying centrifugal pumps presents some challenges that are not immediately obvious. Over estimating the system head can result in overloaded motors. Under estimating the head usually results in poor efficiency and low flow rates.

Consider the pump curves in Figure 9-2. If the application requires 850 gpm at 350 feet of head, for example, then this pump will operate at point 1 with the 9 $^{3}/_{8}$ inch impeller. The pump is appropriately applied with a 100 hp motor. If the system head is reduced to 300 feet, the operating point will move to point 2 and 100 hp motor will be overloaded. If the system head is increased to 400 feet the operating area will be at point 3 and the pump will have widely varying flow between 0 and 350 gpm.

Pump efficiency will be less than 60% and the motor efficiency and power factor will decline at reduced loading. Centrifugal pumps operating at fixed speed do not operate below the curve as a positive displacement pump could. The pump will operate on the curve that corresponds to the impeller size.

Specifying a pump with higher head rating at the desired flow in order to provide a reserve buffer of capacity will result in performance following the curve to the point where the system flow and head matches the pump curve. For instances where the exact pump head is not known in advance, a high head estimate is only a starting point. Trimming the impeller or adjusting the driven speed of the pump will then tune the pump to match the system requirements.

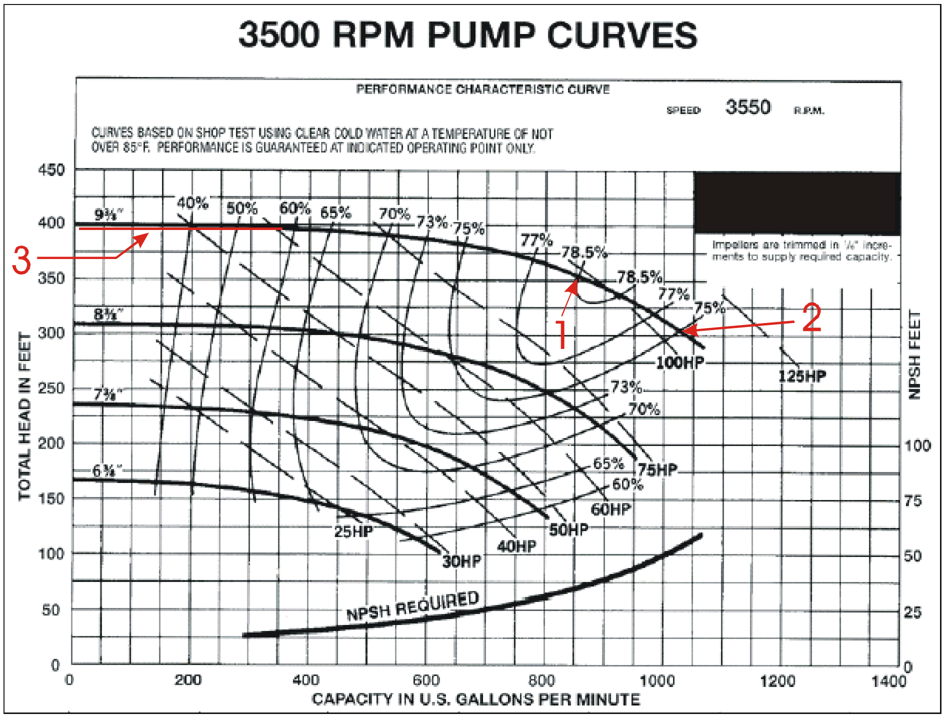

Figure 9-2. 3500 RPM Pump Curves

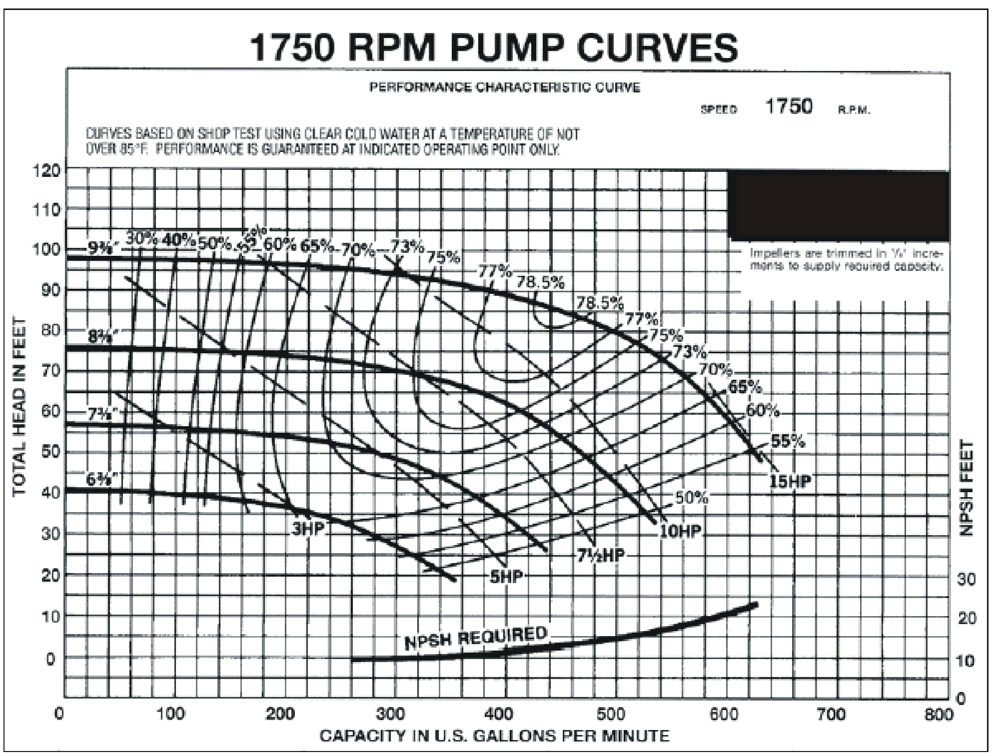

Figure 9-3. 1750 RPM Pump Curves

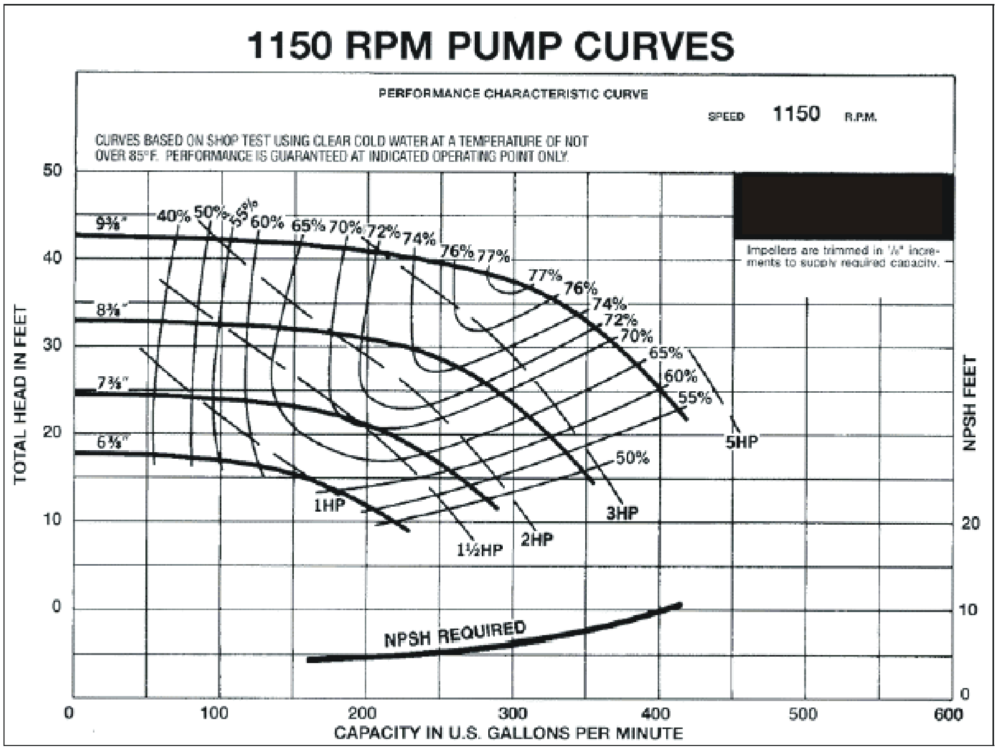

Figure 9-4. 1150 RPM Pump Curves

These three curves, Figure 9-2, 3 and 4, are for the same pump at different motor speeds.

Useful Pump Formulas

$$\text{Pressure (PSI)} = \frac{\text{Head(Feed) x Specific Gravity}}{2.31}$$

$$\text{Head (Feet)} = \frac{\text{Pressure (PS) x 2.31}}{\text{Specific Gravity}}$$

$$\text{Vacuum (inches of Mercury)} = \text{Dynamic Suction Lift (Feet) x .883 x Specific Gravity}$$

$$\text{Horsepower (Brake)} = \frac{\text{GPM x Head (Feet) x Specific Gravity}}{\text{3960 x Pump Efficiency}}$$

$$\text{Horsepower (Water)} = \frac{\text{GPM x Head (Feet) x Specific Gravity}}{\text{Water}}$$

$$\text{Efficiency (Pump)} = \frac{\text{Horsepower (Water)}}{\text{Horsepower (Brake)}}$$

$$\text{NPSH (Available)} = \text{Positive Factors – Negative Factors}$$

Affinity Laws: Effect of Change of speed or impeller diameter on centrifugal pumps.

	GPM Capacity	Ft. Head	BHP
Impeller Diameter Change	$Q_2 = \frac{D_2}{D_1} Q_1$	$H_2 = \left(\frac{D_2}{D_1}\right)^2 H_1$	$P_2 = \left(\frac{D_2}{D_1}\right)^3 P_1$
Speed Change	$Q_2 = \frac{RPM_2}{RPM_1} Q_1$	$H_2 = \left(\frac{RPM_2}{RPM_1}\right)^2 H_1$	$P_2 = \left(\frac{RPM_2}{RPM_1}\right)^3 P_1$

Where Q = GPM, H = Head, P = BHP, D = Impeller Diameter, RPM = Pump Speed

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Variable Frequency Drives

A variable frequency drive (VFD) is a sophisticated electronic device for regulating the speed of three phase motors. Variable frequency drives can be applied to a wide range of farm applications requiring precise speed control or soft-start characteristics. These applications include vacuum pumps, milk pumps, glycol pumps, water pumps, ventilation fans, crowd gates, and air compressors.

A typical AC induction motor runs at its rated speed, based on the input power frequency of 60 Hz (Hertz). If the input frequency is reduced, the motor will run at a reduced speed. VFD's are simply a source of variable frequency three-phase power. As the speed of an induction motor is reduced, so is the 'back EMF'. This 'back EMF' is created by the interaction of the magnetic fields in the motor and serves to limit the current through the motor. If the frequency is reduced while holding the voltage constant, the magnetic flux and magnetizing currents increase as does the torque produced by the motor. The increased magnetizing currents result in greater stator or line currents that could cause over-current trips or destroy the motor. By holding the volts per hertz ratio constant, magnetic flux remains constant, and the motor is considered to have constant torque. The VFD produces the variable frequency output at the proper voltage through a series of conversions of the commercial input power. The VFD rectifies the incoming 60 Hz power into DC voltage through a 6-diode full wave three-phase rectifier. Large capacitors form the 'DC Bus' and smooth the ripple. Insulated Gate Bipolar Transistors or IGBTs are used to pulse the power from the DC bus to the output terminals to form three-phase output. Figure 9-5 is a functional schematic of a pulse width modulated (PMW) variable frequency drive.

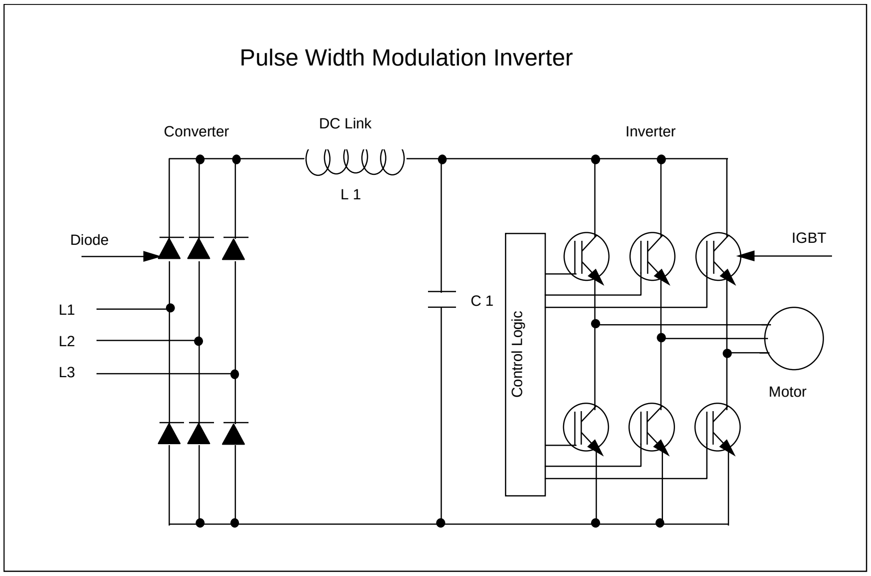

Figure 9-5. Pulse Width Modulated VFD

From the DC bus the drive draws power to create AC voltage at the specified frequency and amplitude. Current drive technology does not produce sine wave output voltage. The drive must draw power from the DC bus in pulses such that the RMS value of the pulses is equivalent to a sinusoidal voltage. Figure 9-6 shows the output voltage and current of a modern VFD.

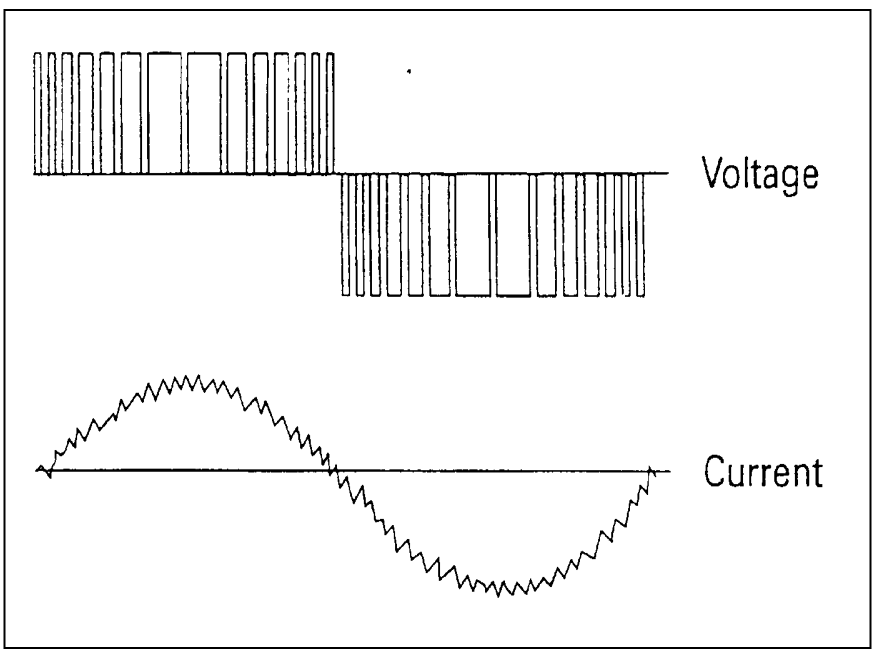

Figure 9-6. Output voltage and current of PWM VFD

The width of the pulse determines the amplitude of the voltage. When the pulses are wide, the duty cycle is high and the pulses are close together, causing the output voltage to be close to the DC bus voltage. When the pulses are narrow, the duty cycle is low and the pulses are farther apart, causing the output voltage to be low. The IGBTs switch on and off at very high frequencies (upwards of 20,000 Hz) in order to create an output current that approximates a standard sinusoidal waveform.

Motors and Conductors

The high switching frequency of the IGBTs creates special concerns for the motor(s) driven from a VFD and the conductor(s) that connect the motor(s) to the VFD. Standard motors may not be suitable for VFD application and an inverter rated or inverter duty motor would be required. These inverter rated motors have a much higher insulation standard than regular motors. The added insulation of inverter rated motors is necessary to endure the high stresses that pulsing the voltage creates on motor insulation. Standard motors with class B insulation typically experience shortened motor life because the voltage spikes cause pinholes to form in the motor winding insulation. These pinholes can lead to frequent short circuit trips on the VFD, even if the motor runs satisfactorily on 60 Hz line power. Inverter duty motors are also more effective at self-cooling. This is necessary because at reduced motor speeds, the cooling effect of the fan is greatly reduced.

Modern VFDs incorporate motor thermal protection within the control circuitry of the drive. Separate motor thermal protection for the motor is not necessary unless multiple motors are driven from the same VFD. Most VFDs act simply as a source of variable frequency three-phase power. As such, the drive will effectively power any number of connected motors as long as the sum of the motor power does not exceed the power rating on the drive. There is no requirement that the motors be the same power, type or even speed.

The drive’s built in motor thermal protection is only effective for a single motor connected to the drive. The drive must also be programmed with the nameplate current rating for the connected motor. When more than one motor is connected, the drive does not know if one motor is in an overloaded state while the other motor is in a partially unloaded state. It is therefore recommended to use separate motor thermal protection for each motor and disable the drive’s internal motor thermal protection.

Some drives use a Sensorless Flux Vector feedback from the motor to precisely regulate the motor speed. Though Sensorless Flux Vector control is not suitable for running multiple motors, most of these drives are capable of running in an open loop or volts/hertz mode. Check with your drive supplier to see if your drive is suitable for driving multiple motors.

The conductor that connects the motor(s) to the VFD is subject to the same voltage spikes as the motor windings. Standard THHN building wire has very thin insulation. While this insulation does not suffer from pinholes, the thin jacket allows multiple conductors to be very close to each other. This close proximity allows capacitive and inductive coupling between the phase wires and leads to false short circuit trips of the VFD.

The appropriate conductor for drive applications is either type XHHW or XLPE. Selecting the proper conductor becomes more critical as the distance between the drive and motor increases. The wiring between the drive and motor should be in metallic conduit or a metal flexible conduit. All joints in the conduit must make good electrical bonds and the conduit needs to be well grounded. This will reduce the emitted electrical noise discussed in the next section. Armored cable is also available for drive applications. This cable contains the phase and ground wires with the appropriate insulation as well as a noise suppression shield.

It is essential that the proper conductor be used on submersible pumps or any other instance where the motor wiring must pass under water. Immersion in water greatly increases the capacitive coupling effect between conductors.

EMI & RFI

A variable frequency drive (VFD) will generate radio frequency interference (RFI) and electromagnetic interference frequencies (EMI) in the range of 0.5 MHz to 30 MHz. This high frequency electrical noise is caused by the high carrier frequencies of the pulse-width modulation, the associated short rise times of the IGBT output devices, and the reflected waves from the motor terminals. This high frequency electrical noise can adversely affect cow ID systems, computers, and AM radio reception.

The largest source of transmitted noise is from the conductor to the motor. This conductor acts as an antenna that broadcasts electrical noise directly through the air. Metallic conduit that is well bonded to ground greatly reduces this noise. Metallic conduit that is also insulated on the outside reduces conduction of noise onto other conduits or metallic building components.
Special flexible conduit is available for connecting the motor to the drive. This conduit consists of a normal metal spiral wrapped in a fine copper or aluminum mesh and then sheathed with plastic to form a liquid tight conduit. This conduit is more effective at reducing noise transmission than solid metal conduit because it provides a low impedance path for the noise back to the drive. The plastic sheath also prevents noise from conducting onto other conduits or structural members and spreading to other parts of the facility.

The electrical noise can also transmitted back into the power distribution system. The noise in the power distribution system can then conducted into other devices or transmitted through the air.

Mitigating noise requires an EMI/RFI filter in the power supply directly in front of the drive. The filter removes the high frequency noise from the power lines and sinks it to ground. It is therefore very important to have a good ground at the filter. High frequency electricity conducts primarily on the surface of the conductors. Fine stranded wire has much lower resistance to high frequencies than solid conductors**.** Fine stranded ground wires should be used on EMI/RFI filters to maximize their effectiveness.

A hazard exists with long motor leads that are run in parallel with other motor leads in a cable tray. When a VFD is operating, EMI/RFI will be coupled from one cable into another. As a result, when replacing a motor, the motor cable may be found to have a high potential at the end of its conductors even though the motor's drive is disconnected from the line.

Harmonics

DC rectifiers used in variable frequency drives, computers, DC welders, and battery chargers, utilize current differently than other AC equipment. Instead of having a constant impedance drawing current in proportion to the sinusoidal voltage, DC rectifiers draw no current for those periods of the voltage waveform where the AC voltage is less than the DC voltage. Once the AC voltage reaches the peak of the waveform, the AC voltage is higher than the DC voltage and the current flows in one pulse per half cycle. The current stops once the AC voltage has again dropped below the DC voltage. For three phase rectifiers, the current flows when the voltage waveform peaks with respect to each of the other two phases so there are two current pulses in each half cycle. Figure 9-7 illustrates the current waveform for a variable frequency drive.

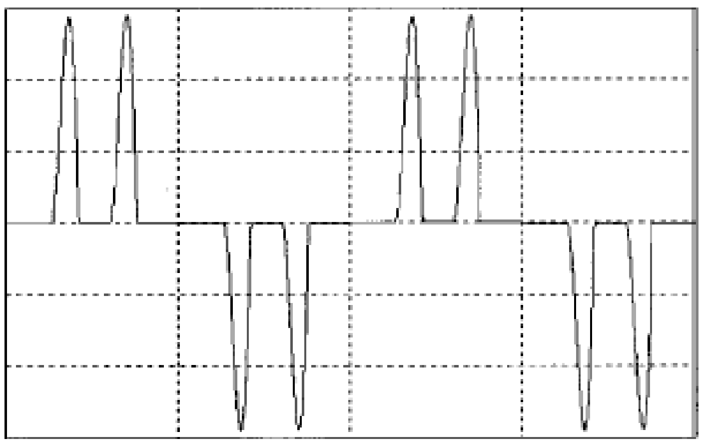

Figure 9-8. Current Waveform For a Variable Frequency Drive

Switching loads on and off during part of the waveform results in short, abrupt, nonsinusoidal current pulses during a portion of the peak voltage waveform. These abrupt pulsating current pulses introduce reflective currents (harmonics) back into the power distribution system.

The harmonic currents operate at frequencies other than the fundamental 60 Hz. Harmonic currents can be likened to the vibration of water in a water line when a valve is open and closed suddenly. As these harmonic currents flow through the impedance of the electrical distribution system, they cause harmonic distortion to the system voltage. The distorted voltage waveform propagates itself through the electrical distribution system and can effect other electronic equipment.

The distorted shape of the current waveform creates special problems for measurement devices like ammeters. The typical digital clamp-on meter is not suited to measuring the current in an electronic device because the meter uses a mathematical approximation to determine the RMS current in a conductor. This approximation is not suitable for electronic power devices where the error can be as high as 40%. In order to obtain an accurate current reading with a VFD, it is necessary to use a True-RMS ammeter.

Harmonic Distortion and Mitigation

Harmonic currents and voltage distortion can cause problems in other electrical devices. In addition to causing electrical problems, IEEE Standard 519-1992 sets a limit on total harmonic currents at the point of common coupling. Harmonic related problems are unlikely when a small percentage of the total electrical load is used by VFD's or other similar harmonic generating devices. Determining harmonic content requires sophisticated power quality monitoring equipment. A low cost remedy for harmonics exceeding the IEEE 519 standard is to install a 3% impedance reactor to the input of the drive. The reactor also serves to protect the drive from transients and imbalanced line voltages. Some variable frequency drives have built in reactors, so check with your drive supplier to see if an external reactor is necessary.

What is True-RMS?

"RMS" stands for Root-mean Square and comes from a mathematical formula that calculates the "effective" value (or heating value) of any AC wave shape. In electrical terms, the AC RMS value is equivalent to the DC heating value of a particular waveform—voltage or current. For example, if a resistive heating element in an electric furnace were rated at 15 kW of heat at 240 VAC rms, then the element would supply the same amount of heat with 240 volts DC as with 240 volts AC. Electrical power system components such as fuses, bus bars, conductors, and thermal elements in circuit breakers are rated in RMS current because their main function is related to heat dissipation. In order to check an electrical circuit for overloading, measure the RMS current and compare the measured value to the rated value for the component in question. If a current clamp is labeled and specified to respond to the True-RMS value of current, it means that the clamp's internal circuit calculates the heating value according to the RMS formula. This method will give the correct heating value regardless of the current wave shape. Most digital current clamps do not have True-RMS circuitry. These ammeters use a short cut method to find the RMS value and are specified to be "average responding-RMS indicating." These meters capture the rectified average of an ac waveform and scale the number by 1.1 to calculate the RMS value. In other words, the value they display is not a true value, but rather is a calculated value based on an assumption about the wave shape. The average responding method works for pure sine waves but can lead to large reading errors up to 40 percent, when a waveform is distorted by nonlinear loads such as adjustable speed drives or computers. Look for the words True-RMS on the front panel to ensure accurate current readings.

Drive Maintenance

Though modern variable frequency drives have very few moving parts and very limited serviceability, several maintenance items do require attention. It is very important to check that the power terminals on the drive stay tight. Loose power terminals can quickly heat and fail, damaging the terminals and possibly the entire drive.

Torque the terminals per the installation manual and regularly recheck that the terminals have not loosened. Check that the terminals are still tight after several hours of operation after startup. Then check the terminals regularly afterwards. If the terminals stay tight, then longer intervals may be used.

Loose terminals can also create a fire hazard. If the terminals loosen regularly, check for excessive vibration at the terminals. Vibration could come from the wall that the drive is mounted on or through the power leads. This is more common on the output side of the drive where the power leads go directly to the motor.

Drives requires clean airflow for cooling. Cooling is typically accomplished with heat sink and a fan. This heat sink assembly must be kept free of dust and dirt. Accumulations of debris in the heat sink can cause localized hot spots in the drive. This heat can contribute to premature component failure. If the heat fins require frequent cleaning then the drive is in an unsuitable environment.

The drive should be installed in a conditioned cabinet or a ventilated enclosure. Typical VFDs have NEMA 1 enclosures which are suited for clean areas only. If delicate paperwork cannot be left in the immediate vicinity of the drive, a NEMA 1 drive should not be located there either. Check with the drive manual for other routine service requirements and environmental specifications.

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