MOTORWISE® Technology
White Paper

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Introduction

The world-wide demand for electrical power is increasing each year. As economies expand and personal income grows, so does the need for more electrical power. Power utilities are under great pressure to deliver power cheaper with a high degree of reliability and minimal impact to the environment. Today, electric power generation represents more than half of all greenhouse gas emissions world-wide. Reducing CO_2 emissions from electric power generation has received world-wide focus from governments, environmental organizations as well as concerned citizens.

An area of great interest is improving the efficiency of electrical devices. More efficiency means less electrical energy consumed and thus less impact to the environment. By far, the largest consumer of electric energy are AC induction motors. In the United States 50% of all electrical energy is consumed by electric induction motors. World-wide, AC induction motors consume over 70% of all electrical energy produced. Improving the efficiency of electric induction motors can have a dramatic impact on world-wide power consumption. Improving electric induction motor efficiency has become the top priority of many organizations charged with developing innovative ways to reduce electric power CO_2 emissions.

MOTORWISE®

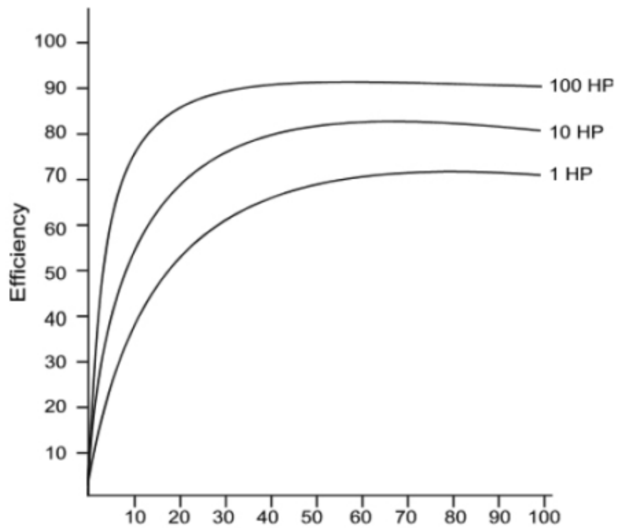
The TechnoWise Group, Inc. has developed a revolutionary induction motor efficiency technology called MOTORWISE®. MOTORWISE® utilizes TechnoWise's patented AC induction motor energy savings technology to dramatically improve the efficiency of electric motors. Utilizing the latest Digital Signal Processing (DSP) energy management technology, MOTORWISE® analyzes the induction motors energy usage and adjusts the power for optimal consumption of incoming electrical energy. Depending upon the application, MOTORWISE® can immediately improve the efficiency of an induction motor by as much as 25%. MOTORWISE® also allows an electric induction motor to run cooler, quieter, and with less vibration. This improves the reliability, reduces motor maintenance, and prolongs the life of the motor. MOTORWISE® is easily installed between the power mains and motor with no additional equipment. MOTORWISE® today has thousands of installations with proven customer testimonials that validate the energy savings, improved equipment reliability, and longevity.

Motor Efficiency and Energy Losses

In a perfect world, AC induction motors would operate at 100% efficiency – in other words, every kilowatt of power delivered to the motor terminals would be converted to useful work at the motor shaft. In reality, the motor only delivers a percentage of the AC power as rotating mechanical energy to the shaft of the motor.

Motor Efficiency

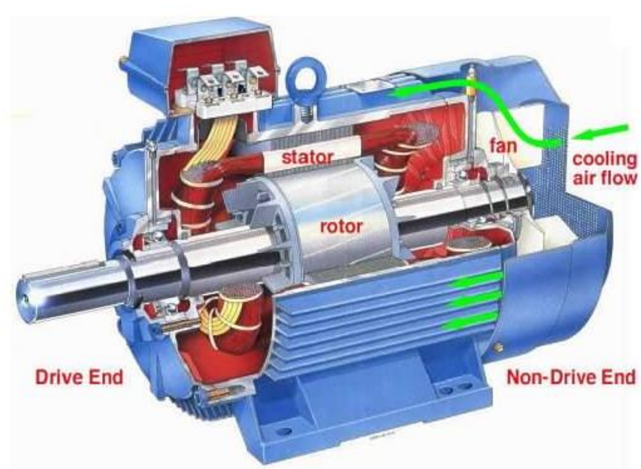
AC induction motor efficiency varies by several factors. AC motor efficiency is the ratio of power delivered by the motor at the shaft, P_{shaft}, to the total electrical power, P_{real}, used by the motor,



$$n_{efficiency} = P_{shaft}/P_{real} \quad (1)$$

the P_{real} is the sum of the real electrical power used to turn the motor shaft plus any electrical losses, P_{loss}. AC induction motors are most efficient when they are run above 75% of their rated load. In other words a 100 horsepower motor is most efficient when the motor shaft is delivering 75 horsepower or more. As the shaft loading drops below 30% horsepower the efficiency of the motor drops off dramatically. This is due to internal motor losses. At lower power motor operation the internal power losses are almost as much as the motor shaft power thus lowering motor efficiency. For lower horsepower motors the internal losses are significant enough to make the motor inefficient even at rated power. Larger motors also experience internal power losses. However, the internal losses are much less than the overall power output thus impacting inefficiency much less.

Motor Energy Losses



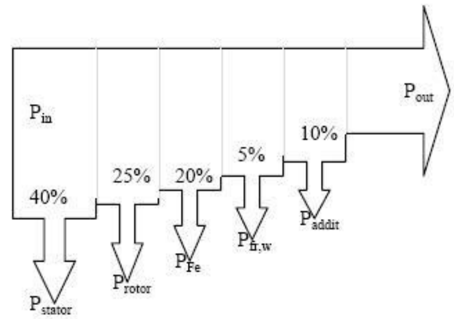
The energy within an AC induction motor can be broken up into three different categories of power – real power converted, power losses and reactive power. The sum of these three components would equal the total electrical energy supplied to the terminals of the AC induction motor.

The real power converted is the actual mechanical work done by the motor. This power is expressed as,

$$P_{shaft} = \Gamma\omega \quad (2)$$

The torque at the shaft of the AC induction motor is Γ and ω is the rotational speed. Real power is easily measured with the motor connected to a dynamometer and an RPM meter. However, this is not always practical in a real world installation.

The Power lost in the AC induction motor can be expressed as,



$$P_{loss} = P_{Fe} + P_{stator} + P_{rotor} + P_{fr,w} + P_{addit} \qquad (3)$$

P_{Fe} is the power lost to magnetize the core of the motor. P_{stator} is the power lost due to heating from resistance in the stator windings. P_{rotor} is the power lost due to heating from resistance in the rotor windings. $P_{fr,w}$ is the power lost due to mechanical heating from friction losses and air resistance due to the motor rotor cooling fan. P_{addit} is additional losses due to leakage fluxes induced by load currents and other minor losses. Many of these losses are difficult to measure directly and are usually derived by other indirect measurements.

Motor Power Factor

The apparent power delivered to the motor can be derived by measuring the voltage and current at the motor terminals. Apparent power is the vector sum of real power, P_{real} and reactive power, P_q. The maginitude of this vector we term "S".

$$S = V_{motor} \times I_{motor} \qquad (4)$$

Reactive power in the electric motor is energy stored in the inductive elements of the rotor and stator. This power is not actually lost. It is power that is stored in the form of electromagnetic energy while the motor is running. Reactive power is measured in reactive Volt-Amps and is a component of the motors Power Factor. In a purely resistive load, both the voltage and current are in phase with each other. When AC power is applied to a capacitive or inductive load, the voltage and current become out of phase. The current in an AC inductive motor then lags the voltage. Since this stored energy returns to the source (in other words, the electric power utility) and is not available to do work at the load, a motor with a low power factor will require more current draw to do a given amount of work than a motor with a high power factor.

The power factor can be derived as,

$$P_f = P_{real}/S \qquad (5)$$

P_f is dimensionless number between 0 and 1 where P_{real} is the real electrical power used by the motor, equation (1), and S is the apparent electrical power delivered to the motor.

We can also determine the power factor by measuring the phase angle difference of voltage and current, ϕ, we have,

$$P_f = |\cos\phi| \quad (6)$$

We can also use the power factor phase angle to determine the power components of S,

$$P_{real} = S \times |\cos\phi| \quad (7)$$

and,

$$P_q = S x|\sin\phi| \quad (8)$$

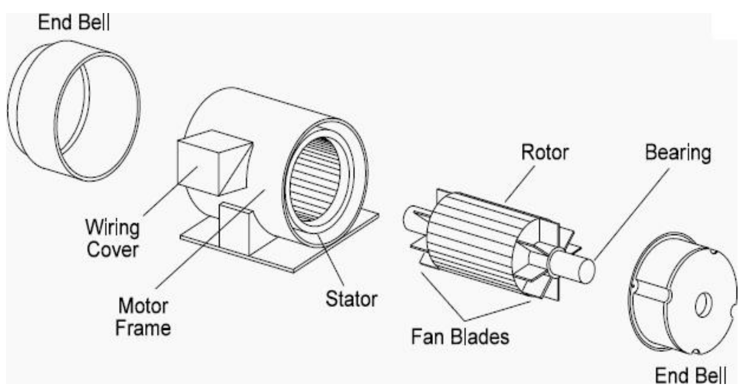
additionally,

$$S^2 = P^2_{real} + P_q^2 \quad (9)$$

As highlighted in equation (5), the power factor is a dimensionless number between 0 and 1. When the power factor is equal to 0, the energy flow is entirely reactive, and stored energy in the load returns to the source on each phase cycle and no work is done. When the power factor is 1, all the power supplied by the source is consumed by the load. Power factors are often stated as "leading" or "lagging" to show to show the sign of the phase angle.

For example, to get 1kW of real power if the power factor is unity, 1kVA of apparent power needs to be transferred (1 kVA = 1 kW x 1). At low values of power factor, more apparent power needs to be transferred to get the same real power. To get 1 kW of real power at 0.2 power factor, 5kVA of apparent power needs to be transferred (1kW = 5kVA x 0.2).

Motor Slip



While power factor and efficiency are not directly related (i.e. there is not an equation that will solve for efficiency given power factor or vice versa), there is a physical correlation between the two.

In an AC induction motor, the input power is used to magnetize the stator core. As the stator magnetic field rotates, it induces a current flow and in turn, a magnetic field in the rotor core. The rotor attempts to align its field with the rotating stator field, and the rotor begins to rotate to follow the stator field. If there were no load on the rotor, the rotor would eventually "catch up" to the stator field and rotate at a synchronous speed. However, since the rotor has mass, and there are other losses within the motor (bearing friction, windage losses, etc.) the rotor will always rotate at a slightly lower frequency than the stator field. The differential in speeds is referred to as "slip", and is simply the ratio of the difference between the synchronous (stator field) speed and the rotor speed to the synchronous speed,

$$\text{Slip} = (f_s - f_r)/f_s \quad (10)$$

Where f_s are the synchronous speed and f_r is the rotor speed. It is the magnetic flux cutting the rotor conductors as it slips which produces torque. The greater the load on the rotor shaft, the larger the slip and the greater the torque produced.

An unloaded motor produces only a very small amount of real consumed power. There is very little torque and the slip is less than 1%. Thus, the motor is operating at a very low efficiency. In a heavily-loaded motor, the slip is high (typically 5% or more) and most of the input energy total is used to move the load. The motor is operating very efficiently. As for power factor, an unloaded motor is similar to a transformer with no resistive load on the secondary. Little resistance is reflected from the secondary (rotor) to the primary (stator). Thus the power line sees a reactive load, as low as 0.1 or 10% power factor. As the rotor is loaded, an increasing resistive component is reflected from the rotor to the stator, increasing the power factor.

The relationship between slip and the power factor is the principle concept of how MOTORWISE® works. As stated earlier, there is no direct relationship between efficiency and slip. However, during high loading where the motor is loaded close or at its rated horsepower, the Power Factor is relatively high. When the motor is lightly loaded or producing very little horsepower, the Power Factor is very low. In a typical motor installation it is difficult to measure the shaft torque and corresponding rotational speed. It can be done but it is expensive to instrument up the motor. However, the Power Factor phase angle ϕ is easily determined by detecting the zero crossing of the voltage and current. ϕ is simply the difference in radians between these two zero crossings. Utilizing the Power Factor ϕ to determine efficiency is key requirement for determining the loading of an AC induction motor.

MOTORWISE® Technology

We have seen from the previous discussion that to achieve the highest motor efficiency you must match the rated horsepower or load output of the motor to the application. Running the motor at 75% or higher achieves the highest efficiency. Running the motor below 75% of its rated horsepower will be less efficient and thus wasted energy. It is not always possible to match the motor rated load to the application. Loads may vary considerably. AC induction motor applications such as escalators, elevators, and material conveyor systems are often operated in a very wide range of the rated horsepower of the AC induction motor.

Measuring the actual efficiency of an AC induction motor is often not practical in real applications. However, it is possible to indirectly monitor the efficiency by measuring the power factor. AC induction motors are most efficient when they are running at their highest rated power factor. They are least efficient when running at their lowest rated power factor. By measuring the power factor the relative efficiency of the motor can be determined.

The primary component that drives inefficiency during lightly loaded operation is P_{Fe} and P_{addit}. P_{fe} is the magnetic losses needed to energize the rotor core. P_{addit} are the losses related to the eddy currents and hysteresis effects in the windings and iron cores of the rotor and the stator. These losses are a direct function of voltage applied to the terminals of the motor. As you increase the voltage the losses increase. As you lower the voltage the losses decrease. Since the motor is lightly loaded almost all of the power being applied to the motor is reactive power and thus a low power factor or large ϕ.

At high motor loading these losses are negligible and the resistive losses in the rotor and stator become significant, P_{rotor} and P_{stator}. Since most of the power loss is resistive the Power Factor is primarily a real component and is high or small ϕ.

During low motor loading we can reduce the voltage coming into the motor and significantly reduce the R_{fe} and R_{addit} losses without effecting the operation of the motor. By lowering the voltage we are reducing the apparent power or energy, S, into the motor – equation (5). The motor will continue to run and not stall because it is lightly loaded however the efficiency will significantly increase. During high loading the voltage is increased to match Power Factor.

MOTORWISE® uses very sophisticated Digital Signal Processor (DSP) to measure the Power Factor phase angle. Once it has determined the phase angle the DSP can determine the amount of loading or horsepower that is being drawn from the motor and modulate the voltage or energy going into the motor. The voltage modulation is done through a series of high power SCR's that are controlled by the DSP. The DSP measures the zero crossing of the voltage and determines when to turn on the voltage to the motor. The timing of when to turn on the SCR's is a function of Power Factor phase angle. If the phase angle is high, or the motor is lightly loaded and the DSP will significantly delay turning on the voltage to the motor. If the phase angle is very low it will reduce the delay with turning on the voltage to the motor. This delay is called the Duty Cycle, or δ. δ is a number from 0 to 1 with 1 being a 100% duty cycle and 0 being a 0% duty cycle. The voltage presented at the motor is a function of the line voltage timesδ,

$$V_{motor} = \delta \text{ x } V_{main} \qquad (9)$$

By varying the δ, the DSP can control the voltage at the motor and thus match the voltage or energy going into the motor to optimize it's efficiency. ***By lowering the voltage you increase the efficiency of the motor and dramatically reduce its power consumption. The principle losses due to P_{fe} and P_{addit} are significantly reduced by lowering the voltage. Because the motor requires very little torque the operation of the device is unaffected but the efficiency increases considerably.***

MOTORWISE® Technology also has several other features that significantly enhance its ability to optimally control the efficiency of the motor. By balancing the phase angle on the positive and negative side of the sinusoidal motor voltage, the vibration and noise is significantly reduced. This significantly improved the motor reliability and longevity.

Also the DSP can sense when the motor is very lightly loaded and actually turn off the motor. Although an obvious and significant reduction in energy usage, the DSP has very sophisticated algorithms to determine when/if to turn off the motor safely. The on/off cycles can be done in a fraction of a second, many times a second optimizing all opportunities to reduce energy usage. This technique has had dramatic efficiency improvements in motors that continuous loaded and un-loaded phases like escalators and oil well pump jacks.

The DSP controller is very fast and can dynamically control the energy being used by the motor. If a sudden increase in loading occurs, the DSP can quickly increase the voltage to match the motor power requirements without stalling. It can also dynamically set the most optimal voltage or energy setting many times a second. This method takes every opportunity to save power.

The product also utilizes a proprietary soft-start motor algorithm to reduce the daily wear and tear of the many start/stop operations. This significantly improved the life of the motor as well as the transmission and load handling device connected to the motor.

It should be noted the MOTORWISE® will not always save power in every application. MOTORWISE® is most effective in applications where the motor is lightly loaded or there are significant changes in motor loading. MOTORWISE® technology can significantly reduce the power consumption of AC induction motors.

Real World Results

MOTORWISE® had gone through significant in-field validation and testing. In every application where MOTORWISE® was used, it achieved on average 15% to 25% reduction in actual energy expenses. The following are some typical examples where MOTORWISE® made a significant difference reducing our customer's electrical energy costs.

Scott Manufacturing, a Steel Mill Fabrication Company in Lubbock, TX has several multi-ton steel punching machines, steel die forming, and steel fabrication machines. All of these machines use 75 to 100 horsepower 3 phase AC induction motors. Scott Manufacturing was looking for ways to cut its manufacturing costs. MOTORWISE® was installed on one of their high production metal forming machines and the company saw a 24.7% decrease in their electrical energy bills. Tim Gragson, Director of Sales at Scott Manufacturing said "We have seen electric energy bill savings of up to 24.7% and that is something to get excited about."

Endeavor Energy Resources of Midland, TX operates thousands of oil field pump jacks. These pump jacks typically use 30 to 100 horsepower AC induction motors and operate continuously in the field. Energy savings as well as highly reliable operation was a critical requirement for Endeavor. They were also concerned about reducing their carbon footprint. After installing 578 MOTORWISE® motor energy controllers, they saw a reduction of 25.8% on their electric energy bills. The machines now run quieter and electric motor maintenance has been reduced as well. Endeavor is now planning to roll-out MOTORWISE® throughout the rest of their operation. Brent Lowery, a Petroleum Engineer for Endeavor said "I was skeptical at first, but after seeing 25.8% reduction in our electric bills, that convinced me."

Similar results occurred at Legacy Reserves in Midland, TX. Legacy operates thousands of oil production jack sites and installed MOTORWISE® on 187 wells. After installing MOTORWISE® motor energy controllers they saw a reduction of greater than 20% on their electric energy bills.

Even more, they experienced a dramatic reduction in pump motor/transmission maintenance. The soft-start and power conditioning technology remedied several common issues with pump jacks located where power distribution is problematic. Barry Johnson, Production Superintendent said "We are seeing typically 19 to 22% and as much as 25% reduction in our electric bills. MOTORWISE® is the next step in the optimization of our oil field production."

These are just a few of the many MOTORWISE® success stories. Everywhere MOTORWISE® has been installed, customers are seeing dramatic and tangible reductions in their electric energy costs. Many customers are reporting a 15 to 18 month payback with the installation of MOTORWISE®.

MOTORWISE® Products

The MOTORWISE® product lineup is focused on providing the lowest cost solution for your motor application. MOTORWISE® has several models that range from 30 to 100 horsepower and 230V to 480V.

MOTORWISE® 30/3 230V with & without Generation
MOTORWISE® 30/3 480V with & without Generation
MOTORWISE® 50/3 230V with & without Generation
MOTORWISE® 60/3 480V with & without Generation
MOTORWISE® 100/3 480V with & without Generation

All models have an option to support motor generation. Motor generation is a feature that turns off the motor during periods where the motor is turning but the torque is actually negative. Several rotating machine applications have this characteristic like oil well pump jacks, hydraulic metal part stampers, certain material handlers. MOTORWISE® senses this condition and turns off the power to the motor and lets the rotational momentum of the machine follow through. MOTORWISE® takes every opportunity to manage and save energy.

MOTORWISE® – Saving Energy, Saving Cost, Saving the Planet

MOTORWISE® is a highly sophisticated AC induction motor energy management and control system. Utilizing the latest in Digital Signal Processing control systems, it is able to significantly reduce energy consumption for AC induction motors. Its operation not only reduces energy costs, it also enables AC induction motors to run more smoothly and cooler – decreasing maintenance costs and improving the reliability and longevity of the motor, transmissions, and load bearing application.

Installation is simple and only needs to be installed on the electrical mains between the power source and the motor – no changes or modification are required for the motor. Its rugged design allows it to be placed in the harshest of environments. It's autonomous, no service operation enables years of trouble free operation. Real world installations have reported 15% to 25% reductions in actual electrical energy costs while seeing improved reliability and down-time. Many customers are reporting 15 to 18 month payback once installed.

If your operation has significant AC induction motor electricity consumption then MOTORWISE® may be a way for you to lower your electric utility bills. Not only will you save money but you will be saving the planet by reducing greenhouse gas emissions and using less carbon bases fuels.

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A MOTORWISE® specialist can analyze your application and explain in detail how your business can reduce energy consumption and save in energy costs.

For a complete list of distributors, please visit www.technowisegroup.com