Energy Saving systems for Induction motors.

Are they a sham? Do they work?

There seems to be a resurgence in interest in the Nola energy saving algorithm for induction motors, with a number of manufacturers beginning to market “new” and “improved” versions of this technology.

The technology was originally proposed and developed by Frank Nola of NASA in the mid to late 70s as a means of reducing energy wastage on small single phase induction motors. From the initial NASA developments, we saw a number of manufacturers world wide gaining manufacturing rights and marketing the technology in various forms. Difficulties were experienced in the early days in applying this technology to three phase motors in a fashion that it would perform with stability and reliability. Many patent applications were made in the early 80s covering variations on the technology as it could be applied to the three phase applications. An early application by Rutherford and Empson was successful in both operating as specified and in being granted letters patent. Many of the other early three phase patent applications were purely speculative and could not possibly achieve the desired results.

The concept of energy saving has always been an attention grabber, especially when the promised savings are high and the potential for a reduction in running costs appears high. The initial introduction of this technology was a marketing person’s dream, and some very extensive marketing plans were implemented in the early 80’s. Unfortunately, the marketing was based on the results achieved with very small machines, and expectations were high because of the results so achieved. There were many promises made to prospective users based on extrapolated data which was not field verified at an early stage, and could not be realized in real applications. I recently reviewed some promotional material which disturbed me in that exactly the same misrepresentation as was common from some suppliers of the technology in the early 80’s was again the foundation for a major promotion of this concept.

As we experienced in the early eighties when we were manufacturing similar products, there appear to be many misconceptions about the performance of induction motors and many claims are based on the presumption that the induction motor at less than full load, is an inherently inefficient device. We withdrew from promoting this type of device as a result of expectations in the market place that resulted from overzealous marketing with totally unrealistic claims which could not be achieved without inventing perpetual motion. - I recall a refrigeration engineer who had been promised a 50% energy saving on his 50KW refrigeration units which were constantly running at about 50% load. He had tried numerous units to no avail, and eventually approached me on a recommendation. I asked him for the efficiency of the motors at this load and he found that it was about 87%. As he immediately began to see, there was no way that he could save 50% of the energy consumed by the motor. To do so would require a motor efficiency of over 100% which is just not possible with an induction motor and today's technology.

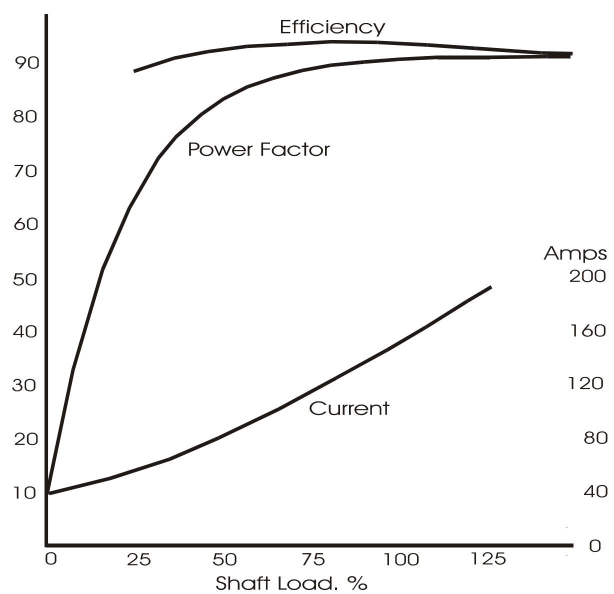
There is no doubt that under the right conditions, the technology as proposed by Frank Nola and the many variants thereof, can reduce the energy drawn by an induction motor, and thereby achieve some benefit. The problem is that as the result of limited technical understanding of the induction motor and it’s characteristics, erroneous claims are being made by extrapolation of results achieved with small motors. Worked examples often show flawed methodology in making power measurements in three phase three wire installations.

1. The Technology.

The basic algorithm is proposed by Frank Nola 20 years ago is to monitor the power factor of the motor, and to reduce the voltage when the power factor is dropping in a manner as to increase the power factor. There is a correlation between the power factor of the motor, and the motor efficiency such that the power factor will begin to fall when the efficiency of the motor falls. As such, the energy saving algorithm will act to improve the motor efficiency by reducing the iron loss in the motor. In some cases of very lightly loaded motors, it will also reduce the magnetizing current and where this is much greater than the work current, the copper loss may also be reduced. Although there may be some slight differences in the way the modern algorithm is implemented, I do not believe that there can be any significant improvement in the energy savings experienced in the early days when we were experimenting with this type of product. We found that the limitation was not the controller, but the inherent efficiency curves and characteristics of induction motors.

2. Induction Motors

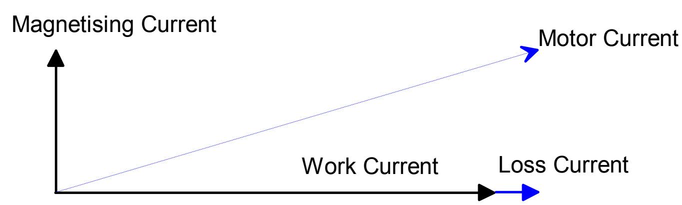
Large induction motors are inherently very efficient with efficiency figures as high as 95% at full load being quoted. The efficiency will fall at reducing load, however the efficiency only falls by a small margin between full load and half load. For example, a Brook Crompton 110Kw motor type 7G-UD315S is rated at 92% efficient at full load, 91% efficient at three quarter load and 89% efficient at half load. As the shaft load is reduced, the current reduces, reaching a minimum of the magnetizing current of the motor. The magnetizing current for an induction motor can vary between 20% of the rated full load current and 60% of the rated full load current of the motor depending on the motor design. As the load is reduced, the power factor of the motor also reduces by a small margin. With the Brook Crompton 110Kw motor, the power factor at full load is quoted at 0.92, three quarter load is 0.91 and at half load is 0.88. In this example, the potential energy saving at half load is very small. It is probably not unreasonable to expect that the maximum efficiency of a given induction motor is not going to be much in excess of its rated full load efficiency, so a half load efficiency gain of 4% may be achievable under ideal conditions, but with the non sinusoidal currents created by the use of an energy saver, this is not achievable in practice.



Toshiba 90KW 4pole motor.

Induction motors have five major components of loss; Iron loss, Copper loss, Frictional loss, Windage loss and Sound loss. All these losses add up to the total loss of the induction motor. Frictional loss, windage loss and sound loss are constant, independent of shaft load, and are typically very small.

The major losses are Iron loss and Copper Loss. The iron loss is essentially constant, independent of shaft load, while the copper loss is an I^2R loss which is shaft load dependent. The iron loss is voltage dependent and so will reduce with reducing voltage. For a motor with a 90% full load efficiency, the copper loss and iron loss are of the same order of magnitude, with the iron loss typically amounting to 25 - 40% of the total losses in the motor at full load. If we consider for example, an induction motor with a full load efficiency of 90%, then we could expect that the iron loss is between 2.5% and 4% of the motor rating. If by reducing the voltage, we are able to halve the iron loss, then this would equate to an iron loss saving of 1-2% of the rated motor load. If the motor was operating under open shaft condition, then the power consumed is primarily iron loss and we could expect to achieve a saving of 30% - 60% of the energy consumed under open shaft conditions. It must be reiterated however, that this is only about 1-2% of the rated motor load. For example, if we take a Toshiba 2 pole 22kW D180M motor, we find a full load efficiency of 90.9%. This motor has a rated iron loss of about 25% of the total loss. This amounts to 22 x .091 x .25 = about 500 watts. At best, I would expect to halve this loss, resulting in a saving of 250 watts at light load. Under open shaft conditions, this may well amount to 30% of the energy consumed by the motor, but it is still only about 1% of the motor rating. If the energy wasted by the motor is small, then there is very little to be saved, irrespective of the technology used.



The current flowing into an induction motor comprises three major components, magnetizing current, loss current and load current. The magnetizing current is essentially constant, being dependent only on the applied voltage. The magnetizing current is at phase quadrature to the supply voltage and so does not contribute to any Kw loading except for the contribution to the copper loss of the motor. The magnetizing current causes a reduction in the powerfactor seen by the supply. The loss current is essentially a Kw loading as is the load current. For a given shaft load, the output Kw must remain constant. As the terminal voltage of the motor is reduced, the work current component must increase in order to maintain the shaft output power. ($P = I \times V$) The increasing current resulting from reducing voltage can in many instances result in an increasing I^2R which is in excess of any iron loss reduction that may be achieved. For a large motor, the magnetizing current can be as low as 20% of the rated full load current of the motor.

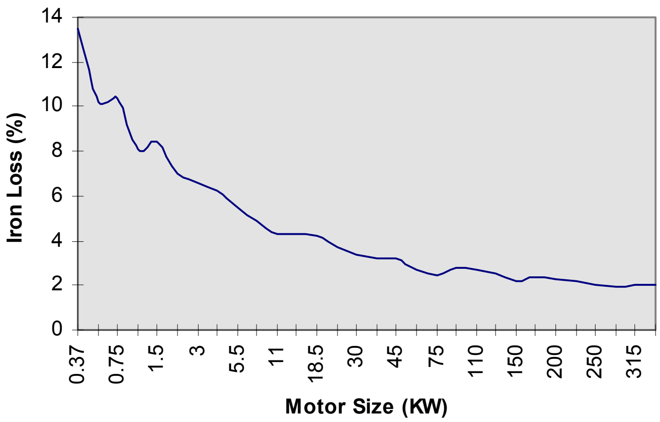
Three phase induction motors have a high efficiency to less than 50% load, and experience suggests that there is no realizable saving to be made until the motor is operating at well below maximum efficiency. (typically below 25% load) A Toshiba 150KW 4 pole machine exhibits a full load efficiency of 94.6%, 75% load efficiency of 94.8%, 50% load efficiency of 94% and a 25% load efficiency of 90.3%. There are many examples such as this which illustrate that the induction motor is efficient at considerably less than full load, and as such there can be very little advantage in using an energy saving algorithm on anything other than a small inefficient motor. Using SCRs to reduce the voltage applied to an induction motor operating at reduced load and a high efficiency will reduce the iron loss, but there will be an increase in current to provide the work output. This increase in current will increase copper loss by the current squared, offsetting and often exceeding the reduction in iron loss. This will often result in an increase in the total losses of the motor. i.e. will have the reverse effect to that for which it was installed. The potential to save energy with a solid state energy saving device, only becomes a reality when the motor efficiency has fallen. This generally requires a considerable fall in power factor, typically down to below 0.4 under full voltage operating conditions.

Large motors have a very low iron loss, (often 2 - 6% of the motor rating) and so the maximum achievable savings are small relative to the motor rating.

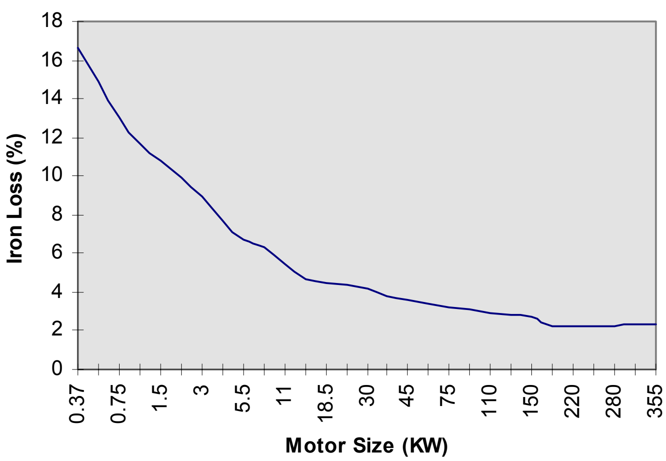
Three phase 4 pole Toshiba motors.

KW	0.37	0.75	2.2	5.5	11	30	110	355
eff	66.2	74	82.5	86.4	89.2	91.6	93.2	94.9
pf	0.69	0.83	0.84	0.85	0.86	88.7	0.91	0.88

Iron loss for Energy Efficient Motors.



Iron loss for Standard motors



Very small motors, (particularly single phase motors) have a much lower efficiency, and a much higher iron loss and so the potential to save energy is considerably higher.

Single phase motors

KW	0.25	0.37	0.55	0.75	1.1	1.5	2.2
eff	63	68	69	70	72	76	78
pf	0.6	0.63	0.66	0.7	0.74	0.84	0.86

3. Measurement techniques.

To establish the energy saved in a given installation, it is important to ensure that the measurement techniques are appropriate and correct.

Three phase Induction motors are a three wire circuit with a power factor which can vary between 0.1 and 0.95. Three phase power measurement techniques must be employed in order to achieve meaningful results. The standard methods of measuring the input power on a three phase three wire circuit, are either to use the single phase watt meters, one per phase and sum the results, or use the two watt meter method, or a three phase watt meter. Measurements made on one phase, and multiplied by three can be extremely erroneous, especially under light load conditions. The Kilowatt loading on the three phases at light loads can be severely unbalanced even though the currents may not be unbalanced to the same degree. When using the two watt meter method, care with phasing is very important as this can totally alter the results. Measurements made by multiplying voltage, current and powerfactor on each phase can work with a continuous sinusoidal current provided that each phase is individually measured, and the power consumption from each phase is then summed to give the three phase power consumption.

Measurements on non sinusoidal currents and or voltage must be made with true integrating watt meters. The formula of $P = V \times I \times pf$ applies <u>only</u> with a continuous sine wave current and voltage. The introduction of SCR or triac switching elements into the circuit to control the voltage results in non sinusoidal current and voltage, and under these conditions current, voltage and power factor measurements are meaningless in determining the power consumed. By definition, power is the integral of instantaneous volts x amps of the period of one or more cycles. At the instance that current is flowing, the SCR or triac is turned ON resulting in full line voltage at that instance in time. Therefore, there is no difference between measurements made on the input of the energy saver or the output of the energy saver with the exception that there is some loss in the energy saver which will appear on input measurements but not output measurements. There is no way that the power consumed by the motor can be measured or approximated by measurement of the current in one phase, the power factor, and the output voltage applied to the motor, all multiplied together. This results in totally fictitious results.

Comparisons are best made under controlled conditions with a true Kw or kWh metering system. The rotating disk kWh meter is what the power bill is based on and so it is a good instrument to use.

4. Claims

A recent review of yet another newcomer on to the international market with an energy saving device for induction motors showed the same inaccuracies and misrepresentations that were common when the technology was first promoted. The information given displays a number of inaccuracies which severely compromise the credibility of the claims that are made. The statement is made that: “induction motors draw the same current whether loaded or unloaded, the efficiency goes down when less than the rated load is applied to the motor.” This statement is demonstrably incorrect and is the foundation of the basic assumption that motors operating at half load will save up to 50% percent power consumed. This statement was contradicted in the same literature by the statement that: ”the current at half load was about 75% of the full load current.” This statement would be true on a small single phase motor with a magnetizing current in the order of 50% of the rated full load current, or higher.

Another statement that, “the company believes that it was the first to develop and introduce an energy savings device utilizing digital technology.” The company is somewhat ill informed as companies such as Fairford had a micro based energy savers available more than 16 years ago. Rockwell have had one available for a number of years also.

Many of the test results, quote irregular results such as induction motors with power factors as high as 0.99 and power factors that drop as the voltage is reduced, when in fact the algorithm works by reducing the voltage to maximize the power factor. One report shows a “voltage saving of 10.7% and a “current saving of 13.0%” resulting in a “KVA saving of 23.7%”. This is absurd and suggests that other figures are also incorrect. In reality, the current only flows through the triac while it is turned on, so the current must be multiplied by line voltage to give the correct results. This can be verified by the use of true power board type metering. The true saving is more like 13% KVA.

A detailed look at the quoted examples of energy saving is quite alarming, as the quoted results are obviously not correct.

In one such quoted example, the application was for a Chilled water pump 75Hp, 95 Amp, 440V 3ph. Tests were quoted as below:
Without energy saving device.

volt	479
amp	68
kw	32
kva	33
pf	1.0

Immediately there are some anomalies here:

a) A three phase motor drawing 68 amps at a line voltage of 479 volts would be drawing P = V x A x pf x √3 = 479 x 68 x 1 x 1.732 = 56KW Where did the 32 KW come from?? 32 = 479 x 68 x 0.98. (*line voltage times current times powerfactor*)
b) The KVA drawn by a three phase load is equal to V x A x √3 . in this case, the KVA demand would be 479 x 68 x 1.732 = 56KVA, not 33 KVA as quoted.
c) Induction motors never have a power factor of 1.0 Even very large and very efficient motors do not very often exceed 0.95 power factor.

With energy saving device fitted.

volt	460
amp	68.8
kw	31
kva	32
pf	0.99

a) The power can not be calculated but would probably be as high as without the energy saving device, in fact it would probably be higher due to the losses with in the energy saver and the increase in i^2R losses in the motor. The power quoted in this example appears to have been calculated on the basis of output current times output voltage times pf. (460 x 68.8 x 0.99 = 31.1KW) If we were to accept this calculation, then the power into the energy saver must be line volts times line current times pf, = 479.9 x 68.8 x 0.99 = 32.7KW. This would be what the consumer was paying for as the supply metering is on the input side of the energy saver, and the net result is that the consumer is paying for more!! If we continue on the assumption that the measurements and calculations are in fact valid, then the energy saver is dissipating 32.7KW - 31.1KW = 1.6KW and will there fore be operating at a very high temperature. I expect that if measurements were made in this installation, there would in fact be a net loss rather than a gain in overall efficiency.
b) Likewise, the KVA will be a little higher than before, 479 x 68.8 x 1.732 = 57KVA.
c) The energy saver should work to improve the power factor, not reduce it. If the power factor reduced, the energy saving device, (provided it was working correctly) would reduce the voltage further until the power factor rose again.

These results have definitely not been made with the correct instrumentation, or the instrumentation has not been used / interpreted correctly. It is obvious that some of these figures are not measured results, but would appear to be incorrectly calculated. I suspect that perhaps the voltage and current readings could be true representations of the installation, but the KW, KVA and pf with and without the energy saver <u>can not be correct</u>.

A second quoted example is for a 10 ton roof top air conditioner.
Tests quoted were:
without energy saving device

volt	485
amp	31.2
kw	24.8
pf	0.95

The quoted kw would appear correct based on the quoted voltage, current and power factor.

With energy saving device fitted.

volt	430
amp	26.4
kw	17.8
pf	0.91

a. The quoted power is equal to the calculated value based on a calculation using the reduced output voltage. This could not be a measured value, as a measured value would certainly not reduce by this amount. As described earlier, the metering is not affected by the reduced output voltage.
b. The quoted power factor has dropped from 0.95 to 0.91. This is contrary to the basic operation of the device. The power factor should improve when the energy saver is used.
c. With a power factor of 0.95 initially, there would not be a drop in current with a falling voltage. As the majority of the KW load is shaft load, a drop in voltage will result in an increase in supply current. If we assumed that in this case we were using an inefficient motor at say 80% efficiency, then we would have a shaft load of 24.80 x 0.80 = 19.84 kw. The shaft load portion of the current at 485 volts would be 23.617 amps per phase. If the voltage was now reduced to the quoted 430 volts, then the shaft load KW remains constant and the shaft load current would rise to 19.84 / 430 / √3 = 26.6 amps which is slightly above the quoted current at the reduced voltage. As there would still be magnetizing current , copper loss current and iron loss current, it would appear that these figures are also fictitious.

These are only a couple of randomly selected examples. There are many more quoted by this one supplier showing similar anomalies.

Another supplier quotes “in typical applications, levels of utilization are approximately 50% with power wastage estimated to be between 40% and 80% of the motor full load rating”. - “ Unfortunately, motors have no way of intelligently adjusting the amount of electricity they draw in relation to the work they do.” The implication is that the motor is inherently very inefficient at less than full load, but this is **not** what the motor manufacturers show in their data sheets. This supplier also “delivers a speedy payback - normally less than two years, …” .???

5. Pay Back Periods

NB The costs quoted here are the costs experienced in New Zealand in the early 90s. Costs have changed and are very dependent on locality. The payback calculated will differ depending on the actual costs you experience, but the theory still stands.

In the right applications, with the right motors, there will be some energy saved. In many such situations, the energy saved would be increased by altering the operation of the machine to spend less time idling. To calculate the payback period, it is essential to have an accurate measurement of the actual energy (KW) being saved. When the energy saved is known and verified, then this can be multiplied by the cost of the energy per kilowatt hour to give a cost saving per hour. Dividing the savings per kilowatt hour into the installed cost of the energy saver, will give the required number of operating hours to give a payback.
For example, a small punch press operated by a 1.1 KW motor, could save as much as 300 Watts per hour, depending on the design of the fitted motor. If the cost of energy is 14 cents per KWH, then

at a 40 hour week operation this would amount to a cost saving of $1.68 per week. To achieve a pay back period of two years, this would require a maximum installed cost of $168.00 Prices quoted recently by one supplier would put the cost of the unit at $3,633.83, or a payback period of 43.2 years!! or a return on investment of 2.3 percent per annum!

With a larger motor, perhaps 22 KW operating a granulator which runs continuously, and spends 90% of its time unloaded, the potential savings could be as much as 1.1 KW per hour during the off load period, amounting to 40 x 1.1 x 0.9 = 39.6 KWH per week. At 14 cents per kWh, this would amount to a savings of $5.54 per week. To achieve a payback of two years, this would require a maximum installed cost of $554.40. A quoted price of $4919.07 would yield a payback period of 17.7 years, or a return on investment of 5.6%.. A greater saving would be made by switching the machine off and only operating it on demand. Turning the machine OFF during it's off load time could save 2.5KW per hour which amounts to a saving of $12.60 per week, or $630 per year. which is much higher than that achieved by using an energy saver.

In many industrial environments, the cost per KWH would be less than the 14 cents used in the equations, and therefore payback periods would be greater, or installed costs must be less than the examples above.

If we take a typical 75 Kw 2 pole motor, and operate it in it's most inefficient state, (open shaft) then we could achieve a 1.5 KW saving. at 14 cents per KWh, this would amount to a saving of $420 per year if the motor runs for 40 hours per week. To achieve a pay back of two years in this situation, the installed cost of the energy saver would need to be less than $840. In reality, with loads of this size connected, the energy cost would be lower, and the machine would not spend 100% time at idle, so the energy saved would be less and the pay back period would be much longer. The cost of a unit to operate on a motor of this size would be a lot more expensive than this also. In this case using the figures quoted, the payback period would be 25.9 years.

Conclusions

There is no doubt that the basic technology of reducing the voltage on a motor which is operating at less than maximum efficiency, can result in a reduction of the iron loss of the motor. In a case where the motor has a very high magnetizing current, and it is operating at essentially open shaft conditions, there can be a reduction in copper loss also. In practice, with a partially loaded motor, a reduction in the voltage applied to the motor will reduce the iron loss, but the corresponding increase in the load current can cause an increase in copper loss that is greater than the reduction in the iron loss, resulting in a net increase in motor losses.

-Worthwhile power savings are only achievable where the iron loss is an appreciable portion of the total power consumed by the motor, and where the amount of the iron loss is significant relative to the motor rating. This technology only achieves useful results on small, inefficient and predominantly single phase motors.

Unfortunately, once again we have examples where a lack of knowledge about basic motor characteristics and a poor understanding of power metering on three phase systems have resulted in extrapolations and estimations which totally misrepresent the achievable results from the application of this technology. **Only energy that is being wasted, can be saved.** Large motors do have a much higher efficiency than small motors, and this basic fact seems to be missed in creating examples of potential energy savings. Proper tests would demonstrate that energy savings per kw motor rating are much higher for small motors than large, and the potential market for this technology is really confined to the small single phase applications. I can find no evidence of a technological advancement which can result in increased energy savings over and above the energy wasted by the motor. According to current laws of physics, this would be considered an impossibility.

Worked examples based on energy costs, motor losses and quoted energy saver pricing yield payback periods in the 10 to 40 year range, nowhere near the quoted figures of less than two years! In many cases, the return on investment is well below standard bank interest rates. To borrow the money to purchase the equipment would be a loss situation. Putting the cash into a savings account would be a higher yielding investment than the purchase of some of these energy saving devices.

In summary, I would like to note the following points:

The basic concept of reducing the voltage on induction motors operating at less than full load, and thereby reducing the energy consumed, works provided that several constraints are applied.

a. The motor efficiency can only be improved when it has dropped considerably below the maximum efficiency for that motor.

b. As the maximum energy that can be saved is a portion of the iron loss, the best savings are going to be on motors with a very high iron loss. Typically, these will be small motors, operating above their design voltage, or below their design frequency.

c. Where payback periods are a consideration, the savings need to be related, not to the power consumed while the unit is running, but to the power saved relative to the cost of the unit, which is dependent on the motor rating.

d. Tests need to be carried out using rotating disk kWh meters, and care must be taken that the operating conditions are the same with and without the energy saver connected. Tests under open shaft conditions, yield a high percentage saving, but the actual savings in kWh is indicative of the maximum dollar saving that can be achieved with that motor. As the load increases, the kWh savings will reduce as will the percentage energy savings.

e. In many situations where energy savings can be made, greater energy savings can be achieved by either altering the operation of the machine to minimize the time operating at idle, or replacing the motor with a more efficient motor. This can yield an improved payback period relative to the use of an energy saving device.

f. Partially loaded motors fitted with energy saving devices can dissipate more energy than without the energy saving device.

g. Experience gained with this type of technology indicated that there was no significant improvement to be made on motors operating with a power factor greater than 0.4.

h. Experience has shown that the best results are on small single phase motors operating continuously, and predominantly under no load conditions. Small motors operating at a voltage well above their design voltage (i.e. 440Volt motor operating on 485Volt) will exhibit a much higher iron loss and therefore achieve much increased savings.

i. Real payback periods of less than two years are rare, requiring a very good application, a very lossy motor and a very cheap energy saver.

Only energy that is being wasted, can be saved.