The Fixed-Speed Induction Motor Energy Optimiser – Science or Snake Oil?

Although ‘optimising’ electronic soft-starters are a well-established technology, so-called ‘energy optimisers’ have recently entered the market, claiming to improve the part-load efficiency of fixed-speed induction motors to levels far beyond that which optimising soft-starters are capable, “20% or more” is frequently bandied about. So, what magic do the makers of optimisers possess which escapes the traditional electronic soft starter manufacturer? In this article, Ray Bristow, the UK member of the International Electro technical Commission working group producing standards for soft starters and former Technical director of Fairford Electronics Ltd looks at the facts.

The three-phase induction motor was invented just before the beginning of this century and has become the workhorse of industry throughout the world. The reasons for this astonishing degree of acceptance are easy to find – the induction motor is simple, reliable and above all else, pretty efficient – 90% or more is not uncommon, with the new high efficiency motors adding 2 – 3% more. Now electronic ‘energy optimisers’ have appeared which claim to make substantial savings for anyone running a partly loaded motor at a fixed-speed.

One supplier of ‘energy optimisers’ who is currently targeting the industry suggested to a quarry manager that as a result of his survey of the plant, it would be possible to save “a minimum of 20% while the motor is running”. By way of an example, he estimated that the saving on the cost of operating a 186 kW crusher motor for 45 hours a week would amount to “£2905 per annum”. Similar ‘suggested’ savings, were offered for other motors on the site. All in all, it seemed to offer an irresistible opportunity to save money with very rapid pay back of the cost of the equipment, and therefore worthy of serious consideration. But, dubious of the figures, the manager called for an independent survey to be carried out of the potential savings before he contemplated an order – wisely, as it happens.

Before anyone can fairly evaluate the claims made for ‘Energy Optimisers’ it is important to understand why electric motors are there in the first place, and the significance of motor efficiency as a whole.

So, what is the purpose of an induction motor and what is meant by ‘motor efficiency’?

The purpose of a motor may seem obvious – to drive a mechanical load. In a more accurate sense its real purpose is to convert electrical energy taken from the supply into rotating mechanical energy to power the driven machine. Any mechanical system, whether a conveyor, grinder, crane or whatever, requires energy to be put into it before it can work and the induction motor is a convenient and flexible means of providing that energy. It is also a machine in its own right.

Almost everyone has heard the expression 'that no machine is 100% efficient'. What this means is that any energy conversion system, whether it's water passing over a wheel to grind corn, an internal combustion engine where petrol or diesel oil are converted into mechanical energy, or an induction motor - all consume more energy than they transmit to their load. In other words, their input energy is greater than their output energy. The difference between these two values is the 'loss'. The 'efficiency' is simply the ratio of output energy over input energy and is always less than unity. For convenience, efficiency is usually spoken of as a percentage, so '95%' for instance, means that the machine converts every kilowatt of its input energy to 950 watts of output energy. The remaining 50 watts of each kilowatt input energy is consumed internally by the machine, and is the 'loss'.

What does this mean for an induction motor?

All motor manufacturers publish efficiency data for their products, or if you contact them, they will happily give you figures for a particular machine. In general, most induction motors have efficiencies at rated output, higher than 85%, and only the very smallest motors, below 1 kW in output will be significantly less. As a rule, the larger the kW rating of a motor, the higher the efficiency, as the following table (taken from a well-known manufacturer's data sheets) shows. Also notice that the half-load efficiency is only slightly less than the full-load efficiency: -

Rated output kW	Full-load efficiency %	Half-load efficiency %	Full-load loss kW	Half-load loss kW
7.5	87	85.9	1.121	0.617
110	94.8	94.3	6.033	3.324
186	96.2	95.8	7.347	4.041
400	96.6	96.3	14.079	7.743

The fourth column of the table tells us that the 110kW motor is 94.8% efficient at its rated output. To find the input kW at full load, merely *divide* the output kW by the efficiency, i.e.: -

$$Input = \frac{Output}{efficiency} \text{ kW.}$$

So, for this motor, the input energy = (110 □0.948) kW = 116.033 kW and the full-load loss is simply input energy minus the output energy, or 6.033 kW. *Note that this is the MAXIMUM loss for this machine operating normally. It is not possible to 'save' any more than this amount, no matter what the load is on the motor.* Doing the same exercise for half-load operation gives values for input energy of 58.324kW (55 □ 0.943) and a loss of 3.324kW.

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Where can the losses be reduced and savings made?

One of the unchanging laws of physics is that in any conversion process, energy can neither be created nor destroyed – there is always an energy balance.

Let us look at the conversion of electrical to mechanical energy. Energy is measured in watt-seconds, although it is normally recorded as kilowatt-hours (kWh). Rotating mechanical energy is torque times speed, multiplied by time. So, for an induction motor, the energy balance equation is: -

$$(kilowatts \times time) = \frac{(torque)x(speed)x(time)}{(efficiency)}$$

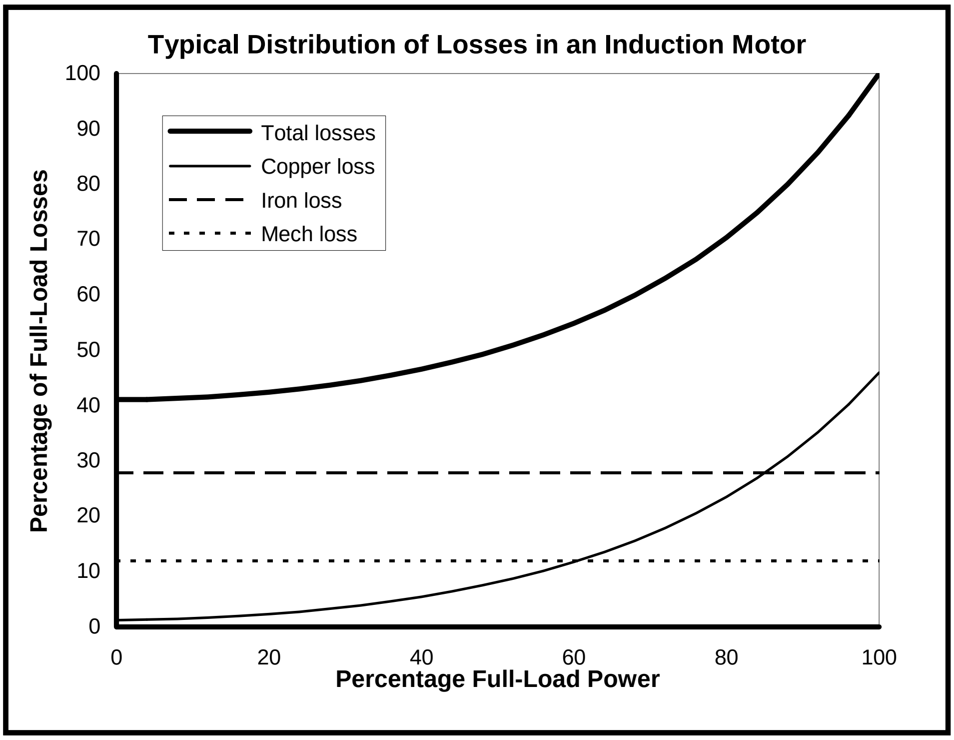
This equation tells all. To reduce the kilowatt-hours you can: -

- Reduce the torque - make the driven machine (not the motor) more efficient.
- Reduce the speed – only possible where torque is proportional to speed such as in fans and centrifugal pumps.
- Reduce the time – switch off earlier!
- Improve the induction motor efficiency.

For the moment we'll concentrate on the last item, for that is where 'energy optimisers' claim to make the most impact – remember the "20% or more"?

The loss structure of an induction motor

The two elements of a motor's losses are the load-related or 'copper' loss, which varies with the square of the load, and a fixed loss that is obviously constant. Although they are very dependent on the individual motor design, they split roughly 60% - 40% between the variable and constant components of the full-load loss. The figure below shows the typical source and distribution of the primary losses for a modern induction machine and at full load the fixed losses are 12% for windage and friction and 28% for the excitation loss..



So, where can we improve the motor efficiency?

Apart from improving the efficiency of the mechanical load (more maintenance), nothing more can be done to reduce the load or copper loss once a motor has been manufactured. In any case, the load loss already follows a square law so at half load, the load loss is a quarter of the full load, load loss. Consequently, it can only be in the constant losses that the energy optimisers make their savings, and these also have two components – the mechanical and electrical loss, and these divide approximately 30 – 70% of the total fixed loss.

The constant mechanical losses relate to the motor's speed which, although varying slightly with load between slip speed and the supply synchronous speed, it is to all intents, constant. These losses are due to bearing friction, turbulence in the air gap and cooling fan load and are determined by the motor designers and cannot be altered in a fixed-speed application.

The other constant loss is the excitation or 'iron' loss and this is where 'energy optimisers' claim to weave their magic. The iron loss represents the heat generated by the current drawn from the supply that is used to create the field across the air-gap between the stator and rotor. Whatever the load – even zero load, a motor must have a field in order to maintain rotation and this will entail a loss – even if the field is perfectly optimised to be just sufficient for the actual load demanded. However, in practical terms it is not possible to save more than 40-50% of the iron loss and to keep it in perspective, it is just 28% of the full-load loss or 1689 watts (28% of 6.033 kW) in the case of the 110kW motor

Science or snake oil?

Now go back to the claims made for the 'energy optimiser' connected to a 186 kW crusher motor. Taking the claim at face value, the implication is that fitting an energy optimiser could save £1.225 every hour the crusher is running during a 52-week year (£2905 □45 x 52)). Put another way, at a unit cost of energy of say, 4p/kWh, the average saving in input power at part load would be 30.625 kW. Amazing stuff - especially as the normal input power for a 186 kW motor delivering 93kW at the output shaft would be around 97 kW! Clearly, the huge disparity between what science tells us is the situation and what is being suggested, needs explanation. Can the use of an 'energy optimiser' make the motor more than 100% efficient?

No, of course not and the claims for energy optimisers are hedged with vague references to reductions in plant outage, increased motor life and 'savings in starting energy'. This latter statement is also interesting because it reveals a failure to understand simple mechanical and electrical theory. Starting a motor involves accelerating the motor and it's load from standstill to full speed, and whether you do it quickly (and destructively) with a direct-on-line starter or gently with a soft starter, the amount of work involved and energy consumed, is basically the same. No energy to be saved there then.

So, where and how can a continuous saving of 30 kW be obtained from half-loaded 186kW motor?

There is no satisfactory answer to this question. If you are told "the excitation losses", then, if it is not deliberately misleading, the reply indicates a total lack of understanding of basic engineering knowledge, and you should deal with someone who is at least, aware of true nature of induction motor efficiency. If it is the "operating costs", then you should probe very deeply because no electronic apparatus yet invented can achieve this level of reduction in input energy without reducing speed – and even then, the load torque must be proportional to speed such as in a fan, before the total energy consumed is reduced. Nor could it ever be possible to save that amount of power when the full-load losses in a modern motor only represent around 10% of the input energy. Any reputable optimising soft starter will achieve between 40 – 50 % saving of the iron loss at partial loads – and provide high quality soft starting and other functions as well. However, that produces at best, a reduction in operating costs in the region of 1- 5% or so at half load. (Remember also that 'optimisers' only offer savings at part loads and although the percentage of savings will increase as the load falls, the value of these savings goes down – a larger part of a smaller amount).

Conclusion

There is no magic in 'optimisers' as such. They offer nothing more and frequently less, than an optimising soft starter from any reputable manufacturer. It is simply impossible for 'energy optimisers' to achieve the savings that they purport to offer, and claims of successful installations should be viewed with great scepticism. Also, it will be hard to challenge the supplier's claims after installation, because it is usually extremely difficult to keep operating conditions (temperature, load density, moisture content etc.) constant long enough for a true before and after comparison of costs to be made.

Anyone thinking of fitting one should consider the alternative of an optimising soft starter – at least they offer something for nothing – the optimising function is free, and they bring all the advantages of less stressful starting to give the ultimate in savings – switching a motor on and off more frequently.

Stand-alone 'Energy Optimisers' are definitely more snake oil than science.

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