White Paper

The importance of power factor in ECR 2 fan motors

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Overview

Wellington's ECR® 2 fan motors offer an extremely high power factor of up to 0.95, compared with the 0.6-0.65 typical of most EC fan motors. This white paper explains how this is achieved, and why high power factor is beneficial to refrigeration system manufacturers and end users.

What is power factor?

Power factor (PF) is a way of expressing how close the current waveform of the motor is to an "ideal" shape, using a single number. Mathematically, PF is the ratio of true power (usually measured as W_{rms}) to apparent power (usually measured in VA). In simple terms, this is the ratio of *"power which is actually being used by the device" to "total power moving around the system"*.

When a resistive load like a heater is connected to the AC mains, the current is synchronized with the voltage, because Ohm's Law tells us that V=IR (R is constant, so V proportional to I). So just as there is a sinewave shaped 50Hz or 60Hz voltage waveform, there's a corresponding current sinewave that is exactly in phase. No power is being wasted; all of it is used. This situation is described as having a PF of 1 (or 100%).

However, many loads aren't ideal resistances. Here are some examples.

- In devices with a large inductance (like an AC motor), the current waveform lags behind the voltage waveform. This is due to the inductance storing and releasing energy as the voltage varies.
- In any electronic device powered by a "bridge rectifier" (like most EC motors), the current is zero for most of the waveform, and current only flows when the voltage is very near its peak. This is because the bridge rectifier charges a large capacitor (the "bus capacitor"), and the capacitor only accepts current when the input voltage is greater than the remaining charge in the capacitor. So, for example, in a 230V 50Hz system, the peak voltage of a half-wave is around 160V (=230/2*√2)). If between one voltage peak and the next, the load has drawn enough charge out of the capacitor to discharge it by 10V, at the next voltage peak the cap will start charging at 150V and stop at the peak of the waveform (at around 160V). So over the 10 milliseconds duration of a half-cycle of 50Hz mains, the capacitor is only charging for a few milliseconds.
- In more complicated electronic loads, there are more complex distortions in the current draw.

All of these cases result in a PF less than 1. In the case of a small EC motor driven by a bridge rectifier, the PF is typically around 0.6-0.65: this is an outcome driven by design decisions about the size, and therefore lifetime, of the bus capacitor. Small shaded pole induction motors also typically have PF of around 0.6-0.65.

Note: In electronics PF is sometimes also referred to as total harmonic distortion (THD). These are not mathematically identical, but are largely interchangeable terms.

Why does power factor matter?

The reason low PF is undesirable is because the “non useful” part of the power flow causes losses in the AC system, all the way back to the power station.

In the case of phase lag (i.e. of AC motors) this is because a proportion of the current is flowing into and out of the inductance (which is essentially an energy store), and hence back and forth into and out of the power grid, without doing anything useful. In the case of electronic loads, it is because the losses are proportional to current squared, ($P=I^2*R$), and the I^2 of a short but high current draw is higher than that of a long but low draw.

All these excess losses are power that the energy company has to generate but doesn’t get paid for, and all the wiring, circuit breakers, etc. in the system need to be rated for the higher (“apparent”) current rather than the “true” current (i.e. that actually used by the device). Additionally, the ability of the generators to produce the grid’s power is limited by the instantaneous current demand. If the sum of all loads on the grid adds up to a low PF, this requires power stations to run inefficiently and more generation capacity to be used then in an ideal situation.

Because of these factors, in the case of industrial or commercial sites, many power companies charge penalties to sites which have a low PF to their overall load. Additionally, a building’s low PF means the required size and cost of its electrical infrastructure are all higher than necessary.

In a typical supermarket installation, specifying ECR 2 motors instead of conventional EC motors can increase the number of cabinets connected to a single circuit by up to 20%. If ECR 2 motors are specified in place of shaded motors, the improvement can be as much as 40%.

In many countries, there are regulatory requirements which dictate the minimum allowable PF for different types of electrical equipment. These do not cover equipment with total power levels as low as that of an EC fan motor, however in installations where many fan motors are used on one site (such as in supermarkets), the total impact of their PF on utility bills and infrastructure costs can be significant.

As an example, if motors were 10% of a supermarket’s total power usage, it could result in a 3% improvement in the supermarket’s PF. Depending on the local utility’s demand tariff structure, this could reduce the facility’s tariff level by enough to save as much as 10% in energy costs.

How ECR 2 motors achieve high power factor

As mentioned before, most EC fan motors use a bridge rectifier and a bus capacitor to convert AC voltage to a directly related DC voltage. This is then reshaped into a waveform suitable to drive the motor by an “inverter” stage, as seen in the block diagram of Figure 1. This has the advantage of being cheap and simple, but it has several disadvantages.

- The voltage fed into the inverter is high, so the electronic components in the inverter are expensive. This makes it impractical to use a sophisticated inverter for these small motors.
- The voltage fed into the inverter is proportional to the AC voltage, so it is impractical to support a wide range of AC voltages with one motor SKU.
- The inverter has very little protection from disturbances in the AC mains, so reliability can be a problem.

- The "inrush current" when the motor is first switched on is high, due to the bus capacitor charging up. This puts a strain on relays and other circuitry in the appliance which supplies the motor.

- The PF is inherently poor, as described above.

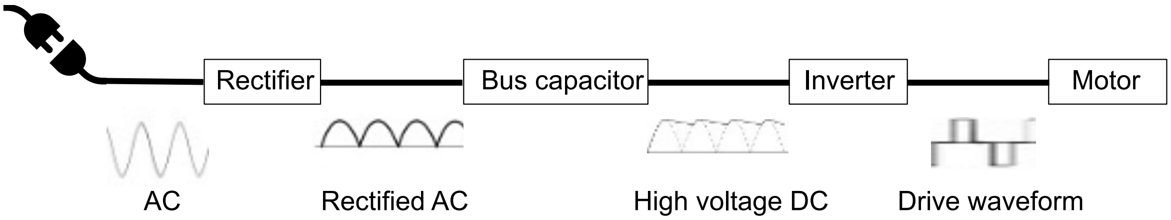

Figure 1: Typical EC motor block diagram

In ECR 2 motors, the AC voltage is instead converted to a low DC voltage (around 40V DC) by a "switched-mode" power supply, as seen in the block diagram of Figure 2. A switched-mode power supply is one which turns the mains voltage on and off very rapidly to create a high frequency voltage, then passes this "chopped" waveform through an electronic circuit and a small transformer, converting it to a DC voltage which need not be related directly to the AC voltage. This system has the following benefits.

- The DC voltage is low enough that low cost electronic components can be used in the inverter stage. This makes it practical for the ECR 2 to have a sophisticated "three phase field oriented control" inverter, a style which is normally only used in much larger and more expensive motors. This enables the very high efficiency and low noise which characterise the ECR 2 motor.

- As the DC voltage is independent of the AC voltage, the motor becomes "universal voltage" so the same SKU can be used in various applications.

- The inverter is isolated from the AC mains by the power supply, protecting it from disturbances and increasing reliability.

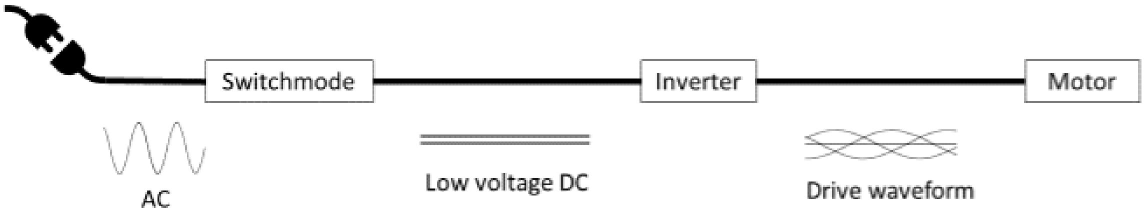

Figure 2: ECR 2 motor block diagram

The power supply type used in ECR 2 motors is called a "flyback converter". When compared with the "buck converter" type used in other universal voltage fan motors, flyback converters have good performance across a wider range operating conditions. Crucially, they are also inherently capable of operating with a very high PF, since they draw current from all parts of the AC waveform. The graph in Figure 3 shows the power drawn from the AC waveform of an ECR 2 compared to that of a typical "conventional" EC motor. Compared to the conventional motor, the ECR2's current draw is much more sinewave shaped and has a much lower peak current.

This electronics architecture enables ECR 2 fan motors to have a much higher PF than most competing EC fan motors. This delivers a significant benefit to end users who have large numbers of fan motors in their installation.

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