GETTING (A LOT) MORE POWER FROM SQUIRREL CAGE MOTORS

The power output of a conventional squirrel cage motor is limited by two factors :-

1) Its Torque output which is determined by the magnetic saturation of the iron core / rotor components.
2) Its speed (rpm) which is determined by frequency and number of poles.

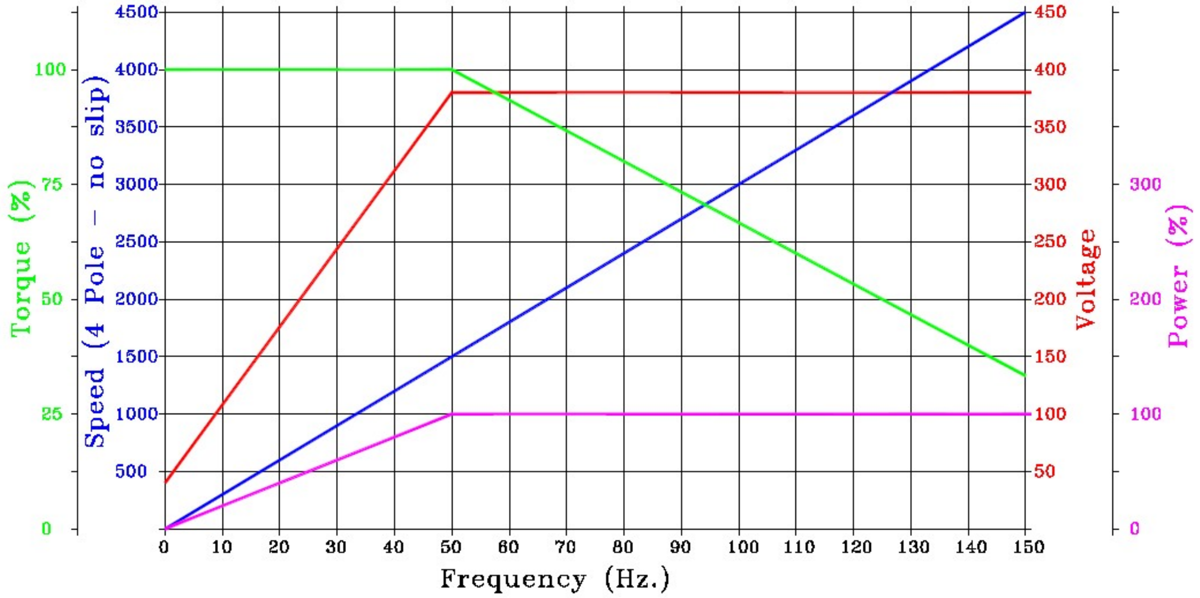
The torque is limited by the magnetic saturation of the rotor & stator and is determined by the laws of physics – so the more torque you need, the more iron has to be designed into the motor – pretty much regardless of the motor type.

It is the speed limit imposed by frequency – maximum 3000 rpm @ 50 Hz. (for a 2 Pole motor) – which curtails the power that might otherwise be available.

Conventional squirrel cage motors are therefore relatively bulky and heavy for their output – this is why they are never used in hand held power tools – instead brush motors are used – since these can typically spin at 20000-30000 rpm then for the same torque (think mass) 10 times the power can be delivered.

You can of course speed up a 3 phase squirrel cage motor by using an inverter to run it at a higher frequency – but you will run into a power limiting problem viz :-

If you take a 380V 3 phase motor and run it off an inverter – the inverter will ramp up the voltage with frequency viz :-



The voltage ramps up according to a **V=mF+c** function – in this case **c** (constant or starting voltage) is 40 volts at Zero Hz. Ramping up to 380 Volts at 50 Hz.
(**V** being the voltage, **m** being the multiplier and **F** the frequency).
(The graphics assume no slip i.e. synchronous speed is achieved – slip is normally about 5% - the assumed linearity is for simplicity / illustrative purpose)

One advantage of using an inverter is that you can get (near) constant torque out of a squirrel cage motor (normally starting torque is terrible if started direct on line – this is because at switch on the rotor is standing still and its impedance is at 50Hz.
If the motor's rated torque is at 5% slip – ie 2.5Hz (as "seen" by the squirrel cage bars) then its starting torque is only 5% of its rated torque – or rated torque x slip). The ramp up function of an inverter allows you to keep the disparity between the rotor and field rpm to a minimum during starting – particularly with high inertia loads.

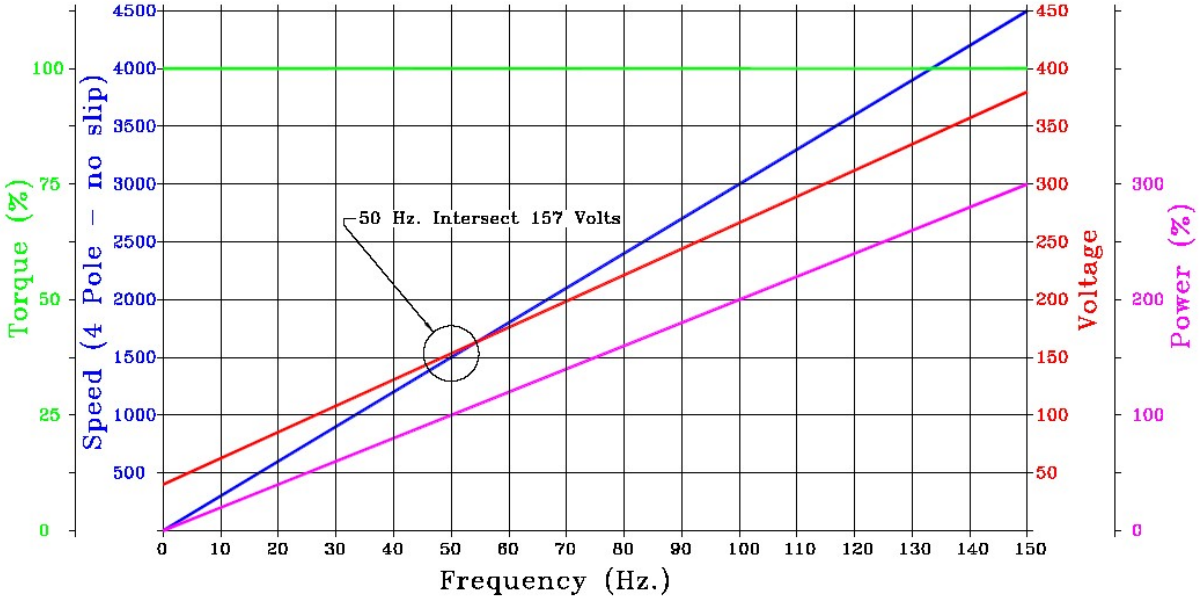
Torque is directly proportional to current (other than in stall or outside of saturation = abnormal conditions) which in turn is dependant on Voltage/Impedance which is dependant on frequency (ignoring the small resistive component) hence the reason for ramping up the voltage with the frequency.

The problem comes in at the top end where the inverter flat lines at 380V (Only 220V if you are using a single phase to 3 phase inverter).
So from this point onward any increase in speed (frequency) results in an increase in impedance and concomitant loss of torque.
So from this point onward the power output "flatlines" (Revs go up, torque goes down and resultant power is constant)

In order to get more power from our motor we need to keep pushing the voltage higher to overcome the frequency imparted impedance in order to keep up the torque.

Since the inverter voltage won't go any higher the only option we have going for us is to rewind the motor to a lower 50 Hz. Rated Voltage.

The following graphic shows the same motor but rewound for 157 Volts @ 50 Hz.



Now the inverter ramps up so that at 50 Hz we are indeed at the rated 157 Volts – only now we can keep pushing the voltage with frequency up to 380v at 150 Hz. thereby maintaining the torque.

So now we can run the motor 3 times faster (as illustrated) and get 3 times more power from the same frame size.

We will of course have to gear down this speed to get the power at the desired output speed (as with hand power tools).

Why Would You Want To Do This ?

Any application where power to weight ratios are a problem (such as in power tools for robotic applications) or where you have space or weight constraints and need more power out of a smaller frame or where an existing motor does not provide enough power but there is no space for a bigger motor – (designed yourself into a corner maybe ? – This trick has bailed me out of that problem more than once).

High frequency motors specifically built for high spindle rpm are available but are generally very expensive (usually built to grinding spindle accuracy – which might be overkill in many applications). These motors also tend to use long rotors to improve torque to keep the diameter of the motor down (at the expense of length).

For reference – Commercial aircraft use 400 Hz specifically to reduce the mass of electric motors used throughout their control systems (more power per unit weight).

So How Far Can We Push This ?

Pretty much as far as you like within the speed rating of the ball bearings (which can be changed to closer fit spec. / higher speed ratings) or a far as you can spin the motor without risking it coming apart.

For motors up to about 3kW you can safely go to 12000 rpm which on a 4 pole motor would be 8 times its rated speed and hence power output. Smaller motors can be pushed to 24000 rpm but you need to consider the failure speed of the rotor or fan as well as using selected fit bearings and fine balancing.

(Note: A ∅30 bore deep groove ball bearing has an 11000-20000 rpm speed rating and much higher as you go smaller – 24000-38000 for a ∅15 bore .)

It's a pretty neat trick getting 24kW out of a 3kW motor.

Remember the only thing you are doing is spinning it faster – its rated torque remains unchanged therefore the overall ampere●turns / field saturation remains unchanged.

Heat Problems

Generally the increase in cooling airflow (because of the speed increase) is much greater than the increase in heat – so in most cases it's not a problem – typically running cooler.

Typically losses in a motor are 50% to copper losses, 20% to Hysteresis losses, 25% to Eddy Current Losses & 5% to mechanical losses.

So for a doubling of speed / power we get approximately 25% more heat – but approximately double the cooling airflow – hence the comment that the increased airflow is generally sufficient to take care of the increased heat. (These figures vary considerably ±10% from motor to motor but the increase in fan speed will easily offset any increase in heat – unless you run beyond saturation and into overcurrent – which will destroy any motor.)

The copper losses (I^2R) losses will be approximately the same – since the rewind uses heavier wire – its cross sectional area changes per the ratio change– but the length of the wire is reduced by the same ratio – so the I^2R is unchanged as a result of the cross sectional wire area change. (Greatly dependant on the actual wire gauge chosen by the rewinder.)

The Iron losses (Hysterysis & Eddy Current losses) in the stator will increase with the increased frequency due to an increase in Hysteresis losses while Eddy Current losses remain approximately the same (as there is no change in the ampere●turns / field saturation although here we might push a further 10% or so – see later).
Mechanical losses to cooling airflow and friction in the bearings will also increase but is not significant.
However the cooling airflow from the fan turning at much higher speed offers significantly greater cooling than the additional heat created.
Overall the motor generates more heat but the increased cooling is generally more than sufficient to offset this.

What should also be apparent is that running a motor at higher speed actually improves its efficiency.

A word of caution – you can run into a problem where the extra iron loss heat in the stator cannot conduct out to the cooling fins fast enough – in which case you will need to de-rate the motor slightly. To check for this monitor the temperature of the case under load until it stabilises – firstly is this temperature within the range of “normal” – 40°C to 60°C over ambient (what was the donor motor’s original rating) – secondly on stopping the motor does this temperature continue to rise significantly – indicating that the core is running considerably hotter than the external temperature suggests.
Using a quality brand high duty cycle (S1 = 100% duty rating) donor motor in the first place will obviously help. (S2 = Intermittent duty & S3 = Light duty cycle.)
The rotor will run at the same “Slip” frequency and delivered torque remains the same so there should be no increase in Iron losses in the rotor.
However there may be increased rotor temperatures and rotor shaft / bearing temperature which is detrimental to bearing life. A great deal of heat can be generated in the bearings themselves – particularly with respect to lubricant and speed rating of the bearing.
Again the selection of a quality brand which has cooling blades cast into the aluminium end rings of the rotor will perform better than plain end rings.

Note: – problems can set in when motors are run “slowly” off inverters – forced cooling by external constant speed fans is then required – the rule here is not to run an “overclocked” motor too slowly (or add external fans).

Since the donor motor was never intended to run at a higher speed, additional fine balancing might also be required particularly if vibration is going to be an issue.

All in all it generally presents no problem but err on the side of caution as the duty cycle increases and be very wary of running overclocked motors at 100% of their now overrated output 100% of the time – although this is possible (it depends).

If these sort of speeds bother you, then consider your typical wire wound armatures of power tools (of similar diameters) that spin at typical speeds of 20000 to 30000 rpm – these open frame windings are considerably more fragile than a stocky, closed lamination squirrel cage with its cast in-situ aluminium conductor bars. Typically the plastic fan is likely to fly apart long before the rotor.

How Do You Do This ?

Firstly determine what power you want, what speed and what frame size motor you wish to use.
If you require a low final drive speed, consider how you are going to gear it down taking care not to exceed pitch circle velocity limits of gear and toothed drive belts etc. – for this reason you might like to start with a 4 pole (1500 rpm) or 6 pole (1000 rpm) motor to reduce the effort in gearing down later.

So let's say we have in mind a 3kW x 380V 4 Pole motor with a rated output of 1425rpm (as a result of "slip" the rotor must turn somewhat slower than the field in order for current to be generated in the squirrel cage bars and is typically - as in this case - 5%)

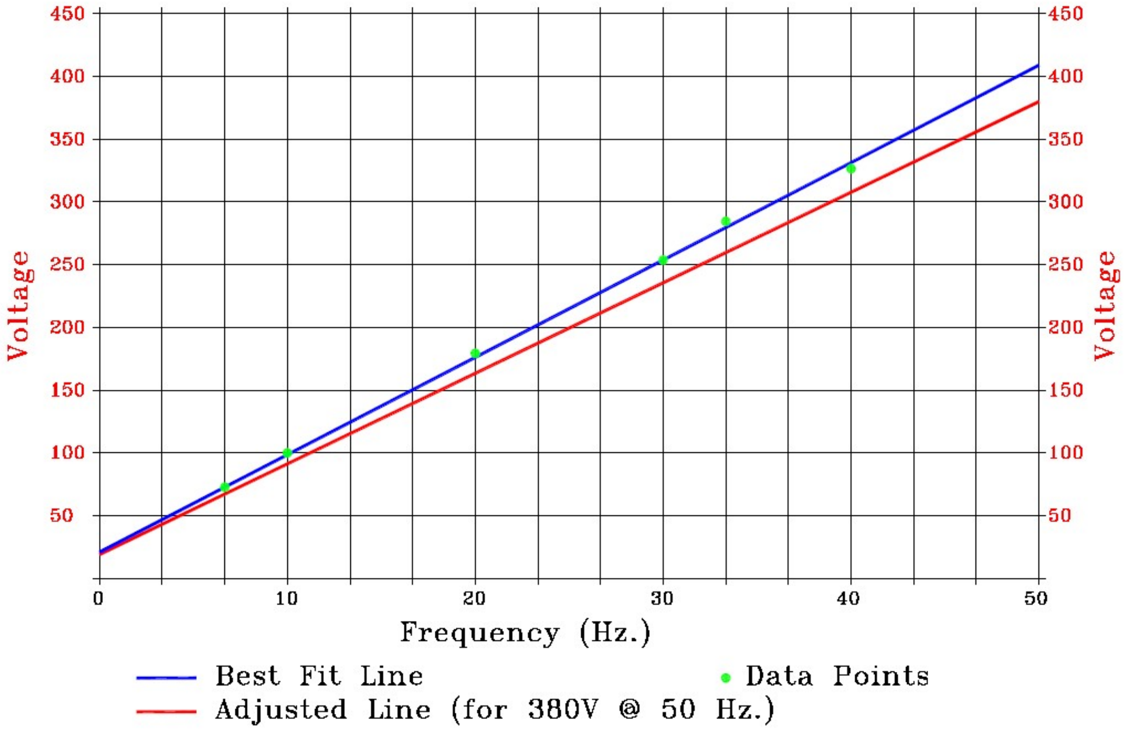
We require 15kW – so we have to spin this motor 15/3 = 5 times faster – so we are going to run it at 5 x 50 = 250 Hz.

To determine the 50Hz rewind voltage we firstly need to know the **V=mF+c** function of the unmodified donor motor. (Note: This linear function is a generally accepted practice approximation of a slightly non-linear function – for simplicity.)

One "guestimate" is to presume **c** is a function of the "slip" so we take its rated speed versus its synchronous speed 1425/1500 = 95% or 5% slip.

Then **c** = 380 x 0.05 = 19 Volts.

A more complicated and correct way is to run the motor {no load} off the inverter at a variety of lower speeds and push the voltage up at each point until we start seeing a disproportionate increase in current with voltage which means we have exceeded saturation – do this for several data points and you will get a graph something like the following :-



[Note: Some inverters (Yaskawa) have an “Autotune” function and the inverter determines & sets these values (in much the same way – by pushing the voltage until current / voltage disparity indicates saturation) – the determined values can then be looked up from the display.]

Our best fit line projects a 50Hz saturation limit of 418 Volts (which is about what you would expect since the manufacturers typically allow for 10% over voltage conditions) and a Zero Hz. Voltage of 21 Volts.

Adjusting this back (in this case by 90% - from the above saturation vs specification) we get the unmodified donor motor specification line from 19 Volts to 380 Volts.

Note: When running off an inverter, its output voltage is unaffected by input voltage fluctuations (within reason) and you can run the motor much closer to saturation than you would dare with direct on line – so typically there is another 10% or so power to be gained here as well by not adjusting back from saturation vs specification (let the autotune take care of it).

So now we know our **V=mF+c** function of the motor. (We might also try asking the motor manufacturer – but that can open a whole can of worms – alternately choose a figure between 5 & 10% for **c** as a rule of thumb.
A further rule of thumb to determine the 50Hz wind value is simply divide the voltage by the amount you are going to goose it up – in this case 380/5 = 76V and then add the slippage (5%) = 79.8V which is pretty close to the more complicated calculations.)

Our **V=mF+c** function gives 19 + 7.22**F** so for a frequency of 40 Hz we would set the inverter to 19 + 7.22 x 40 = 307.8 Volts etc.

Now we have to imagine we are going to run at 250 Hz. (re prior determination) and we would require 19 + 7.22 x 250 = 1824 Volts

Let ***L*** = revised impedance ratio

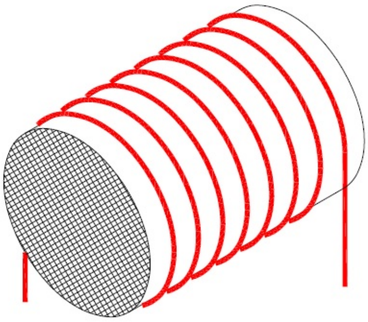
Then 19***L*** +7.22 ***L*** x 250 = 380 (both constant & multiplier are involved)
∴1824**L** = 380
∴ ***L*** = 380/1824 = 0.208333

So we rewind the motor for 20.8% of its prior impedance.

Or rewind for :-

380 x 0.208333 = 79.2 volts (at it's nameplate rating of 50Hz.)

The formula for Inductance is :-



$$L = \mu_r \frac{N^2 A}{l} 1.26 \times 10^{-6}$$

Where:

L is the inductance in Henrys
μ_r is the relative permiability of the core
N is the number of turns
A is the area of the core in square metres
l is the length in metres

Now since impedance is an outcome of the number of turns **Squared**.

You will need to take the original windings, square that, apply the correction and then take the square root of that. (We can generally ignore the resistance component as it is very small relative to the overall impedance.)

Example:

If the original motor was 200 turns of #20 SWG wire (Ø0.655mm)

The our revised wind will be $\sqrt{(200^2 \times 0.20833)} = 91.28$ or ≈ 92 Turns.

Since the original cross sectional area of the wire was

$200 \times \pi \times 0.655^2 \div 4 = 67.39\text{mm}^2$

Then the replacement wire must be = $\sqrt{(4 \times 67.39 \div 92 \div \pi)}$ = Ø0.965

Nearest SWG is #19 = Ø0.81 (unfortunately the next size up is too large).

Our rewind specification is 92 turns of #19 SWG !

Note: This assumes the density of the wind (cross sectional area of wires ÷ cross sectional area of the slot) remains about the same.
In practice it is ±85-90% (maximum theoretical density is 90.6%) and it get less as you put thicker wire into the same area slot.

Note: If you are rewinding a 2 pole to a 4 pole, or rewinding a single phase to a three phase then the coil is going to be wound around a different number of stator pole pieces and must be allowed for in your rewind calculations. It's a lot easier if you retain the same configuration – see later on changing the number of poles.

Rather than explaining yourself its often easier to simply tell the rewinder "*Here, rewind this 380V motor to suit 80V*" (and some can't even manage that) that way you avoid getting involved in a long technical debate as to why you can't do what you're trying to do.

(The standard response from most motor manufactures and rewinders is "*You can't do that !* " – they are wrong ! – if you find a technically savvy engineer or rewinder they will understand – salesmen – forget it – dumb as a box of rocks.)

Alternately, have the rewinder strip the motor and advise you of the wind layup and you do the calculations yourself and advise him of the rewind – of course it is all on you if it doesn't work.

Your rewound motor now has the **V=mF+c** function (multiply by your ***L*** ratio value) of **V** = (3.96 + 1.5041F)

for 50Hz = 79.2 Volts (our rewind specification for 50 Hz.)
for 250Hz = 380 Volts (Our target top end.) Which is what we were looking for.

Remember (from the above) your current is now going to be 5 times higher (the power has to come from somewhere). So the inverter has to be large enough (15kW in above example) to drive it. (You might be able to get 15 kW out of a 3 kW motor but you can't get 15 kW out of a 3 kW inverter.)

After rewinding we can again use the "Autotune" feature to set up the rewound motor.

Note: Depending on configuration the “Autotune” feature may set up the correct non-linear relationship as a series of 3 or 4 straight line relationships to further optimise the set- up.

As a final precaution – re-mark the rating plate – just in case some idiot tries to connect it to 380V @ 50 Hz. – in which case all the blue smoke packed into the motor by the rewinder will come pouring out. (This motor’s rating is now 380V @ 250Hz – so just add a 2 before the 50 on the rating plate so it now reads 250Hz.)

A “Quick & Dirty” 70% - 90% More Power.

Most three phase motors have six terminals which can be bridged to “Star” connection for 380V or “Delta” for 220V – so here we can simply wire up in “Delta” but run it at 380V at an appropriately higher frequency.

Using our previous example of a 3kW motor with c=19V @ 0Hz and 380 @ 50Hz in “star” would be c=11V @ 0Hz and 220 @ 50Hz so :-

m = (220-11)/50 = 4.18 V/Hz.

So to run this configuration up to 380V :-

(380-11)/4.18 = 88.3 Hz or ±2516 rpm (4 pole, 5% slip) vs prior 1425 rpm or 76% more power.

[Since the star delta ratio is √3 = 1.732 – then the outcome of this trick is always going to be ±73% more power.
Also as stated earlier, most manufacturers allow for 10% overvolt safety margin which we can use as well - 1.732x1.1 = 1.9 or 90% more power.
If you do push to the maximum please make sure you do not wander out of A/V linearity past saturation and into smoke !

Remember, you will only derive an improvement in torque if you gear down by the same ratio – the motor itself cannot put out more torque.
For this “trick” to work, your inverter output voltage must exceed the motors normal Delta voltage.

Final Caution: Raising the voltage on a three phase squirrel cage motor will not make it turn any faster (as is the case for a D.C. motor). You can only raise its speed by raising the driving frequency – but this raises the impedance and for that you do need to raise the voltage if you want to maintain the current & torque.

Below a “tiny” 300W 240V single phase, rewound to 112V three phase (@ 50 Hz.) run at 380V @ 200 Hz (12000 rpm) producing 1.2 kW.

The Ø26mm coin is for size comparison. This is a very small motor for 1.2kW.
The rewind cost a couple of percent the price of an off the shelf high speed motor.
An acquaintance who imports high speed fan drives decided to see if he could reverse engineer a motor based on the above.
He took a 5kW 4 pole 50Hz – rewound it to suit 300hz to produce 30kW at nearly 9000rpm – he fitted the motor with ceramic ball bearings, added lubrication ports to the bearing housings and fine balanced the assembly. The result ran within 2% of the specification of the imported German unit and even as a “prototype” cost only 40% of the import. I’d chalk that up as a success.

Changing The Number Of Poles.

This will occur if you rewind to a differing number of poles and/or from single phase to three phase.

Take a 2 pole motor (3000rpm) and have it rewound to a 4 pole motor (1500rpm).
If our stator had 24 slots and the 2 pole motor had its coils wound through every 4th slot, when we rewind to 4 poles they will be wound through every second slot thus halving the permeable iron area of the core which would further halve its impedance and require a √2 (1.414) times the number of turns from our prior calculation.

Similarly if you rewind a single phase 4 pole to a three phase 4 pole then the wire will be wound around 2 slots where it was previously 3 so you would need to increase the number of turns by √(3/2) = 1.224

Similarly if you rewind a single phase 2 pole to a three phase 4 pole then the wire will be wound around 2 slots where it was previously 6 so you would need to increase the number of turns by $\sqrt{(6/2)} = 1.732$

I have assumed 24 slots in all the above – obviously if you are going to change the number of poles, you need to ascertain whether the number of slots are suitably divisible (they usually are 12, 24, 36 etc.) and then the above ratios would apply in most cases.

Finally, after rewinding you can determine the point at which the core saturation occurs at what voltage by plotting a current vs voltage graph and noting where the current starts to rapidly diverge from linearity.
You can also get this information from an inverter with autotune features (after running the autotune feature).

Setting Up Your VFD.

Depending on your VFD, you have to set the various parameters to get the desired voltage frequency output “curve” outlined earlier.
The simplest form for any rewind would be the **V=mF+c** function explained earlier.

However most modern VFD’s have an Autotune function – which have two (or more) principal setting methods :-

a) Rotating Autotune which spins the unloaded motor up at various frequencies and voltage profiles to “hunt down” the saturation limits and determine the best frequency / voltage “curve”

b) Does a static impedance hunt – but this requires the motor rating plate input data.

To a lesser extent method a) requires some plate data as a starting point as well.

Because we have now totally screwed up the motor relative to its original rating plate we need to at least come up with some idea of what the rating plate should be.

We need to invent a new “rating plate” series of values.

We already have voltage and frequency from our earlier calculations but now we also need an estimation for amperage.

We can do this one of two ways :-

Firstly based on our estimation of output of earlier example of a 3kW motor we ran up to 15kW we can re-engineer the amperage from that figure.

Lets say the original rating plate was 380v, 3kW, 5.4A, $\cos\Phi = 0.85$

Then we can just multiply the 5.4A x 15/3 = 27A

If we have changed the number of poles (or changed a single phase to a three phase) then we need to work back to the Ampere•Turns (At) for the original winding and work back from that since the At value would remain the same.

Because of the pole configuration change you would also have to allow for how much more (or less) core material the coils are wound around. (See Next)

If you dial in an inappropriately high number the Autotune will error out (because it will detect that it is wandering beyond saturation) – but you can be cautious and underestimate.

To further test the motor, leave it running flat out and keep an eye on the temperature – if it heats up rapidly you have probably wandered beyond saturation limits – (where further voltage increases cause massive increases in current and heat for no gain in output power) – dial down your expectations.

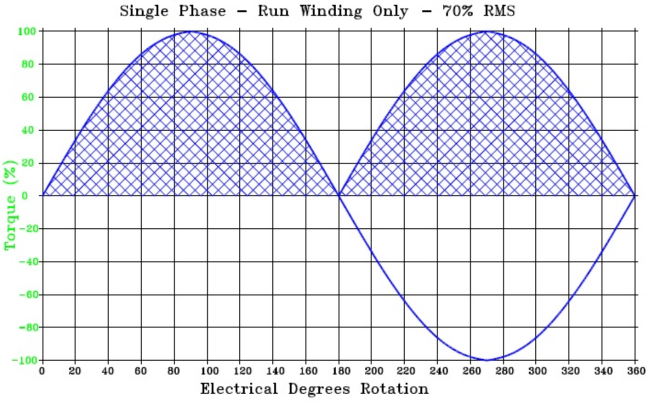
Similarly you can keep on autotuning with increasing values – when you start to see a disproportionate upward increase in current and heat (or the Autotune errors out), then you have reached saturation. Dial back about 5% for safety margin.

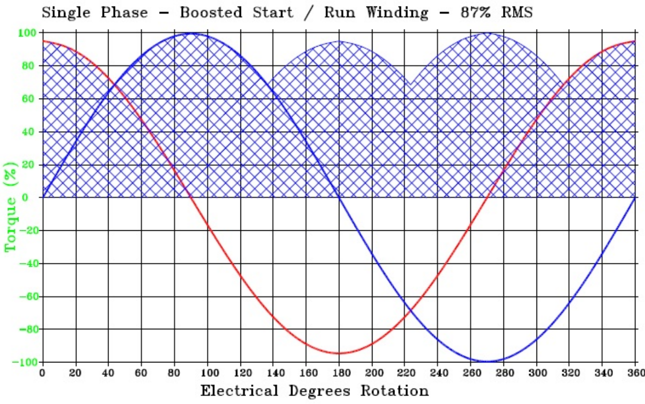
Just to make sure you got what you intended.

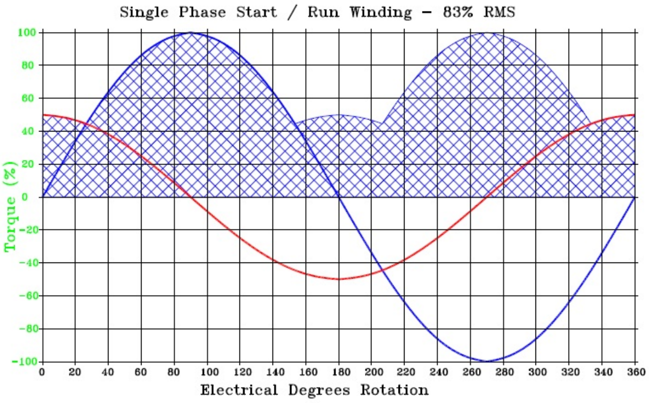
Single Phase vs 3 Phase Motors.

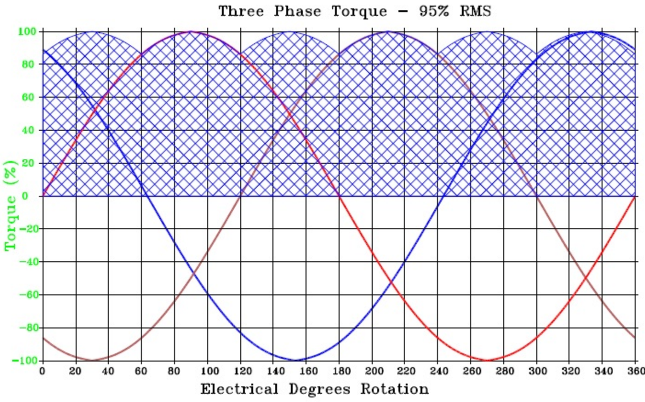
Firstly – a single phase motor is a non-self starting push-pull system which does not generate equal torque over a 360° (electrical cycle) – to get it to start, requires the addition of a “start” winding via a capacitor which shifts the electrical phase angle of the start winding by 90° so we now have two push-pull systems at 90° (or thereabouts) which is much better – starting torque is still poor so in some cases an additional booster capacitor is added for starting and is switched out by a centrifugal switch once up to ±70-80% of rated speed. Note some single phase motors switch out the “start” winding completely – leaving you with a very inefficient push-pull system. (However this can still be built to deliver the required power – but up to twice as “coggy”).

A three phase motor generates 3 sets of push-pull motions at 120° to each other and so delivers much smother and consistent torque and is obviously self starting. A three phase motor in fact generates a perfectly rotating magnetic field (long boring explanation omitted).









The top left graph shows the torque delivery from a single phase motor (after starting and switching out the start winding) – which typically is about 70% of what could be achieved if the available torque from the iron components was delivered smoothly all the time. (≈ the shaded area between the curve and zero – adjusted for the RMS figure quoted in the header.)

The top right shows a single phase – during startup - with the start winding (red curve) boosted by a larger capacitor to improve the starting torque. Typically for this type of motor the windings are often the same for start and run (they don't have to be – the start winding is more commonly a "lighter wind").
During starting, the additional capacitor raises the "start" bumps in the graph from 50% to 95% (again, anything is possible).

The bottom left shows a single phase with the start winding (red curve) permanently running – typically the start capacitor matches the impedance of the windings thus delivering a field approximately half as powerful but shifted by 90° by the capacitor to induce a rotation to the field.

Many single phase motors are run this way without a centrifugal switch cut out for the start boost capacitor (or the entire start circuit).

Some very old single phase motors use only induction – by using a "shaded pole" – this is a start winding shorted out by the centrifugal start switch – which induces an out of phase current in the start winding to get the motor turning – this is normally switched off after starting. I haven't seen one of these in over 30 years except on small low powered fan motors and such but for some curious reason, Chinese manufacturers appear to be making large shaded pole motors.

For illustrative purposes, I have drawn the graphics “idealized” in practice these waveforms would have all sorts of “noise” in them.
I have also chosen to have the start winding at 50% power and shifted by 90° - it’s always somewhat less than 90° in practice and it doesn’t have to be 50% - the manufacture can do an uneven wind and capacitor match-up that will equal the run winding – makes it more expensive and I have seen it done which can get you to about 90% delivered torque.
However these days it is more common to see what I have described above or the start winding is more usually the “lighter” winding in the case of capacitor run (without a centrifugal switch cut out).

So a “capacitor run” single phase motor gives an improvement from 70% to 83% torque delivery, a ≈18% improvement which is also smoother with less noise (Hum) over a single phase run only wind.

The lower right diagram of a three phase motor shows that the torque delivery averages about 95% of the available.

Thus a three phase motor can deliver ±15% (depending on the original single phase configuration) and up to 36% more torque than a single phase run only wind – from the same frame size / ironmongery. Whilst simultaneously being smoother (less “coggy”) and with less noise (Hum).

So simply rewinding the motor to three phase will produce a significant improvement in torque and power – as much as 36% but more likely 15%.

Manufacturing Issues For High Efficiency Motors.

Finally – motor manufacturers are now required to classify the efficiency of their machines according to specifications still being formulated / evolving :-

Class 1 = High Efficiency
Class 2 = Medium Efficiency
Class 3 = Low Efficiency

Since efficiency is mostly a function of heat lost to iron and copper losses it is obvious that you should start with a high efficiency motor as a donor for your project.

i.e. Start with an S1 E1 frame motor from a quality manufacturer and you can’t go wrong !

For a motor manufacturer to improve his motor’s efficiency he would need to :-

1) Control Copper Losses – optimizing the wire cross section to the iron core.
In order to get more copper into the stator, tidy winding (N.C. winding) and thinner / better quality wire lacquer as well as the best conductivity copper – will all lead to lower copper losses.

Note: This may pose some problems for our rewind process as the rewinder may not be as "neat" as an N.C. wind and the commercial thicker lacquer may result in his using thinner wire (relatively speaking) and this will push up the copper losses to more than the original motor.

2) Control Iron Losses – here the use of the highest magnetic permeability & electrical resistance iron, thinner laminations and close control of the surface treatment used to isolate the laminations from each other is required. This poses no problem for our rewind process – only benefits.

3) Control Mechanical losses – typically this would be losses to the fan and airflow which if cut to the bone might also pose problems for our rewind process.
External thermostatically switched fans are typically only used on large (>20kW) drives – the emphasis on efficiency may well see this being applied to smaller motors in future.

Clearly the manufacturer has to optimize all three of the above in an economical fashion (hence design changes over time with changes in consumer demands, technology, economics, commodity prices and politics).

As mentioned earlier with direct on line (DOL) starting, the starting torque is slip x running torque – from this it follows that the better your slip (desirable from an efficiency point of view) the worse your DOL starting torque is going to be.
Once again the laws of physics are not always on your side.

The reverse of this is that increased slip will improve your starting torque. This is accomplished via more resistive squirrel cage material / reduced cage bar cross sections and larger air gaps and is typical on DOL water pump and compressor applications where slip of up to 10% is not uncommon.

Look for a low slip value in your donor motor.

As an aside, politics will be a design factor in order to score points or incentives for improved efficiency in order to tackle the Climate Change phantasm. This might lead to a motor manufacturer using copper conductor bars or larger cross section Aluminium to reduce slip – this will reduce starting torque and we may well in the future see replacement "efficient" motors failing to start under loads its "inefficient" predecessors handled with ease.
I rather suspect the whole thing will turn into a hoodwinking exercise as manufacturers may be forced to fit higher power "efficient" motors (in order to score brownie points) where lower power "inefficient" motors would have sufficed. So you might well end up paying more for an "efficient" motor which actually uses more power.

This is the usual outcome of politicians dictating that physics, engineering and economics must do their bidding – it simply doesn't work !

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Ken Irwin – 30th September 2020

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