There is a good article in the wonderful Appliance Design magazine about driving motors. It was written by Eric Persson, the Field Applications Director at International Rectifier. The article is great because it was written from the application side and will help you understand the differences between an ac induction motor (ACIM) a permanent magnet dc motor (PMDC) and a permanent magnet ac motor (PMAC). I had always heard that PMAC and PMDC motors are the same, you just drive the DC one by banging the windings on and off while the PMAC you feed a three sine waves that you have to fabricate. Eric points out that the motors are indeed different and notes that if you spin a PMDC you see a trapezoid generated on the windings just like the trapezoids you drive the thing with. If you use a PMAC motor like a generator you would see sine waves coming off the windings. Makes sense to me.

Eric seemed so knowledgeable that I wrote him with a few questions. One was whether an ACIM or a PMAC motor would be better for an electric car. Mary Tolikas from Ansoft said that in theory a PM motor can be more efficient since you don’t have to use power to create the magnetic field. But when I read Eric’s article about field weakening, maybe that is why there are few PMAC motors in the electric vehicle world. Tesla uses an induction motor. Is it fair to say that a PMAC motor with a transmission would be better than an ACIM for efficiency? Then again there are the whole commutation losses– making a sine wave is way more lossy than trapezoidal commutation. So I could see PMDC being simple but noisy and cogging. PMAC being great for some applications but when the drive is large enough the switching losses kill you. What are the trade-offs for electric vehicles vis-à-vis motor type? I also noted that Mary said that when she worked at Delphi she was using Ansoft (and that doctorate from MIT) to reduce the noise in a reluctance motor meant for the EV-1. But the EV-1 came out with an induction motor (ACIM). Eric responded:

Thanks for the feedback - I’m glad you enjoyed the article! It is always challenging to take a complex subject and summarize it into a few thousand words with some graphics. I think that is especially true in the world of motors, drives, and control where there are SO many factors and variables to consider - which leads to your questions...

I agree that PM motors are typically more efficient than Induction Motors (IM). This is due to a combination of rotor losses and the "excitation penalty" (the overhead current to produce flux) in an IM. But this generalization is strongly dependent on the size of the motor. As the size increases, the current required to produce a given flux density increases linearly - but the cross section available for copper increases by the square. This means that larger ACIM (such as those used in EV) can add a lot more copper cross-section, and more effectively remove any heat from the stator. Of course this increases the cost of the stator compared to running skinny wire. But then there is the magnet cost of a large PM machine...
So as a general rule, I think that somewhere below about 5kW that it makes sense to use permanent magnets for excitation. Permanent magnet motors will have higher efficiency and more torque per amp. Above approximately 5 kW, magnet costs begin to dominate, and the ACIM becomes much more attractive from a price/performance standpoint. ACIM is also seen as more rugged by the automotive industry - no worries about accidental degradation or demagnetization due to over-temperature or accidental over-current. And, large PM machines are riskier to assemble due to the enormous axial forces of the permanent magnets. To answer your question directly, I am sure a PMAC would be more energy efficient than an ACIM for an EV application - but it may be economically unfeasible. By the way, DOE did a teardown and complete efficiency analysis on the Toyota hybrid electric motor and transmission. It is publicly available at http://www.osti.gov/bridge/-just do a search for Toyota (lots of cool info here!)

Your friend Mary is also correct about the SR motor. It looked promising on paper as a low-cost, high efficiency synchronous machine (some appliance-makers tried it as well). But the noise, due to magnetostriction and structural stress as the magnetization rapidly commutates, was unacceptable. In addition, SR motors require a very small air gap, and the manufacturing tolerances drove the manufacturing costs up to uncompetitive levels.

Great stuff, and also a great tip about the government website. My pal Otmar Ebenhoech actually has a GM EV-1 motor, apparently some clueless GM dealers would sell them from the parts counter, not realizing GM never wanted anyone to get their hands on one. Otmar tore down his EV-1 motor here. Otmar also had a comment about Eric’s answer:

Shucks, someone who actually knows the subject. I must say that seems rather rare these days. Good on him. I appreciate that.

The one thing he did not mention about PMAC motors and on road EV’s is that the efficiency depends on the peak to average power ratio. A “normal” car these days runs about a 10 X peak to cruise power ratio. The eddy current losses of a BLDC/PMAC (whatever the wankers want to call it today) motor are relative to the peak torque. Stronger magnets and more iron = more losses. A single ratio joke (sorry, “motor”) makes over 1500 W of waste heat at highway cruising speed, and that’s with the power turned off. Not so good for a car that takes about 15kw to cruise. So if you made a 15 kW PMDC and attached it to a 100 KW Induction for acceleration plus peak you would be golden, but that’s complicated and a bit expensive. Years ago some people suggested and even mocked up a light PM machine with extra windings to beef up the field for higher current. It was a green box visiting all the shows in the mid 90’s. Can’t remember the name now but I’m sure they had a patent or some such. A bit large it was, and surely a bit expensive, but efficiency was in the cards.

Then again, who cares about a few percent in efficiency when you can gain a few percent in battery capacity by waiting 3 months? Such is the reality of EV’s these days.

And my pal Dave Ruigh sent a link from good ol’ Circuit Cellar on some folks trying to adapt the Microchip DSP motor control system to an electric vehicle. Like Otmar, I think they would have better luck if they put some bus capacitors on those copper bars.