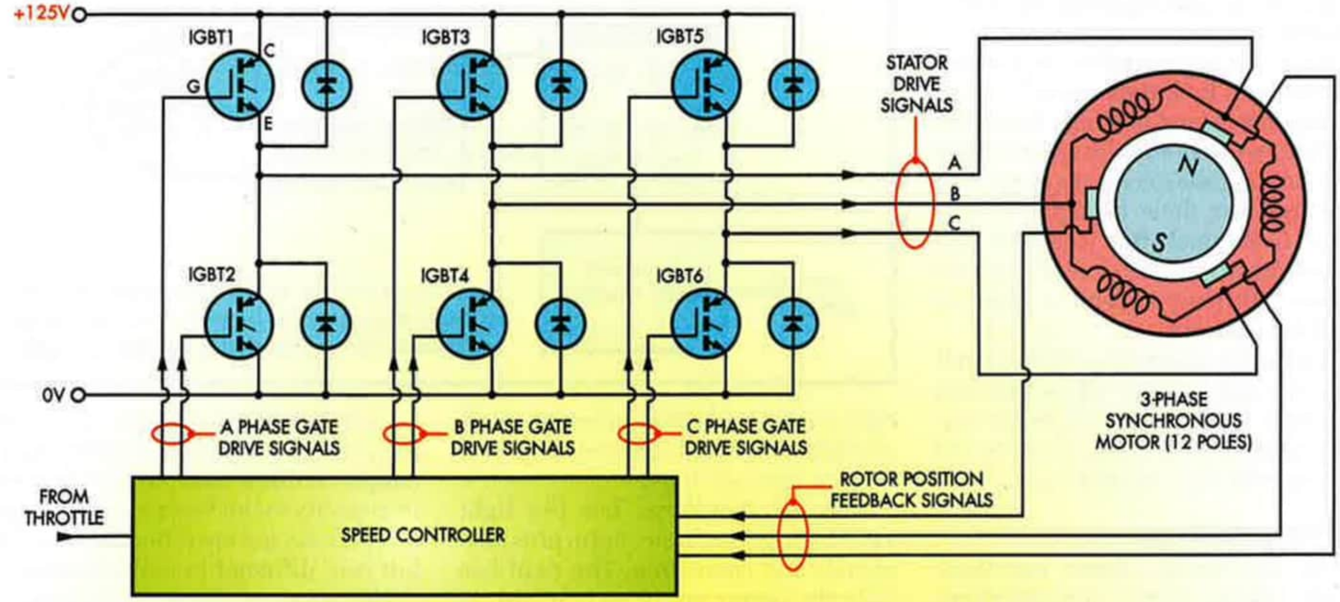
"Brushless DC" motor control – how does it work?



The hub motor used in the Vectrix motorbike is variously described as a "brushless DC" and also as a "12-pole 3-phase" motor which is likely to confuse many readers. In reality, there is no such thing as a brushless DC motor.

All DC motors have brushes and a commutator while brushless DC motors are actually 3-phase motors driven by a 3-phase variable frequency converter.

For power ratings up to about 20kW, as used in the Vectrix, the motor can be regarded as a synchronous motor with permanent magnets providing the rotor field. Larger brushless motors can be regarded as induction motors.

Synchronous motors are always locked to the rotating magnetic field produced by the stator but the rotor may lag the field by a small amount depending on the load.

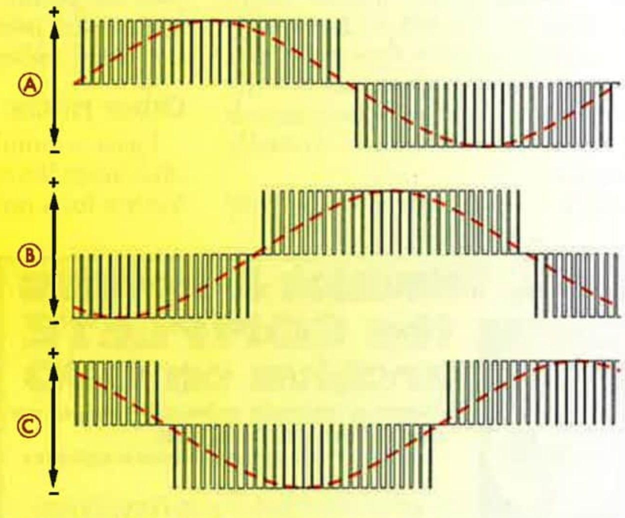
By contrast, induction motors are never locked to the rotating magnetic field and their speed is always less than the synchronous speed. This is measured as "slip" which is typically around 5% at rated load. Such a motor (4-pole) would have a rated speed of 1440 RPM compared to synchronous speed of 1500 RPM.

The circuit above shows the general arrangement of the motor and its controlling electronics. The heart of the circuit uses six Insulated Gate Bipolar Transistors (IGBTs) powered by 125V DC from the NiMH battery pack.

That much we know from the limited information in Vectrix literature. From here on we are speculating on just how it is controlled but the method is typical of brushless DC motors. Nor do we know if the motor is connected in star or delta configuration.

Note that the IGBT symbols shown in the circuit above are not incorrect. They are typically, although not always, shown with arrows for the collector and emitter. Also note that the motor's rotor is shown as having only two poles (N & S) whereas it actually has 12.

The six IGBTs are driven with pulse-width modulation (PWM) signals to provide three sinewave averaged output voltages with 120° phase separation, ie, as for a normal 3-phase motor. The frequency of the outputs is varied between 1Hz and 300Hz, giving a maximum motor speed of 3000 RPM. Furthermore, since the motor's impedance will vary in direct proportion to the frequency,



the amplitude of the drive voltage must be reduced as the frequency is lowered.

Note that the motor is rated at 7kW continuous but as with many (if not most) 3-phase motors, the peak power output is considerably higher at 20kW. The limitation will be due to power dissipation limits in the windings of the stator and power dissipation in the 3-phase converter. Peak currents from the battery pack can be as high as 275A.

The PWM signals to give the variable sinewave outputs to the motor may be up to 25kHz or higher. The motor responds to the average value of the phase outputs (A, B & C) and ignores the pulse width modulation.

For precise speed control, the stator will include three Hall Effect devices to give rotor position measurement. This will allow the speed controller to vary the phase-lead or phase lag of the rotating magnet field (produced by the stator winding) with respect to the magnetic fields produced by the of the rotor's permanent magnets. With phase lead, the motor will provide power to the wheels via the planetary gearbox. With phase lag, the motor will become an alternator to provide regenerative braking. Alternatively, by changing the direction of the rotating magnetic field in the stator, the motor will drive the bike in reverse. (L.D.S.)