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Some ideas regarding operation of PMS-Motors in field-weakening

Theory: With increasing calculation power of microcontrollers together with strategies of field oriented control (FOC), the ideas of operation of PMSM in the range of field-weakening have become popular. In general, the range of field-weakening is entered by injection of negative Id-ref. In physical terminology, a phase shift between the rotating field and the magnets is configured, controlled by FOC. But it is essential, to remember the physical facts: you cannot get more continuous power out of the motor than it is designed for, at nominal speed with nominal torque. All other operation points can only be used for intermediate stages considering the disadvantages and risks.
The mechanical and physical attributes of the motor are the crux of the matter, together with the application requirements and restrictions of the inverter hardware. These difficulties cannot be overcome by any control strategies. Precautions inside the hardware would be required. For theoretical background we recommend the literature:
Control of Electrical Drives, Werner Leonhard, Springer Verlag, ISBN 3-540-41820-2,
Vector Control of Three-Phase AC Machines, N.P. Quang, J.-A. Dittrich, Springer Verlag, ISBN 978-3-540-79028-0.

Motor: Motors with surface mounted magnets only allow very little increase of speed above the voltage limit (about 10% to 20%, or a factor of 1.1 to 1.2). Motors with embedded magnets allow factors of up to 4. Such motors typically have great differences between stator impedances in direct and quadrature axes. Motor manufacturers, sometimes publish these data in their data sheets, but it is not standard.

Inverter: Without any additional protection against over voltages due to back EMF of the motor in trip condition, the maximum operation limits of the inverter have to be considered.
A simple example: the maximum DC-voltage of an inverter is e.g. 400 VDC. The battery voltage is 200 VDC. Keeping the maximum voltage in mind, you can only achieve a factor of 2 for speed increase, even lower when maximum inverter voltage and battery voltage are closer together. With mains supply of 400 VAC (560 VDC), limit voltage of 800 VDC, the allowed factor would only be 1.42.
Also the uncontrolled current flow into the DC-link or battery via free-running diodes, when back EMF is larger than the DC-link, will cause substantial problems. In particular the high inertia in traction applications is causing high energies levels, which are difficult to handle.

Application: Traction applications always have a base load. It is not possible to accelerate without load, as in typical spindle applications. The operation in field-weakening range with additional Id-current causes additional heat losses in the motor and drains additional current from the battery.
For short operation times and little factors of speed increase, it can make sense to apply such control strategies, but you still cannot solve any mismatch between the motor voltage and the supply voltage in this way.
Typical applications which do not have to care about above restrictions, are racing teams in the contest covering one mile in minimum time, or military vehicles escaping from battlefield with maximum speed.

An application with reduced supply voltage from a battery back-up instead of the mains supply is a really useful area of operation, for reaching nearly the same speed using a lower supply for a short time.

Control: Implementation of field-weakening is done by a so called voltage controller.
See page "Speed" in NDrive PC-program, bottom right corner, and page "Auto".
The output of PI-controller is used as the reference value of the Id-control. When actual output voltage V-out < V-red, output of PI-controller is 0, when V-out > V-red, output is working between Id-nom and Id-min.

Parameters required are:
V-out: actual output voltage representing modulation index, not normalized to Volts,
V-out = sqrt(Vd*Vd + Vq*Vq), number of 4096 is maximum.
V-red: enter point of field-weakening as percentage of Vout, Typical in the range of 80 to 90,
value of 0 or 100 disables voltage controller,
V-kp: proportional kp-factor of voltage controller, typical in the range of 100 to 500.
V-Ti: integral Time of controller, larger value is slower reaction, typical in the range 100 to 1000.
Id-nom: nominal Id-reference , in percent of nominal motor current. 0 for PMSM, 20 to 50 for ACIM.
Id-min: minimum Id-reference, in the range of -20 to – 95 for PMSM, Idnom to 0.1 Idnom for ACIM.
Independent from any current limitations < Idnom , a rest of 5 % current limit is always reserved for Iq- reference to keep motor under control.
Lsd, Lsq: With increasing speed (omega), the decoupling network between Id- and Iq-controller output (Vd and Vq), becomes more important. So you should know the values of Lsd and Lsq.
Value in uH on page "Auto" in NDrive.

In general, the regulation has a tendency towards instability above the nominal operating point. Even accuracy of offset-angle becomes more important.

In practical applications with motors with embedded magnets, we have covered factors of 1.2 to 1.8 with respect to the above mentioned problems.