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A Survey of Traction Permanent Magnet Synchronous Motor

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Abstract

The paper deals with analysis of dynamic behavior of a feedback flux weakening control of PMSM traction drive for light vehicles. The PMSM flux weakening is very important for traction drives. Two torque control structures were analyzed - pure feedback control and feedback control with prediction of the field producing current component. The principles, control structures, simulation and experimental results are given.

Keywords: Permanent magnet synchronous motor, traction drive, torque control, magnetic flux weakening, vector control speed

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I. INTRODUCTION

Usage of permanent magnet synchronous motors (PMSMs) as traction motors is common in electric or hybrid road vehicles. For rail vehicles, PMSMs as traction motors are not widely used yet. Although the traction PMSM can bring many advantages, just a few prototypes of vehicles were built and tested as in [1], [2] and [3]. The next two new prototypes of rail vehicles with traction PMSMs were presented on InnoTrans fair in Berlin 2008 Alstom AGV high speed train and Škoda Transportation low floor tram 15T "ForCity".

Advantages of PMSM are well known. The greatest advantage is low volume of the PMSM in contrast with other types of motors. It makes possible a direct drive of wheels. On the other hand, the traction drive with PMSM has to meet special requirements typical for overhead line fed vehicles. The drives and specially their control should be robust to wide overhead line voltage tolerance (typically from -30 % to +20 %), voltage surges and input filter oscillations. These aspects may cause problems during flux weakening operation.

There are several reasons to use flux weakening operation of a traction drive. The typical reason is constant power operation in wide speed range and reaching nominal power during low speed (commonly 1/3 of maximum

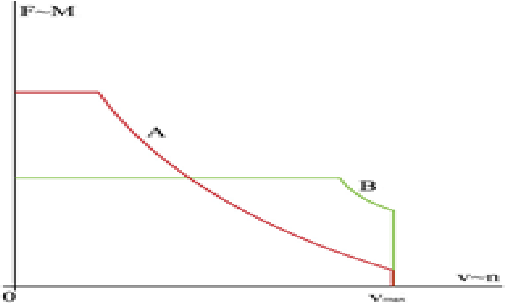

Fig. 1: Traction diagram (tractive force vs. velocity).

A high torque PMSM should be used to meet traction curve A. It leads to higher number of turns in stator windings. This is also disadvantage due to higher winding resistance which implies higher losses.

As it was mentioned earlier, a PMSM traction drive control should be robust. A flux weakening control is especially sensitive to voltage surges and high acceleration of drive (typically during wheel set skid).

II. FLUX WEAKENING OF PMSM

The flux weakening control of a traction drive is desirable. It is common for traction drives with asyn-chronous motors as well as for dc motors. Although it causes other problems, the flux weakening is unavoidable also for PMSM. A point of flux weakening is suppressing of back emf in high speed of drive. When the drive reaches nominal speed, a converter generates maximum voltage magnitude. Without flux weakening, the torque rapidly decreases to zero with increasing speed above the nominal speed and it can be even negative. This state of drive is very unstable and it is responsive to dc bus voltage surges. In fact, the drive is out of control in this state. It can happen also by low dc bus voltage. The flux weakening ensures correct control in the whole speed and voltage range.

The back emf (induced voltage Ui) has effect in quadrature axis q. In the same axis, a voltage drop on in-ductance caused by id has effect, too. If a negative flux component current is set, the back emf will be suppressed by the voltage drop. This state is similar to an overexcited synchronous machine.

The aim of the flux weakening control is the optimal setting of id to reach the highest power and efficiency of a PMSM drive during flux weakening operation. There are many ways to flux weakening control realization. Some interesting solutions are given in papers [4]-[6]. Equations (1) and (2) represent voltage equation for stator windings specified to d, q components (p is the number of pole pairs).

$$\frac{d}{dt} i_d \quad \frac{1}{L_d} u_d \quad \frac{R}{L_d} i_d \quad \frac{L_q}{L_d} \quad i_q , \qquad (1)$$

$$\frac{d}{dt} i_q \quad \frac{1}{L_q} u_q \quad \frac{R}{L_q} i_q \quad \frac{L_d}{L_q} i_q \quad \frac{PM}{L_q} , \qquad (2)$$

$$M_i \quad 1,5\, p\, PM\, i_q \quad L_d \quad L_q \quad i_d\, i_q \quad . \qquad (3)$$

For id, we can derive using (1) and (2), (the R and the derivations are neglected):

$$i_d \quad \frac{U^2 \quad L_q i_q \;{}^2\, PM}{\sqrt{\quad L_d}} \quad . \qquad (4)$$

The (4) is solvable for:

$$U^2 L_q i_q \;{}^2 0 . \qquad (5)$$

We get an important condition by solving (5):

$$U L_q i_q . \qquad (6)$$

In fact, the voltage drop caused by i_q is always lower than phase voltage, but this condition is important for flux weakening control to limit i_q setpoint. This is secondary limit for i_q setpoint. The i_q setpoint is primarily limited by maximum *I*. The PMSM design is important. If a PMSM is designed to meet traction curve *A* requirements, it will be probably necessary to use the secondary limit (due to higher inductance and resistance). In the case of a *B* curve designed PMSM (in Fig. 1), the secondary limit doesn't need to be used.

III. CONTROL ALGORITHMS

We analyzed two flux weakening control algorithms. Both of the controllers worked like front-end controllers for field oriented control (FOC) of PMSM. We used well

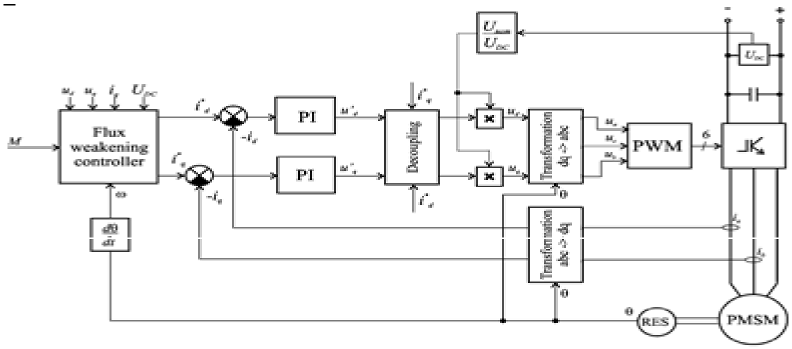

Fig. 2: Field oriented control with front-end flux weakening controller.

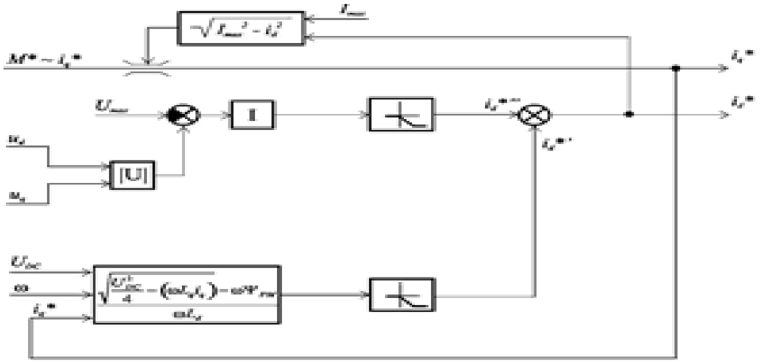

Fig. 3: Flux weakening control enhanced by prediction of id.

Known FOC control structure enhanced by a decoupling block and dc bus voltage correction (Fig. 3).

The decoupling block improves dynamics of the FOC during transient effects. The decoupling is based on induced voltage and voltage drops in both control loops. The voltage correction ensures robustness to dc bus voltage changes.A disadvantage of the algorithm without prediction of id is low dynamics which can make problems during transient effects. Higher dynamics of the control can be reached by higher gain of the integrator but the high gainof the integrator leads to unstable behavior. The philosophy of the second controller is prediction of id and correction of the predicted value by the feedback controller. Therefore sufficient dynamics can be reached with lower gain of the integrator and also the behavior is stable during transient effects. The prediction uses (4).

IV. SIMULATION RESULTS

The Matlab Simulink application was used for simulations. A mathematical model of the drive cor-responds to real drive,

V. EXPERIMENTAL RESULTS

Experiments have been carried out using a special stand with a 58 kW traction PMSM. The stand consists of PMSM, tram wheel and "continuous" rail. The PMSM is a prototype for low floor trams. PMSM parameters: nominal power 58 kW, nominal torque 852 Nm, nominal speed 650 rpm, nominal phase current 122 A and number of poles 44. Model parameters: R = 0.08723 Ω, Ld = Lq = 0.8 mH, Ψ = 0.167 Wb. Surface mounted NdBFe magnets are used in PMSM. Advantage of these magnets is inductance up to 1.2 T, but theirs disadvantage is cor-rosion. The PMSM was designed to meet B curve re-quirements. The stand was loaded by an asynchronous motor. The engine has parameters as follows: nominal power 55 kW, nominal voltage 380 V and nominal speed 589 rpm.

An IGBT inverter was used for feeding of PMSM. For control, a DSP TMS320F2812 by Texas Instruments was used. Maximum operation speed of drive was up to nominal speed of the motor to avoid dangerous overvoltage in dc bus during faults of inverter at speeds higher than nominal. To reach flux weakening operation, the maximum voltage threshold for flux weakening was 75 %. Also the torque rate was limited during the steps for safety reasons. To reach a dc bus voltage change during torque setpoint steps, a front-end resistor of 2 Ω was used.Experimental conditions were: converter switching frequency 5 kHz, nominal dc bus voltage 560 V, dead times 2 μs.For the construction of workplace the high re-quirements of construction had to be taken into con-sideration from viewpoint of EMC according to [7]. The reason is cooperation of the controlling and measuring microprocessor circuit. The power part is a strong source of interference because inverter with PWM generates voltage pulses with hundreds of V/μ s. Satisfactory elimination of all parasitic signals caused by the operation of power electronic converters was reached by compliance to requirements of workplace construction from viewpoint of EMC (particularly shielding of power and signal con-doctors, filtering of network currents, galvanic separation and site layout).

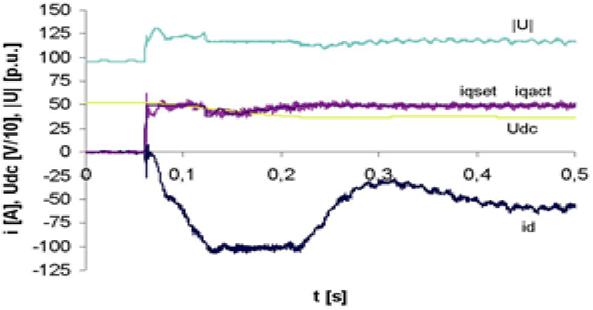

Fig. 4. No-load start of the drive, feedback controller, lower integrator gain (simulation) obvious voltage over-shoot at transition to weakening mode.

VI. CONCLUSION

The main aim of the paper is analysis of dynamic be-havior of the drive using feedback based flux weakening control. Two control structures were tested. The first of them was a pure feedback control and the second one was feedback control with added prediction of the id. The tests were performed on the mathematical model and also on a real PMSM drive.

This work can be used as one part of background for analysis of traction drive with PMSM influence on the supply network. Drive influence on the network in various modes (i.e. motor/generator mode, low/high speed, weakening mode, steady state/transient effect) is researched from the viewpoint of EMC. Limitation pos-sibilities of the drive negative effects are researched at the level of models and experiments both from the viewpoint of electric drive parameters choice (i.e. especially input filter) and from the viewpoint of semiconductor converter control strategy (i.e. switching frequency, dead time, PWM algorithm, feedback control) as well.

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REFERENCES

[1] TAKAO, K., URUGA, K. Gauge change EMU train outline. Railway Technical Research Institute Report, 2003, vol. 44, no. 3, p. 103-108.
[2] YOSHIDA, K. Development of main circuit system using direct drive motor (DDM). JR East Technical Review, 2002, no. 1, p. 46-52.
[3] OSAVA, M. Toward creation of a railway car meeting the 21st-century requirements. JR East Technical Review, 2002, no. 1, p. 9-12.
[4] ŠIMÁNEK, J., NOVÁK, J., ČERNÝ, O., DOLEČEK, R. FOC and flux weakening for traction drive with permanent magnet synchronous motor. In IEEE International Symposium on Indus-trial Electronics. Cambridge (United Kingdom), 2008, p. 753 - 758.
[5] MIHAILOVIC, Z. Modeling and Control Design of VSI-Fed PMSM Drive Systems with Active Load. M. S. Thesis. Virginia (USA): Virginia Polytechnic Institute and State University, 1999.
[6] LETTL, J. Matrix converter hybrid drive system. WSEAS Transactions on Power Systems, 2006, vol. 1, no. 7, p. 1217-1222.
[7] NOVÁK, J., ŠIMÁNEK, J., ČERNÝ, O., DOLEČEK, R. EMC of frequency control electric drives. Radioengineering, 2008, vol. 17, no. 4, p. 101-105.