VECTOR CONTROL OF LOW-VOLTAGE INDUCTION MACHINE

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ABSTRACT

This paper deals with creation of an exact model of low-voltage traction drive which is used in battery stacker fed from batteries with nominal voltage 24 V. This complex model consists of particular models of induction machine, inverter model, load model, battery model and model of vector control. The model of induction machine is a standard model with considering magnetic circuit saturation. The inverter model includes impact of output voltage distortion by dead times, on-state voltage drops on switching elements and DC-link voltage ripple. All the simulations were done in MATLAB-SIMULINK.

1 INTRODUCTION

One of the main problems in independent traction is high ratio of weight and capacity of accumulator. For that reason it is important to research losses in the individual parts of the independent traction drive (fig. 1: battery – inverter – motor – gear – wheel). Decreasing these losses and thereby increasing efficiency is important for usable qualities of the vehicle.

Fig. 1: *Components of the electrical vehicle*

There is used an induction machine with nominal voltage 14 V which is fed from the accumulator with nominal voltage 24 V in the simulated vehicle. In order for the motor to reach the same torque and power using this voltage as compared to supplying it from the mains, the phase currents have to be much stronger. These currents cause voltage drops on inner resistance of the accumulator and on switching elements of the inverter. These effects have significant influence on features of the whole low-voltage drive.

2 MODEL OF THE INDUCTION MACHINE AND LOAD

The mathematical model of low-voltage induction machine is assembled from voltage equations of the machine in general reference frame [1]. To these equations the equations of linkage fluxes have to be added. To include impact of temperature on motor resistances, constant resistances were replaced by variables depending on temperature. Considering saturation of main magnetic circuit is done by replacing constant value of main inductance L_h by approximated curve dψ/di according to figure 2b. Based on knowledge of instantaneous magnetizing current is taken off instantaneous main inductance.

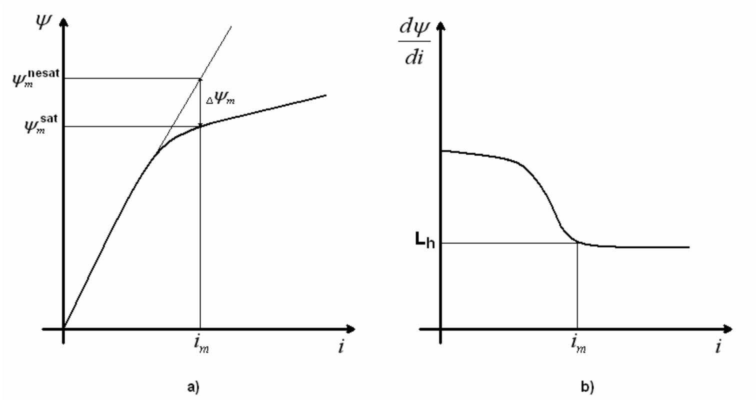

Fig. 2: *Magnetizing curve (a) and its derivation by magnetizing current (b)*

There are considered force by inclination on slant plane, wheels rolling resistance, air resistance, gearbox losses, moments of inertia of gear, motor and wheels in the model of the load.

3 MODEL OF THE INVERTER

Special attention by creating model of the inverter was focused on description of impact of dead time and on-state voltage drops on switching elements which cause distortion of inverter output voltage and affect magnitude of the first harmonic of output voltage especially in low-voltage applications. It can significantly affect machine torque. Two models of inverter were created.

3.1 PULSE MODEL OF THE INVERTER

The scheme of pulse SIMULINK model of the inverter is shown in figure 3.

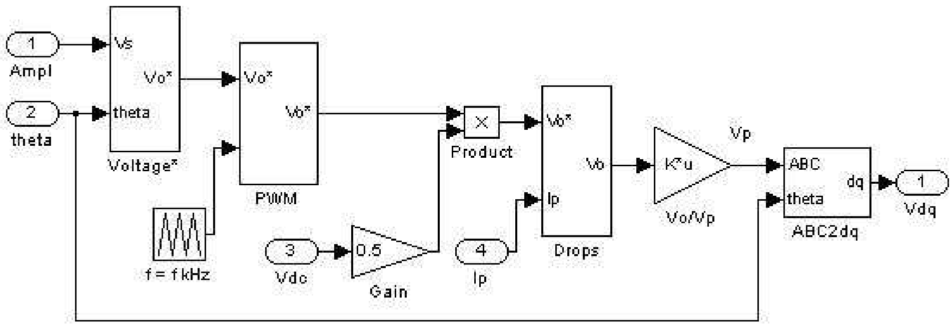

Fig. 3: *Scheme of pulse model of inverter*

From desired value of magnitude and frequency are created three desired pole voltages which are modulated in PWM block and multiplied by instantaneous value of DC voltage and shifted. In “Drops block” are computed distorting voltages from instantaneous phase currents and they are added to output pole voltages. After it these output voltages are converted into phase voltages and transformed in *dq* reference frame.

3.2 DISCRETE MODEL OF THE INVERTER

The scheme of discrete SIMULINK model of inverter is shown in figure 4.

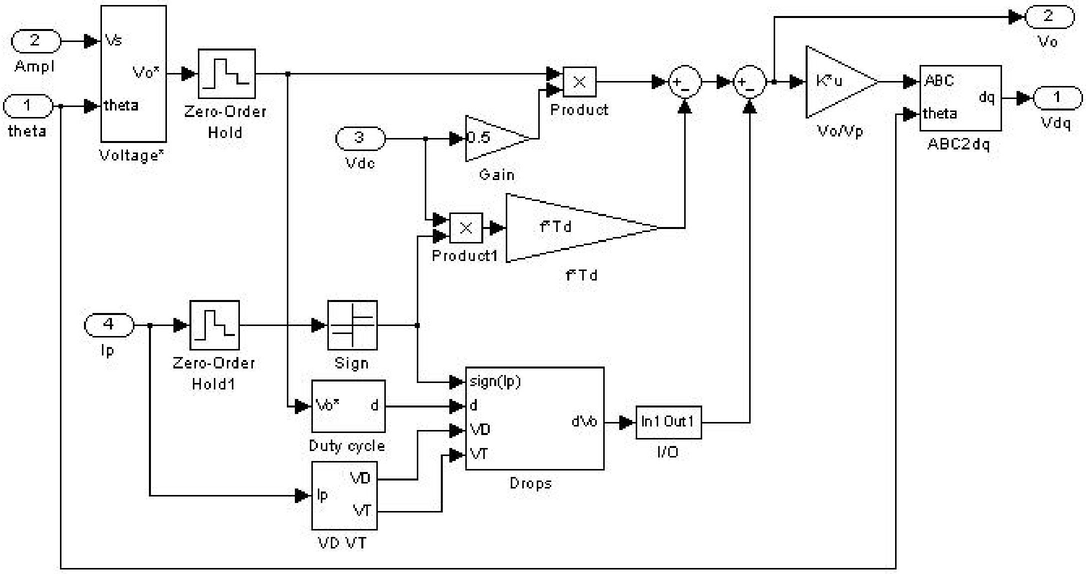

Fig. 4: *Scheme of discrete model of inverter*

From desired value of magnitude and frequency are created three desired pole voltages which are sampled with switching frequency. They are decreased by distorting voltages which simulate on-state voltage drops and dead time effect. After correction of pole voltages by both of these effects phase voltages are computed again and transformed into *dq* reference frame.

4 VECTOR CONTROL MODEL

By connection of previously described particular models we get a model of the whole drive. To complete the model we have to add some control. How it is shown in figure 5 the rotor flux orientation vector control was used. The model of DC-link (Battery) allows computing instantaneous value of DC-link voltage V_{DC}, when we know instantaneous DC-link current. The model allows switch between constant or computed DC-link voltage and also can be switched on or off effect of dead times and on-state voltage drops.

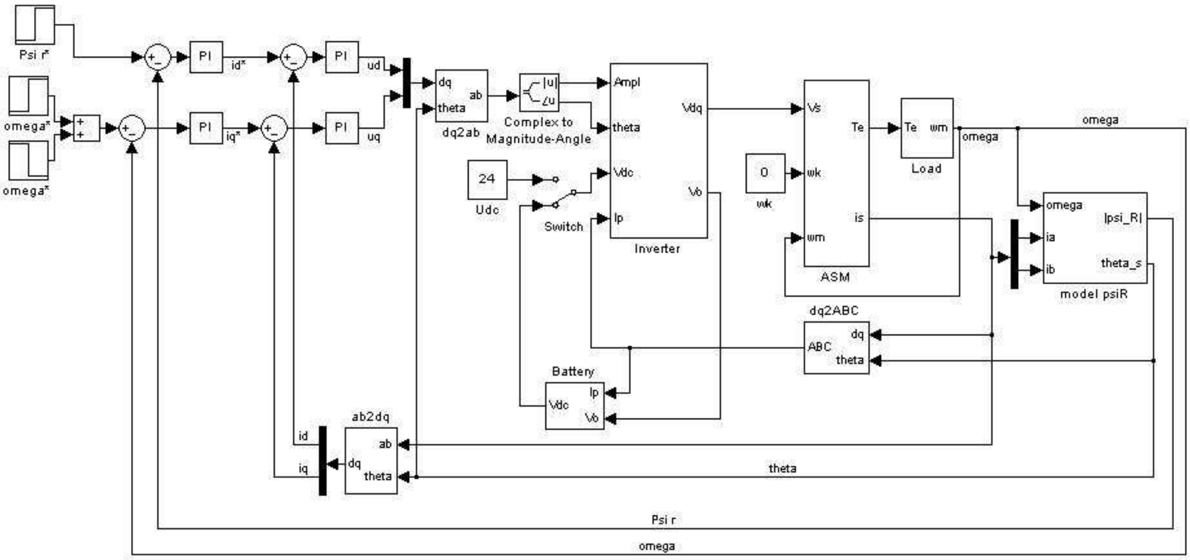

Fig. 5: *The whole drive model*

5 SIMULATION RESULTS

The four-pole induction machine with nominal voltage 14 V and nominal frequency 96 Hz was simulated. System was fed by battery with nominal voltage 24 V with internal resistance 0.005 Ω. Threshold voltage of inverter transistor was 0 V and diode 0.4 V. Dynamical resistances were 7.5 and 6 mΩ. Inverter switching frequency was 4 kHz. Weight of the vehicle was 800 kg and slope of slant plane 3 %.

There is possible to watch distribution of power and losses in the model. Figure 6 shows course of total losses in mechanical part ΔP and input and output power P_1 and P_2 during acceleration. Figure 7 presents particular compounds of losses in mechanical part. It is possible to see instantaneous power consumed in acceleration of rotating mass of inertia (gear ΔP_{jp}, motor ΔP_{jm} and wheels ΔP_{jk}). ΔP_t and ΔP_p are losses by rolling and gear friction resistance and ΔP_v are losses by air resistance. ΔP_s is power consumed in inclination on slant plane.

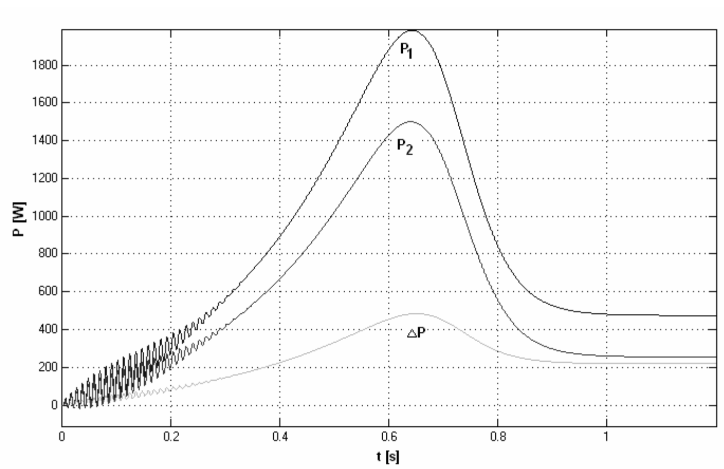

Fig. 6: *Input and output power and total losses course in drive mechanical part during vehicle start (after connecting drive to nominal voltage)*

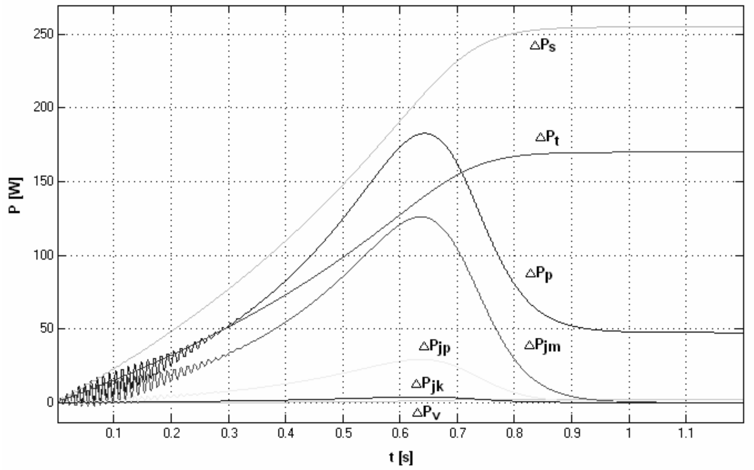

Fig. 7: *Losses distribution in mechanical part of the drive*

6 CONCLUSION

In the article the complex model of low-voltage traction asynchronous drive for baterry stacker is described. Model considers mechnical part (wheels, gear and motor) losses and allows simulation of load for battery stacker dynamic parameters testing upon inclination on slant plane. Electromagnetic model of the motor considers saturation of main magnetic circuit. Inverter model includes impact of dead times and on-state voltage drops on inverter switching elements. Last, model of accumulator is simulated as DC voltage source with internal resistance.

For computing speed increasing was created “discrete model” of inverter which has the same qualitative results for whole drive simulation.

Thanks to this complex model it is possible to observe drive feature during an operation. The knowledge of behavior of the whole system (instantaneous value of DC-link voltage, magnitude of first harmonic of inverter output voltage, course of load torque and inner machine torque) can serve for optimization of inverter control processes and for optimized design of driving system.

ACKNOWLEDGEMENTS

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[1] Neborak, I.: Modelling and simulation of electric regulated drives. (Modelování a simulace elektrických regulovaných pohonů). VSB – Technical University of Ostrava, 2002. 172 pages. ISBN 80-248-0083-7.