SIMULATION OF AN INTEGRATED STARTER-ALTERNATOR SYSTEM FOR NEW-GENERATION AUTOVEHICLES

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Abstract. This paper first discusses the requirements and selection of the electric machine and electronic power converter for an automotive integrated starter/alternator (ISA). Then, the design of a 6 kW interior permanent-magnet synchronous machine (IPMSM) for a direct-drive ISA application is addressed. Finally, the simulation results for the IPMSM in different ISA operating regimes are presented.

1. Introduction

In last years, the automotive electrical load has increased, by replacing of different mechanical equipments with servomotors, by using electrical equipments that improve the internal combustion engine (ICE) performances, in parallel with the comfort and safety (e.g. positioning and regulation systems, navigation and control systems). Today, the average electrical power load on the automotive alternator is between 750 W and 1 kW. It is expected to increase to 4 – 6 kW, in the next decade. Since, the present automotive 12 V system didn't cover this power. It is likely to adopt the 42 V system for the new-generation autovehicles.
The changing of this voltage level will be a good opportunity for substituting the automotive starter and alternator, by a single equipment, the integrated starter-alternator (ISA).
The conventional Lundell (claw-pole) alternator is coupled to ICE, by a transmission belt (typically 3:1 ratio), and the starter, a DC brushed motor, accelerates the ICE to cranking speed, due to a large mechanical gear (typically 10:1) (Figure 1).

2. Automotive direct-drive integrated starter-alternator requirements and selection

The proposed solution is represented by a direct-drive, where the electrical machine of ISA is coaxial with the shaft of the ICE and the transmission (clutch and gear box). (Figure 2)

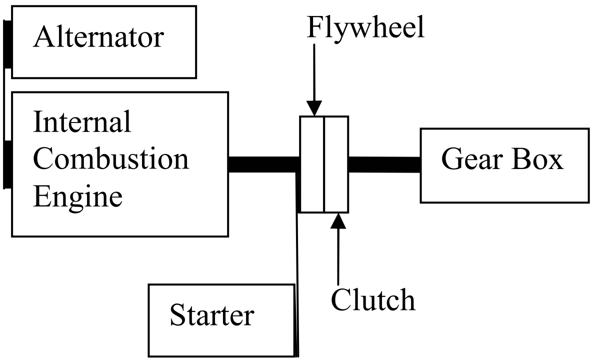


Figure 1 Automotive classical starter and alternator.

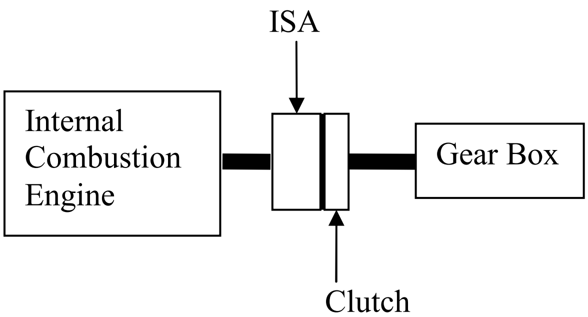


Figure 2 Automotive integrated starter/alternator (ISA).

The integration of the starter and alternator in just one electrical machine will make more efficient the use of electrical equipment, and eliminate the space and weight problems, improving in the same time the performances and reducing the generator and starting noises. Another advantage is that ISA eliminates mechanical elements, such as transmission belt, pulleys and flywheel.
ISA allows at start the operation in motor regime, as a starter, and after that, will work in generator regime, providing electrical energy as an alternator.
In motor regime, the ISA system should reach 500 rpm in maximum 3-5 s, overcoming a load torque of 80 – 150 Nm.
In generator regime, the ISA system transforms the mechanical energy in a.c. electrical energy, which after rectification recharges the automotive battery.

Table 1 summarizes the automotive starter and alternator performance requirements, for both, conventional and integrated system.

Conventional starter and alternator system		Integrated starter-alternator system (ISA)			
ICE	n_{ICE} = 500 - 6.000 rpm	ICE	n_{ICE}= 500 - 6.000 rpm		
Alternator	P = 1.2 kW n_A = 3* N_{ICE} = = 1.500 – 18.000 rpm	ISA	Electrical machine for ISA	Motor regime:	PM = 4 - 6 KW T_{ISA} = = 100 to 300 Nm Time = 3 -5 s n_{ISAm} = n_{ICE} = 500 rpm
Starter	n_{ICE} = 500 rpm n_S = 10 * n_{ICE} = 5000 rpm T_{ICE} = 100 to 300 Nm T_S = T_{ICE} / 10 = = 10 to 30 Nm			Generator regime:	P_G = P_M / 2 n_{ISAg} = n_{ICE} = = 500-6000 rpm
			Electronic power converter	Bi-directional IGBT three-phase bridge Current limitation at 10 – 20 A	
Battery	U = 12 V	Battery	U = 42 V		

Table 1 Automotive starter/alternator performance requirements

The interior permanent-magnet synchronous machine (IPMSM) has been selected to fulfill the above-stated performance requirements for an automotive ISA (Figure 3). The associated electronic power converter is considered of bi-directional AC-DC three-phase bridge type in IGBT technology (Fig. 4). The control of ISA system means the current control by hysteresis regulators, in function of the motor speed error.
The main challenge in the selection of an ISA direct-drive is the fulfillment of performance at the lowest possible system cost.

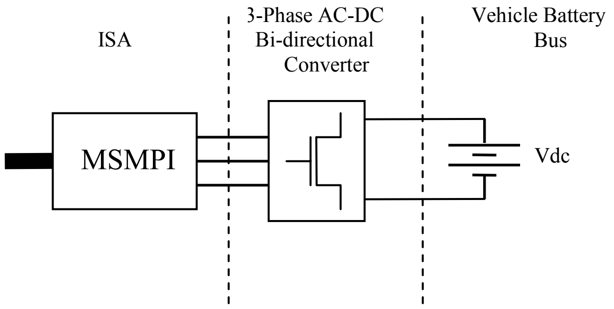


Figure 3 Electrical power systems for new-generation automotive.

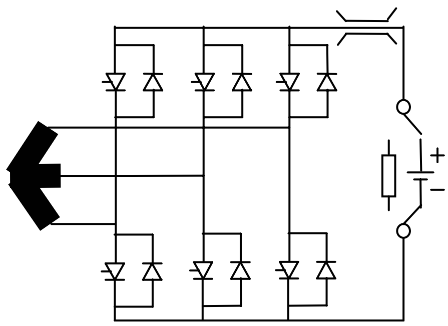


Figure 4 Electronic power converter.

3. Design and simulation of an interior permanent magnet synchronous machine for the automotive direct-drive ISA applications

The main data and parameters of the IPMSM designed for automotive direct-drive ISA are the following:

- Rated voltage: U = 42 V;
- Output power: P = 6 KW;
- Stator phase resistance: Rs = 0,0103 Ω;
- d – axis inductance: L_d = 0,06497 * 10^{-3} H;
- q – axis inductance: L_q = 0,30505 * 10^{-3} H;
- Permanent magnet excitation flux: ψ_{PM} = 0,063 Wb;
- Number of poles pairs: p = 12;
- Moment of inertia: J = 0.07 Nm^2.

The overall block diagram of the IPMSM-based ISA, built in the Matlab-Simulink environment, is given in Figure 5. As details, the modeling of the IPMSM and associated AC-DC converter for the ISA system are shown schematically in Figure, 6 and 7.

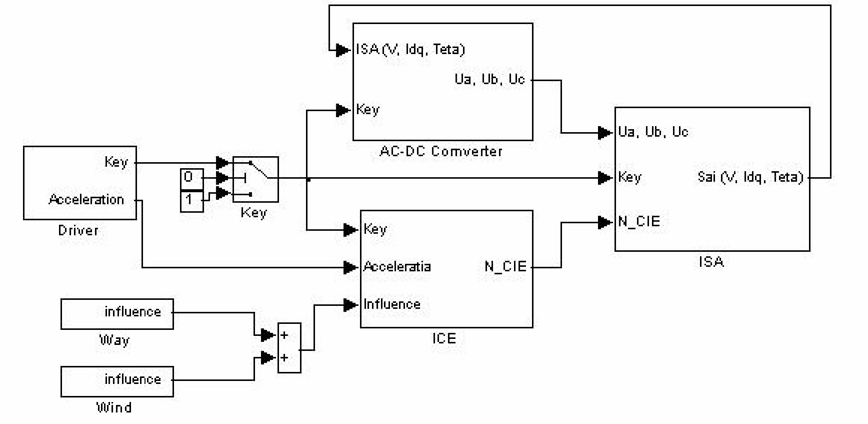


Figure 5 Matlab-Simulink overall diagram for ISA.

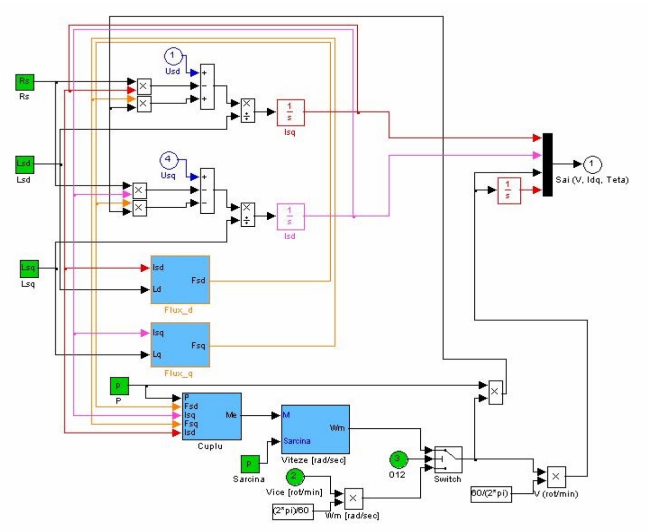


Figure 6 Matlab-Simulink of the AC-DC converter for ISA

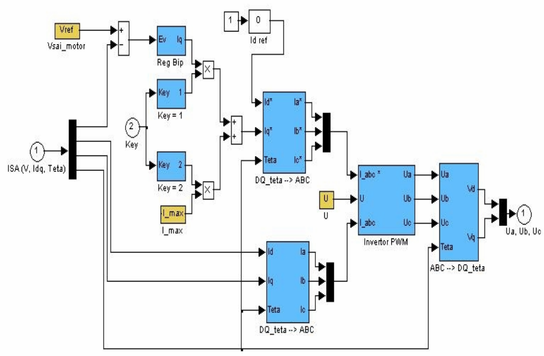


Figure 7 Matlab-Simulink diagram of the IPMSM for ISA

Simulations of IPMSM in ISA application have be conducted for two regimes:
(i) Motor starting from standstill to the reference speed, 500 rpm (Figure 8 and 9).

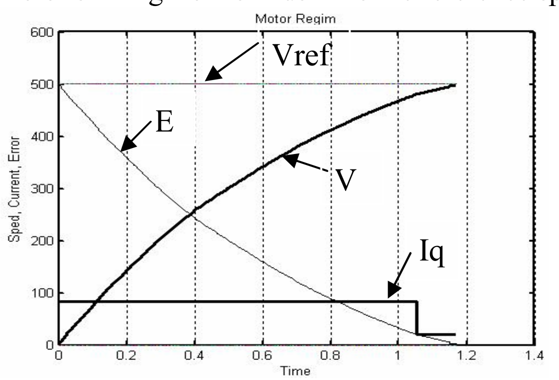


Figure 8 Speed and q-axis stator current at motor starting of IPMSM in ISA.

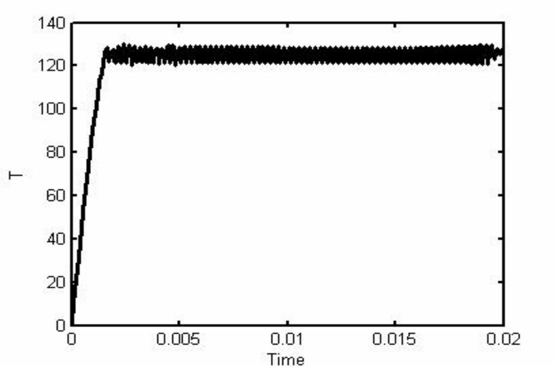


Figure 9 Developed torque at motor starting of IPMSM in ISA.

The q – axis stator current (Iq) is regulated by hysteresis controller, depending on the speed error, and the d – axis stator current (Id) is assumed zero.

Figure 10 shows the three-phase stator current at motor regime of IPMSM in ISA.

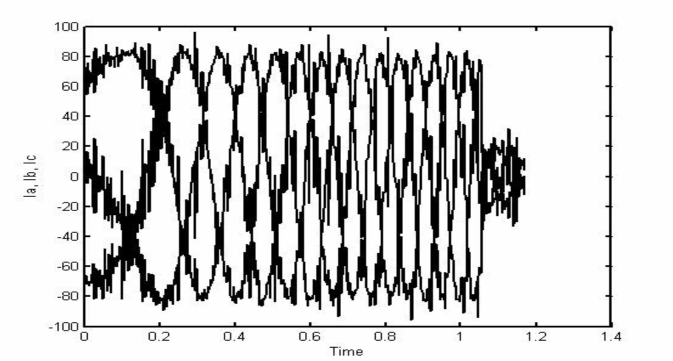
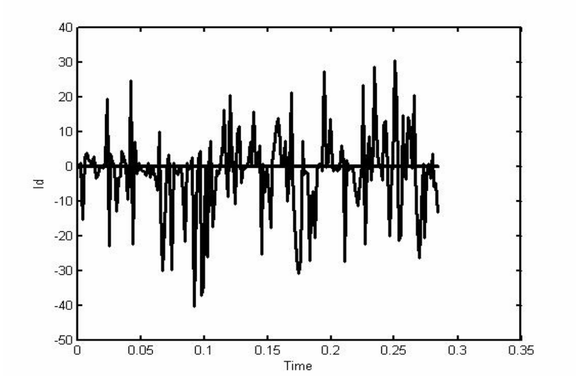
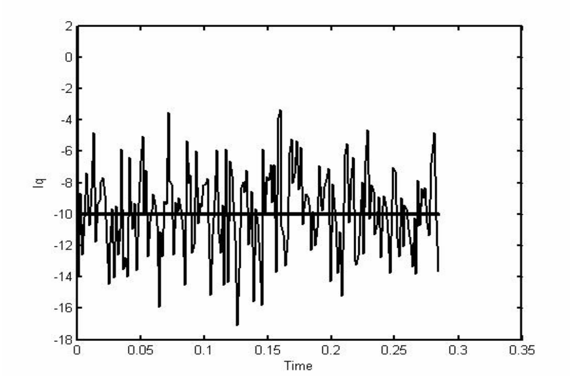


Figure 10 Three-phase stator current at motor starting of IPMSM in ISA.

(ii) Generator regime with battery recharging.

Because the generator speed is much higher then the rated speed (500 rpm), the q – axis current was limited at -10 A during simulations.





(a) (b)

Figure 11 Simulated d – axis (a) and q – axis (b) stator current at the IPMSM generator regime, with battery recharging.

References

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Rezumat. În conformitate cu caietul de sarcini şi condiţiile de exploatare ale starterului, respectiv, alternatorului unui autovehicul, se propune utilizarea maşinii sincrone cu magneţi permanenţi interiori (MSMPI) în realizarea unui starter-alternator integrat pentru autovehicule de nouă generaţie. În regimul de motor (starter) al MSMPI, se propune controlul curentului statoric prin regulatoare bipoziţionale cu histerezis, în funcţie de eroarea de turaţie. În regimul de alternator al MSMPI, curentul de reîncărcare a bateriei de acumulatoare este limitat de constrângerile impuse acesteia.

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