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ScienceDirect

Procedia Engineering 206 (2017) 386–391

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Industrial Engineering, ICIE 2017

Starter-Generator Design and Dynamic Processes Simulation for HEVs

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Abstract

Hybrid vehicle is characterized by the unification of the two functional systems, namely, the generating electricity system in the vehicle's electrical system and the starter system of the internal combustion engine (ICE). The development of power electronics, as well as the growth of power consumed by vehicles, allow us to combine a starter system and power supply in one power unit - the starter-generator. It is the combination of the AC machine (ACM) and the power electronic converter. AC outs of the electronic power converter connected to the ACM stator. DC outs of this converter connected to the battery and (or) capacitive energy storage (CES). The ACM starts the ICE in the motor mode. In electric vehicles, the starter-generator allows recuperating electric energy and acts as a part of braking system. The article is devoted to the design of the induction starter-generator for the Russian automobile "LADA". The result of dynamic processes simulation is given.

Peer-review under responsibility of the scientific committee of the International Conference on Industrial Engineering

Keywords: hybrid electric vehicle; induction machine; power electronic converter; dynamics; stator windings.

1. Introduction

Starter-generator is used as a part of the combined power-unit (CPU) in hybrid and electric vehicles (HEV). In motor mode, starter-generator operates as a starter for internal combustion engine, and during the vehicle movement – in generator mode. Its operation in vehicle drive system allows to decrease exhausts [1-3]. Induction machine with concentrated stator windings [4,5] and intelligent stator [6,7] for CPU with reduced material intensity was designed. Multi-phase electronic converter for HEVs and autonomous power systems was proposed [8-10]. Similar electric

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1877-7058
Peer-review under responsibility of the scientific committee of the International Conference on Industrial Engineering.
10.1016/j.proeng.2017.10.490

machines can be implemented in renewable energy [11]: micro hydro power stations and wind turbines, for example.

In vehicle application, starter-generator allows to refuse a number of the devices, installed on a common vehicle engine (a flywheel and starter drive mechanism) [12], and to expand the functionality of vehicle chassis. For example, electric machine as a part of brake system assists vehicle stopping and recuperate electric energy [13], together with CES serve as a damper during the engine operating, assists silent shutting off and on the engine [14]. In some cases, starter-generator can operate as traction motor for the vehicle. The results of starter-generator design and start/stop processes analysis are shown below.

2. Construction features and calculation of the electric machine

2.1. Substantiation of electric machine choice

As the electric machines of starter-generators, DC machines, synchronous with permanent magnets (SMPM) and three-phase induction squirrel-cage machines (SCIM) for CPU are used.

DC commutator machines are generally used in traction systems due to the simplicity of rotor speed regulation. AC machines need frequency converter for this aim. Nowadays SMPM and SCIM are among the main types for CPU application [10,15].

Significant advantage of the synchronous machine is in direct current excitation and its power factor $cos\varphi = 1$, consuming no reactive power from the line; in case of undervoltage synchronous machine has acceptable overload capacity; and its efficiency is higher than in induction machine due to stray load steel and rotor losses reduced in big air gap [10]. However, the synchronous machines construction is more complex than SCIM, start process and speed control are more difficult, and synchronous machine needs exciter for field winding and permanent magnets, that leads to improved costs of the machine. These are the reasons for taking into consideration squirrel-cage induction machine.

SCIM is structurally simpler and more reliable, than DC and synchronous machines, simple manufacturing defines low costs of SCIM. High efficiency and possibility of current and torque control are also among SCIM advantages and structure makes it possible to reduce weight and size characteristics [4-7,16,17]. These are the reasons for taking into consideration squirrel-cage induction machine.

2.2. Design of the electric machine

For russian automobiles “LADA” coaxial placement of the starter-generator and the crankshaft of the internal combustion engine is preferable (Fig.1a). Researched CPU has clutch gear between the electric machine and gearbox [18]. This improves the reliability of the mechanical part of a hybrid vehicle.

Fig.1b shows 3D-model of the starter-generator stator core. External diameter is *390 mm*, and internal diameter – *345 mm.*

The machine has 12 pole-pairs, due to the design feature of the stator winding. Designed SCIM has an increased diameter and reduced length of the stator magnetic circuit.

2.3. Choice of pole-pairs number

Already known method of starter-generator design includes serial electric machine magnetic circuit and innovative winding [19]. They allow to reduce overhang deviation, dimensions and weight of electric machine to make possible its application in CPU.

One of the CPU edition is a machine with two-layer core wave stator winding with number of slots per pole and phase $q = 1$ and two conductors in a slot.

Turn voltage for the known core length and magnetic induction: