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Design considerations of a multitasked electric machine for automotive applications

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ABSTRACT

This paper introduces a new electric machine for Front-End Accessory Drive (FEAD) of Hybrid Electric Vehicles (HEVs). The novelty of the electric machine lies in its ability to perform multitasking. Besides the independent motor or independent generator operation like any other electric machine, the proposed machine is able to run as motor and generator simultaneously. A dual winding electric machine forms the core part of the proposed system. Windings of the electric machine are concentrated type so that electrical and magnetic isolation is maintained. This allows simultaneous motoring and generating operation in the single housing of electric machine. Design considerations of the proposed electric machine have been outlined in the paper. Comparison between proposed and conventional approaches has been made to highlight potential benefits of the new approach. Thermal analyses have been performed to show the suitability and limits of the multitasked electric machine in the HEV applications. Overall performance of the proposed machine is presented by experimental results.

1. Introduction

Electric machines designed with dual winding sets in their stator have recently become popular due to providing opportunities to solve many industrial problems. For instance, continuous operation of the mechanical and the electrical accessories in HEVs with stop/start functionality can be achieved by using such a dual winding electric machine which has simultaneously motor and generator operation capability [1,2].

The goal of this study is to present design considerations on a decoupled dual winding permanent magnet synchronous machine (DWPMSM) for continuous operation of accessory loads such as air conditioner compressor, power steering pump, water pump and etc. The proposed machine is able to run as motor and generator simultaneously without interaction between these operations. Concentrated winding type is used in the proposed machine to achieve decoupling between winding sets. Since each concentrated coil around any stator tooth has an independent magnetic circuit, magnetic decoupling between winding sets is possible [3–7]. Other advantages are shorter end windings, higher slot fill factor, wider speed range of flux weakening, easier manufacturability and higher efficiency.

On the other side, there are some deficiencies related to concentrated winding like noise, torque ripple, unbalanced magnetic forces due to additional harmonic contents [8–15]. Furthermore, MMF harmonic spectrum of concentrated winding machines contains both super-synchronous and sub-synchronous components. Whereas a balanced distributed winding has only super synchronous harmonic content in its MMF. Sub-synchronous space harmonics would cause higher rotor core and magnet losses because of relatively higher frequency [16–18]. Furthermore, sub-synchronous space harmonics have relatively greater wavelength and this causes deeper penetration of the flux to the core and further increase in losses [17]. So, electric machines with concentrated winding would have higher core and magnet losses at high speed region. In particular, the losses become more significant in high-pole count machines. This drawback of the concentrated winding has been extensively elaborated in the paper.

2. Material and methods of accessories drive systems in HEVs

In hybrid electric vehicle (HEV), nonstop accessory load-driving feature is implemented with drive-by-wire concept as shown in Fig. 1(a). With this concept, each of the accessory loads is powered through its own electric motor and drive system fed by high voltage

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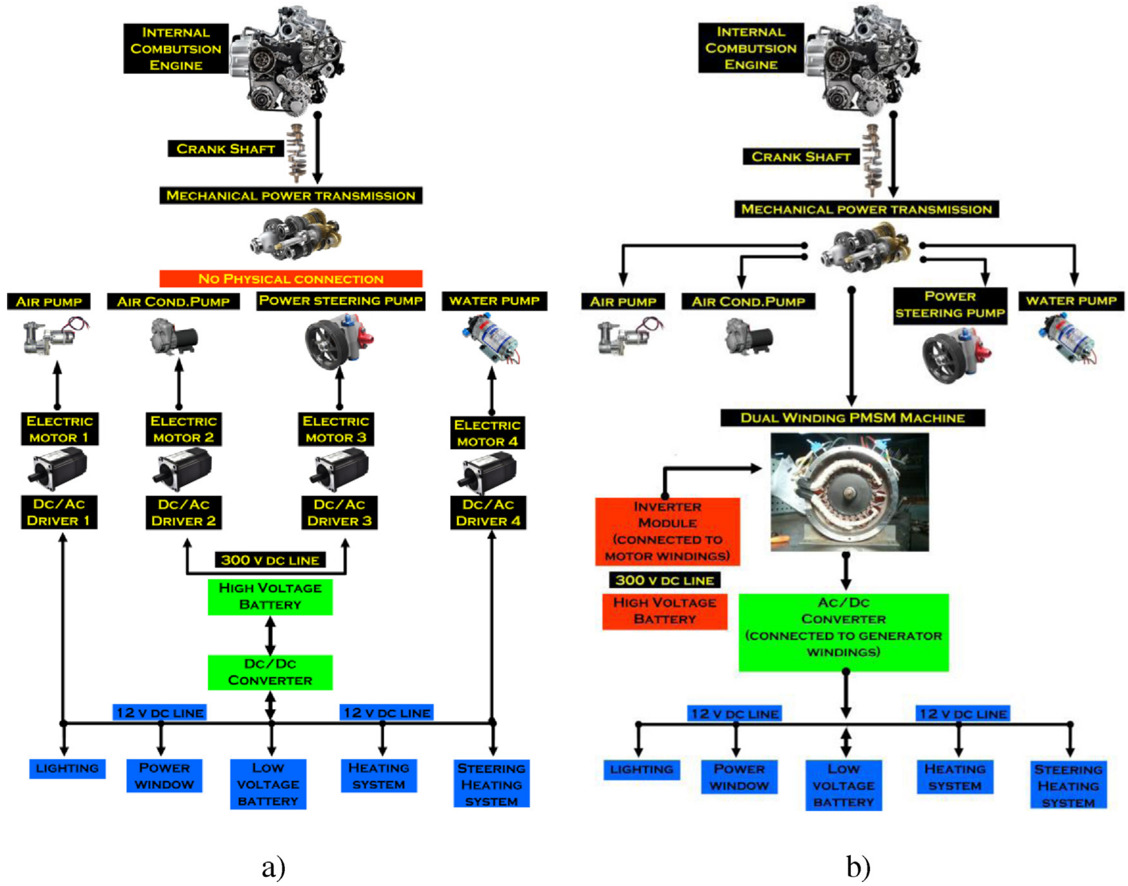

Fig. 1. (a) Drive by wire system, (b) proposed electrical accessory drive system.

battery. Drive by wire is an expensive method since many motors and inverters must be used. Furthermore it is an inefficient method since fractional power motor drive systems tend to be less efficient than high power motor drive systems. In addition, duty cycle of single motor is more likely filled with higher load intervals compared to the distributed multi-motor system.

On the other hand, low voltage (12 V) power is provided through a DC/DC converter as shown in Fig. 1(a). Lundell alternator can also be used for 12 V power. The low efficiency of this alternator, which varies between 45% and 60%, depends on its speed and load level, is the main drawback preventing from the future vehicle applications [19].

Electrical accessory drive system with the proposed machine for driving accessory loads and charging 12 V battery in HEVs is shown in Fig. 1(b). As seen from the figure, the proposed dual winding machine runs as motor and generator simultaneously or just operates as a generator. If the engine is running the dual winding machine operates only as generator. Otherwise, simultaneous motor and generator operation takes place.

With the decoupled dual winding sets, mechanical and electrical power can be generated in a single electric machine instead of two separate machines. By using electrical accessory drive system with the proposed machine several small motors and their drivers in drive by wire system are removed. Furthermore, several inherited components of conventional accessory drives of conventional ICE based vehicles (such as pumps and compressors) can be still used. These facts are considered as cost saving advantages by some automotive manufacturers. Table 1 summarizes components of the conventional and proposed accessory drive system. The high voltage DC/DC converter or Lundell alternator used for charging low voltage battery (12 V) in drive by wire system is eliminated with the generator side of DWPMSM. On the other hand, a DC/DC converter with an uncontrolled rectifier or a controlled rectifier is to be used to regulate output voltage of the generator side of DWPMSM. However, these converter structures are more efficient and cheaper solution compared with the high voltage DC/DC converter due to lower input voltage.

The output power of the DWPMSM is to be determined depending on power requirement for accessories in vehicles as shown in Fig. 2. As can be seen from the figure, DWPMSM should process around 6 kW power at 1500 rpm to drive all accessories. Power flow of the proposed accessory drive system and operation modes are detailed in Fig. 3.

There are two operation modes of DWPMSM depending on mechanical power generation of internal combustion engine (ICE).

Table 1
Part count comparison among different accessory drive systems.

Parts	Conventional non-hybrid	Drive by wire	EADS
Crank pulley	X	X	X
Pulley clutch			X
Belt	X	X	X
Water pump	X	X	X
Alternator	X		X
Air pump	X	Unique	X
Air pump eMotor		X	
Power steering pump	X		X
EPS pump		Unique	
EPS eMotor		X	
AC compressor	X	Unique	X
AC comp. eMotor		X	
Auxiliary power unit (DC/DC converter)		X	
eMotor + Inverter			X