Computers and Electrical Engineering 000 (2017) 1–14

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Modeling and synchronized control of dual parallel brushless direct current motors with single inverter☆

Mohsen Ebadpour*, Mohammad Bagher Bannae Sharifian, Ebrahim Babaei

Faculty of Electrical and Computer Engineering, University of Tabriz, Tabriz, Iran

ARTICLE INFO

Article history:
Received 3 January 2017
Revised 18 August 2017
Accepted 18 August 2017
Available online xxx

Keywords:
Brushless direct current motor
Dual parallel motors
Electric vehicle
Synchronized control
Master motor
Stability

ABSTRACT

Parallel connected electrical machines drive systems have received significant attention due to their use in special purpose applications. Recently, control of such systems using a single inverter has been considered for improving stability during uneven load conditions on machines. In this paper, a synchronized control strategy for stable operation of dual parallel brushless direct current motors using a single three-phase inverter is proposed. Control of parallel connected brushless direct current motors suffers from instability under different load torques. To obtain the stability, an effective control method based on master-slave strategy is presented. To analysis the stability, the detail model of the proposed system is developed for an electric vehicle propulsion system. Therein, the motor with the highest load or with lagging rotor position is selected as the master and is directly controlled. The effectiveness of the proposed system is demonstrated by a series of case studies in different operation conditions.

1. Introduction

Electrical machines are the main devices used for electromechanical energy conversion in existing power systems. Although the conventional single-machine drive systems are dominant, there has been an increasing interest in using multi-machine drive systems in special purpose applications such as textile and paper industry, naval, and vehicular propulsion systems [1–3]. Such systems are commonly finding their role in propulsion system in electric vehicle (EV). Electric vehicles are a powerful solution to environmental and energy problems throughout the world. These vehicles offer major economic and social advantages in power systems including the reduction in fuel consumption, carbon emission, and power grid congestion at the aggregated level [4,5]. The key components in an EV propulsion system are the DC energy source, the inverter, the electric motor, and the gear reduction system. Overall, the EVs improve the efficiency and also severs to reduce the total cost compared with conventional internal combustion engine vehicles [6].

The most necessary requirements of an EV are reduced design effort, lower cost, less depreciation, and optimization of the volume needed by the traction drive system. These necessities have led to developing a new generation of electric traction drives which are called multi-machine drive systems [7]. Optimization of the weight and volume, reliable performance with minimum protection, and low drive cost compared to conventional propulsion systems are the sensible reasons of using the multi-machine systems fed by a single inverter in EVs [8]. In some EVs topologies with the multi-machine

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Guest Editor Dr. S. Rajasekar.

* Corresponding author.
E-mail addresses: m.ebadpour@tabrizu.ac.ir (M. Ebadpour), sharifian@tabrizu.ac.ir (M.B.B. Sharifian), e-babaei@tabrizu.ac.ir (E. Babaei).

http://dx.doi.org/10.1016/j.compeleceng.2017.08.016

propulsion system, electric machines controllers create a central control unit as an electric differential, in addition to control of the vehicle. Therefore, the use of multi-machine propulsion system for EVs could eliminate the need for a mechanical differential system [9]. Most of the recent literature about the multi-machine drive system has been established on the induction machines due to their inherent stability coming from the machine slip [10–13]. The torque control of the parallel connected dual induction motors fed by a three-phase inverter for an EV is presented in [10]. The control method is based on orienting the average stator and rotor current vectors. Therein, in transient situations, differential torque control may be momentarily lost, which leads to severe transient currents and speed fluctuations occur during the load change. Then, this approach degrades system performance during dynamic operations.

An improved V/F control of multi-machine drive system has been proposed in [11] for symmetrical load sharing between mechanically-coupled induction motors. The control scheme is effective; however, the possibility of load sharing among drives under V/F control using measurable parameters like stator currents and voltages is not considered. In [12], dynamic performance of the field oriented controlled dual induction machines with single inverter has been presented. Therein, torque dynamics of the drive system are studied using small-signal analysis. However, small-signal analysis requires significant computational resources and makes it difficult to be realized in inexpensive motors with low-power and low-cost microcontrollers. In [13], a synchronous current control based on model predictive control for a two-motor drive supplied by a five-leg inverter is considered. The independent control of machines is typically achieved using an existing pulse width modulation (PWM) technique in conjunction with field-oriented control. However, presented control schemes along with switching process of five-leg inverter require a powerful microcontroller, which comes at a cost of significant processing time.

As discussed before, an electric motor is one of the key components of the EVs. Desired features of electrical motors used for EVs are high power density, fast torque response, high instant power, low cost, high efficiency over the wide speed, high torque at low speeds for initial acceleration, and gradeability [14]. Brushless direct current (BLDC) motor is one of the most suitable electric motors for EV drives because of the higher power per dimension ratio and efficiency than that of the other motors [15]. Since the BLDC motor is a kind of permanent magnet synchronous machine (PMSM), driving parallel connected synchronous machines by single inverter suffers from the instability due to the absence of the slip. However, some studies are presented about the dual parallel synchronous machine drive system fed by a single inverter despite the instability problem [16–20].

The averaging technique of phase current using vector control for dual parallel PMSM is presented in [16]. This technique allows the phase currents for both motors coupling each other. However, when the different large loads applied to motors, the oscillation in speed becomes higher, which degrades the system performance. The control method based on Mean strategy for parallel permanent magnet brushless motors fed by a single inverter is proposed in [17]. Therein, the control algorithm is based on an auxiliary condition to maximize the torque/current ratio. Although control method has acceptable dynamics in transient operations, there are considerable fluctuations in speed and current in presence of heavy variations of the load torque on motors. In [18], a predictive torque control for mono-inverter dual parallel PMSM drive system is presented. Therein, one cost function for both PMSM is defined to be minimized through the predictive torque control approach. However, in order to build the predictive model of dual parallel PMSMs, it is necessary to use the discrete-time model of the system, which causes solution of the cost function and system operation depend on both machines parameters, and increases system sensitivities. Stability of the multi-PMSM drive system using auxiliary inverter is established in [19], in which the resonance of the multiple PMSM between the moment inertia and synchronous reactance is analyzed. In [20], an improved relative coupling control for the multi-motor speed, synchronous driving system is presented based on an additional speed controller. Although the speed synchronization can be regulated to promote the performance of the system, it is not a good choice for low-cost drive systems.

As shortly reviewed the last literature based on multi-machine drive system, control of two synchronous machines with a single three-phase inverter, especially in the case of different loads must guarantee both the stability and acceptable performance in terms of torque ripple and efficiency. Therefore, in this paper, modeling and stability of the single inverter dual parallel BLDC motor drive system based on master-slave (MS) control strategy are analyzed. The stability of such a system due to the rotor position is specially pointed out. The analysis results verify the electrical relationship between parallel connected motors according to their rotor positions difference. Simulation results using MATLAB/Simulink are established on EV propulsion system to validate system performances. Overall, the contributions are:

- Only one three-phase inverter associated its control system is used for both motors instead of two inverters with two separate control systems.
- Since the position Hall sensors are commonly used for the switching of the inverter, just these sensors are used for choosing the master motor no complementary sensors are needed.
- The stability of the system is always respected due to using the synchronized control.
- The proposed drive system has a simple but effective algorithm to improve the overall performance of parallel BLDC motor operations under uneven road conditions compared to conventional EV drive systems.

The rest of this paper is organized as follows. Section 2 explains the modeling of single and dual parallel BLDC motor drive systems and choosing a master motor method. Section 3 describes the system control method. Then, Section 4 shows simulation results of the proposed drive system. Finally, the paper is concluded in Section 5.

Please cite this article as: M. Ebadpour et al., Modeling and synchronized control of dual parallel brushless direct current motors with single inverter, Computers and Electrical Engineering (2017), http://dx.doi.org/10.1016/j.compeleceng.2017.08.016