

DOBRUCKY Branislav<sup>1</sup>  
 KASSA Jan<sup>2</sup>  
 SPANIK Pavol<sup>3</sup>  
 PRAZENICA Michal<sup>4</sup>

## Possibilities of 2-phase electronic converters for electric vehicle drives

*Keywords: Two-phase system, full- and half bridge 2-phase converter, resonant LLC converter, direct matrix converter, two-phase AC motor, torque-speed characteristic*

### Abstract

The paper deals with power electronic two-phase propulsion system with IM/SMPM motors for electric vehicle drives applications. The proposed system consists of two-stage converter comprises: resonant LLC converter with AC output, two-phase matrix converter commutated by HF AC input voltage, and two-phase induction/synchronous motors. Such a system with AC interlink, in comparison with currently used conventional system configurations features a good efficiency of electronic converters (due to soft switching of both converters) and also good torque-speed characteristics of two-phase AC motors. Results of simulation compared to experimental verification carried-out ones are in good accordance between them.

### MOŻLIWOŚCI DWUFAZOWEGO PRZETWORNIKA MOCY W NAPĘDACH ELEKTRYCZNYCH DLA ZASTOSOWAŃ W TRANSPORCIE

#### Streszczenie

Artykuł dotyczy zastosowania dwufazowego przekształtnika mocy w napędach z silnikiem indukcyjnym lub silnikiem synchronicznym z magnesami trwałymi (z ang. IM/PMSM) dla urządzeń transportowych. System ten składa się z: przetwornika rezonansowego LLC z wyjściem AC, dwufazowego przetwornika matrycowego komutowanego napięciem wejściowym AC o wysokiej częstotliwości i z dwufazowego silnika indukcyjnego/ synchronicznego. Proponowany system cechuje się mniejszą ilością urządzeń półprzewodnikowych, większą sprawnością przetworników mocy oraz dobrą charakterystyką mechaniczną dwufazowych silników prądu zmiennego w porównaniu z konwencjonalnymi systemami. Wyniki z symulacji oraz ich weryfikacja na podstawie wyników z laboratorium przedstawiają dobrym zgodności.

## 1. INTRODUCTION - BASIC PRINCIPLE OF TWO-PHASE MOTOR PROPULSION SYSTEM

### 1.1 Why two-phase propulsion electronic system?

Classical electric drive for electric vehicle with AC motors (e.g. Toyota Prius [1]) is shown in Fig. 1.

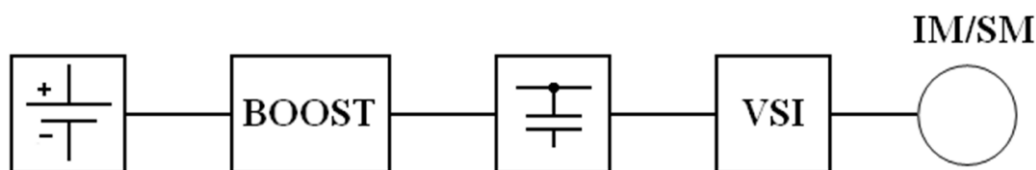


Fig. 1. Block diagram of EV drive with boost converter, DC link, 3-phase VSI inverter and 3-phase AC motor

In spite good properties of that, the 2-phase propulsion system offers also some further advantages. Its basic scheme is depicted in Fig. 2.

<sup>1</sup> University of Zilina, Faculty of Electrical Engineering, 010 26 Zilina, Slovak Republic, dobrucky@fel.uniza.sk

<sup>2</sup> University of Zilina, Faculty of Electrical Engineering, 010 26 Zilina, Slovak Republic, kassa@fel.uniza.sk

<sup>3</sup> University of Zilina, Faculty of Electrical Engineering, 010 26 Zilina, Slovak Republic, spanik@fel.uniza.sk

<sup>4</sup> University of Zilina, Faculty of Electrical Engineering, 010 26 Zilina, Slovak Republic, prazenica@fel.uniza.sk

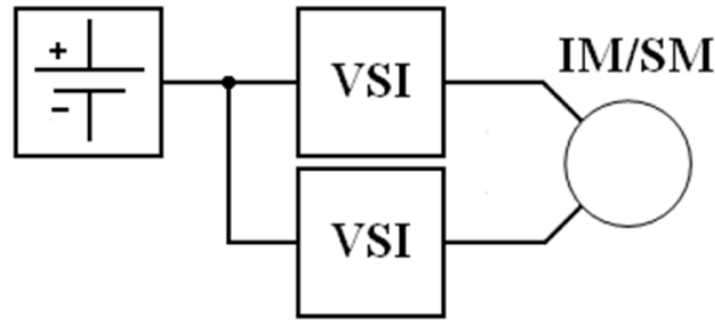


Fig. 2. Block diagram of EV drive with two 1-phase VSI inverter system and 2-phase AC motor

Such a two-phase system denotes by much higher transferred power (2.6-times) and by better utilization of semiconductor switches (~ 2-times), [2], [3]. There is no need a boost converter, since the phase voltage of each of single-phase inverters is exactly 2-times higher that of 3-phase inverter phase voltage. Also, 2-phase induction motor has starting torque 4- times higher than nominal one [4], [5] since 3-phase motor just one. Two singlephase inverters instead of one 3-phase inverter have, of course, drawback of higher number of semiconductor switches (8 instead 6). Therefore, there are in the next text, presented further modification of two-phase inverter system to neglect or to decrease mentioned disadvantage.

## 2. NEW CONCEPTS OF ELECTRONIC CONVERTERS FOR EV DRIVES

One of the new concepts is presented in Fig. 3. It consists of two half-bridge VSI inverters supplied from capacitor divider. The number of semiconductor switches is substantially smaller (4 instead 8) but the capacitor divider should be bulky. Therefore, the next solutions are based on AC high frequency interlink with simply half bridge inverter for supplying of the VF transformer. One such a solution is depicted in further Fig. 4.

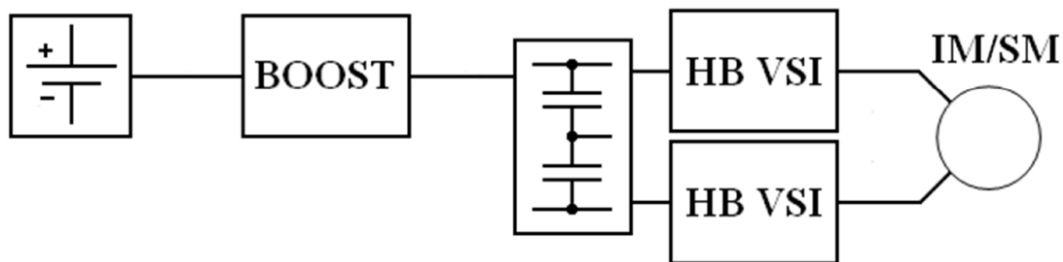


Fig. 3. Block diagram of EV drive with two single-phase half bridge VSI inverters and 2-phase AC motor

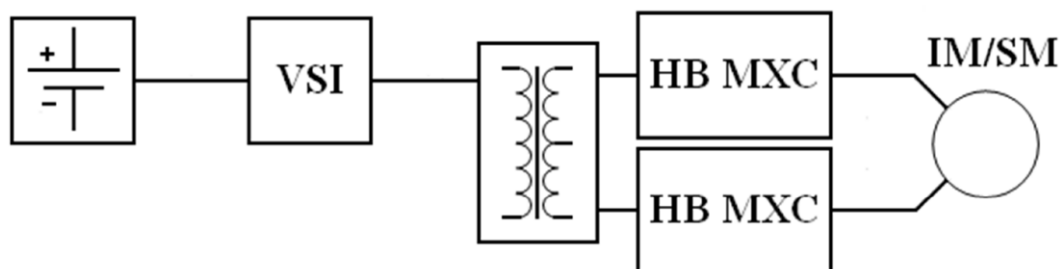


Fig. 4. Block diagram of EV drive with two single-phase half bridge matrix converter and 2-phase AC motor

Propulsion systems with AC HF interlink needs AC/AC- that means matrix converters equipped by bidirectional switches. The reverse blocking IGBT transistors (RB IGBT) can be used as switches connected antiparallel to each other. So, instead of 4 diodes have to be there 4 additional RB IGBT. On the other hand, the commutation of them is naturally, so switching losses of the matrix converters are minimized. Also, HF transformer operated with hundreds kHz frequency, is surely smaller the two bulky capacitors in previous connection (Fig. 3).

To decrease the switching losses to minimum one it is necessary to use the soft switching of input inverter. One of the possibility is using of resonant LLC converter as shown in Fig. 5.

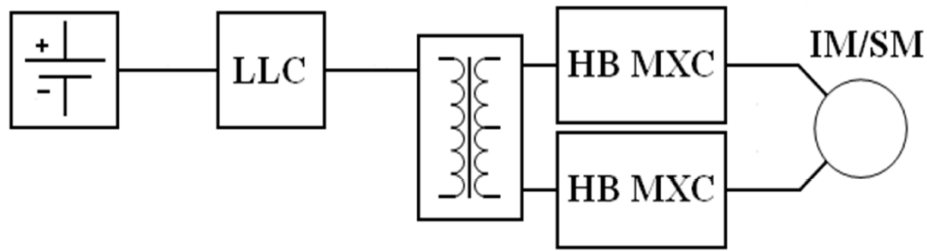


Fig. 5. Block diagram of EV drive with LLC converter, HF transformer, two single-phase half bridge matrix converter and 2-phase AC motor

**2.1 New concept of electronic drive for EV application**

New concept of electronic propulsion system for EV application different to [1], [2] is shown in Fig. 6.

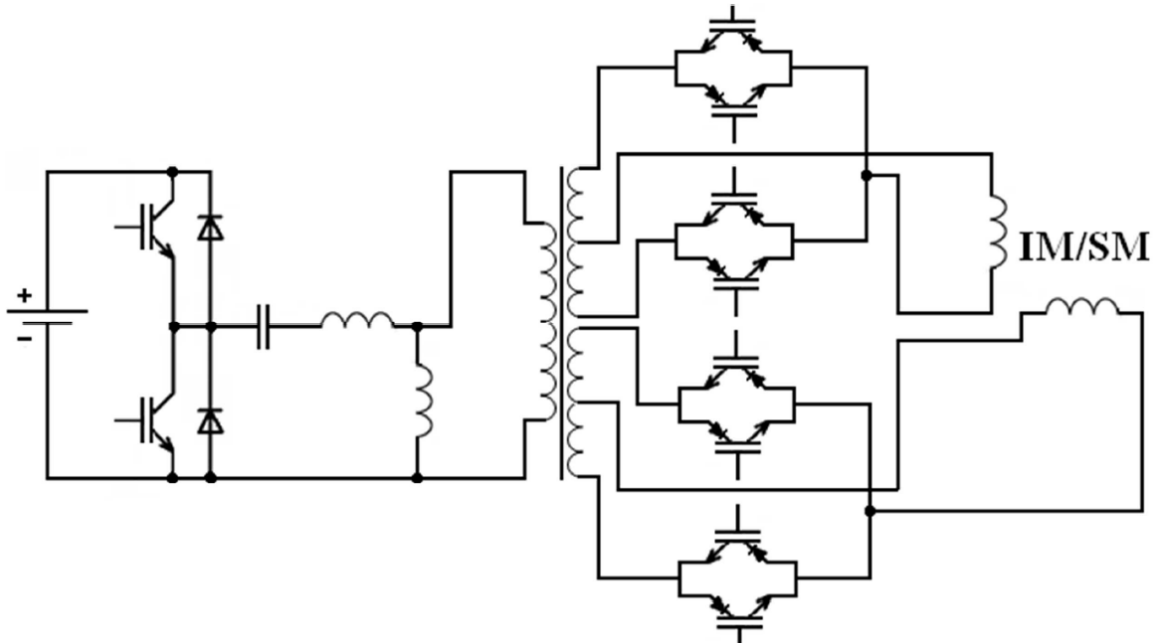


Fig. 6. Circuit diagram of EV drive with LLC converter, HF transformer, two single-phase half bridge matrix converter and 2-phase AC motor

The proposed concept consists of a of resonant LLC converter [6], [7], [9] small coupling HF transformer (~200 kHz), DC or AC link, two single-phase matrix converter in halfbridge connection and 2-phase induction/PM synchronous motor [8]. Contrary to common scheme with 3-phase inverter and 2-phase motor, Fig. 7, the scheme with AC HF link has some advantages in spite of bigger number of the switches.

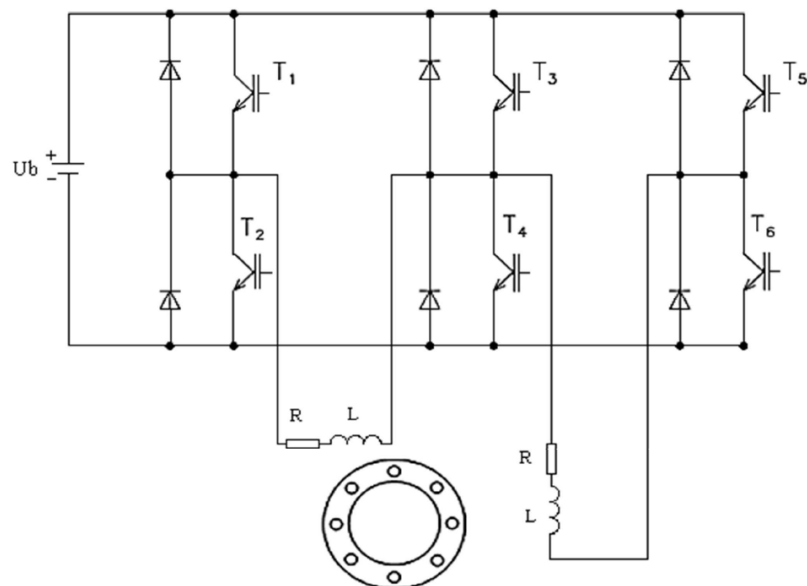


Fig. 7. Circuit diagram of EV drive with direct DC link (without capacitor divider), 3-phase inverter and 2-phase AC motor

AC link version need not smoothing filter (input capacitor); due to soft switching of both converters the configuration features a better efficiency of the converters (depending on switching frequency) and also good torque-speed characteristics of two-phase AC motor. Its output voltage is not restricted.

Drive concept shown in Fig. 7 is lighter but it operates with hard commutation, so its efficiency can be smaller and its output voltage cannot reach the maximum value as belongs to full width of voltage pulses.

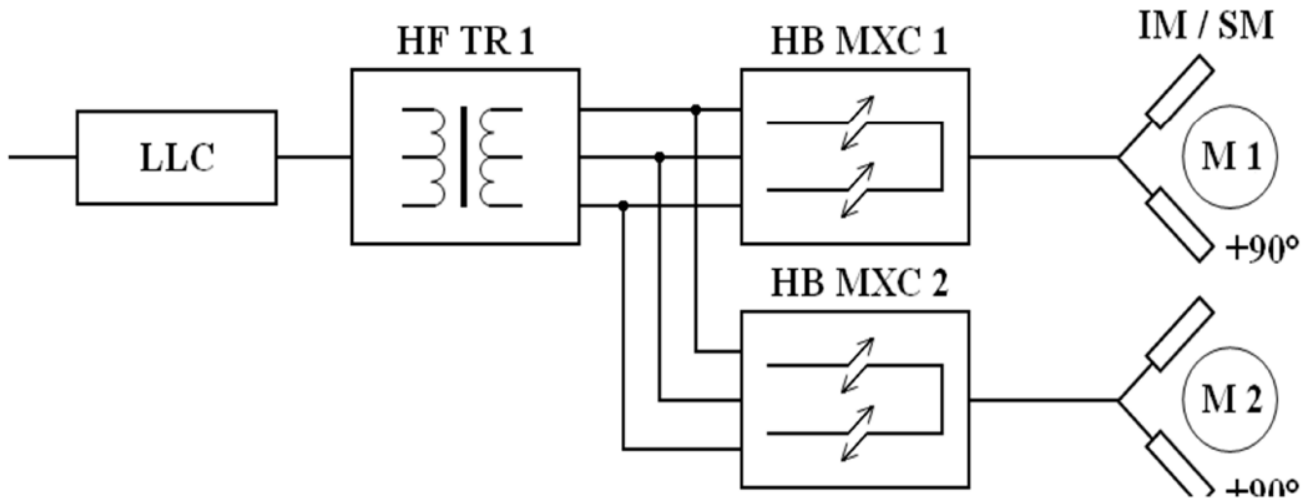


Fig. 8. Concept of propulsion configuration with electronics system given in Fig. 6 and two 2-phase AC wheel motors

Computed mechanical torque-speed characteristics for various value of the motor frequency are depicted in Fig. 9.

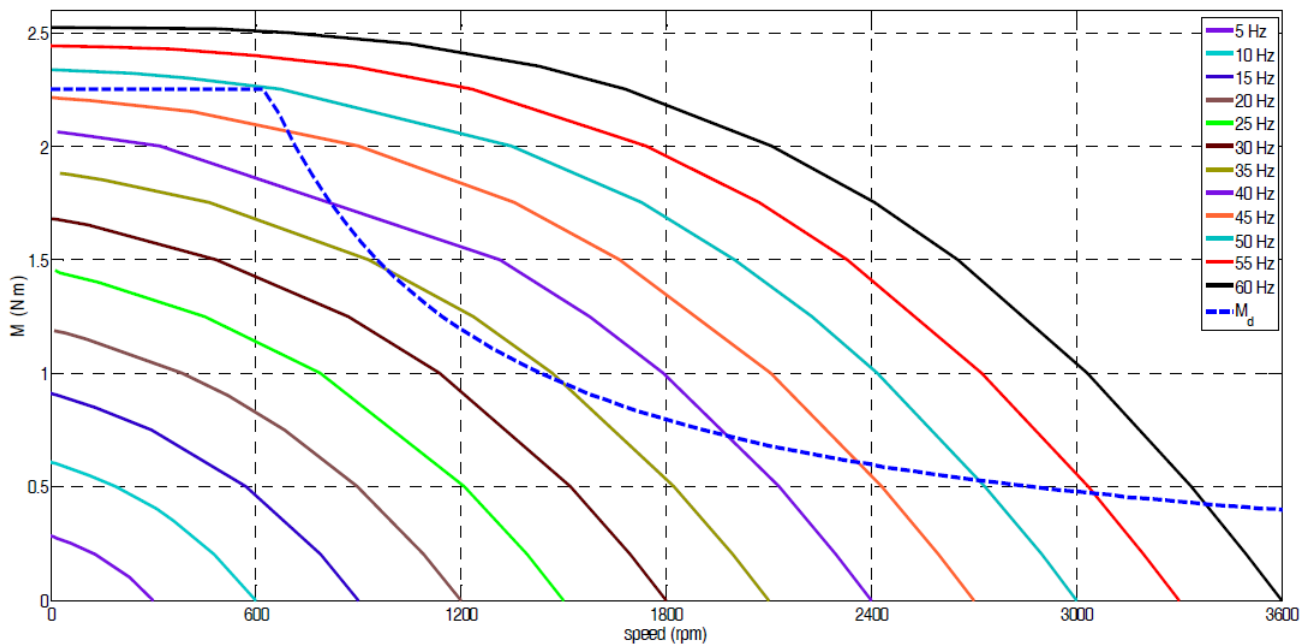


Fig. 9. Torque-speed characteristics for various value of the motor frequency; dashed line – requested traction characteristic

Torque-speed characteristics, verified by experimental measurements have been done and given in [4]-[5] with good accordance between computed and measured waveform lines.

### 3. CONCLUSIONS

As mentioned the AC link version of propulsion electronic system need not smoothing filter (input capacitor); due to soft switching of both converters the configuration features a better efficiency of the converters (depending on switching frequency) and also good torque-speed characteristics of two-phase AC motor. Its output voltage values are not restricted.

Based on configuration in Fig. 6 is possible to design concept of electronic propulsion system for 2 driven wheels. Proposed concept is suitable for synchronous wheel motors. For induction motor propulsion system is more suitable to use one asynchronous traction motor for common drive of both wheels.

## Acknowledgement

The authors wish to thank for the financial support to R&D operational program Centre of excellence of power electronics systems and materials for their components No. OPVaV-2008/2.1/01-SORO, ITMS 26220120003 funded by European regional development fund (ERDF) and VEGA Agency for the project No. 1/0470/09.

## 4. BIBLIOGRAFIA

- [1] Ehsani M., Gao Y., Emadi A.: *Modern Electric, Hybrid- and Fuel Cell Vehicles*. CRC Press, Boca Raton (USA), 2010, ISBN 978-1-4200-5398-2
- [2] Gonthier, L., et al.: *High-Efficiency Soft-Commutated DC/AC/AC Converter for Electric Vehicles*. In: *ElectroMotion* 5 (1998), No. 2, pp. 54 – 64, ISSN 1223-057X.
- [3] Kasa J.: *Connection Choosing of Two/Stage Converter for 2-Phase Drive Application from the Point of View of Efficiency Parameter Increasing*. Research Work, Department Mechatronics and Electronics, Zilina (SK), 2011
- [4] Dobrucky, B., et al.: *Two-Phase Power Electronic Drive with Split - Single- Phase Induction Motor*. In: *Proc. of IECON'10 Conf.*, Phoenix (AZ, USA), Nov. 2010
- [5] Dobrucky, B., Prazenica, M., Benova, M.: *Converter Topology Design for Two-Phase Low-Cost Industrial and Transport Application*. In: *Proc. of TransComp'09 Int'l Conf. on Computer Systems Aided Science, Industry and Transport*, Zakopane (PL), Dec. 2009, pp. 70, ISBN 978-83-7204-857-8.
- [6] Szychta, E.: *Multi-resonant ZVS DC-DC converters* (in Polish). Monograph, Publish Office of the University of Zielona Gora (PL), 2006, ISBN 83-7481-040-08.
- [7] Luft, M., Szychta, E.: *Commutation Processes in Multiresonant ZVS Bridge Converter*. In: *AEEE - Advances in Electrical and Electronic Engineering*, University of Zilina (SK), No 1-2, Vol. 7/2008, pp. 84-91, ISSN 1336-1736.
- [8] Zaskalicky, P., Zaskalicka, M.: *Behaviour of the Two-phase Permanent Magnet Synchronous Motor Supplied by Rectangular Voltage*. In: *Acta Technica CSAV* 50 (2005), 195-206, Prague (CZ).
- [9] Szychta E.: *Zero voltage switched multiresonant converters – analysis and design*, University of Žilina, Žilina 2008. ISBN 978-80-8070-889-4.