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Modelling of DC/DC Multi Quadrant Converter for Hybrid Electric Vehicles Applications

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Abstract. In the current paper a model of bidirectional DC/DC multi quadrant converter is developed. The proposed model is composed by a separately excited DC motor, a buck-boost converter and a proportional-integral (PI) regulator. The solution is described with the aid of system of differentials equations and realized in the visual environment MATLAB/Simulink. Two operation modes are studied: acceleration mode and braking (regenerative) mode. From the presented and discussed results it is observed that the proposed solution is suitable for hybrid electric vehicles applications with multiple energy source such as battery and supercapacitor.

INTRODUCTION

The increasing number of vehicles create the environmental problems such as global warming, air pollution and etc. That leads to the necessity of implementation of new generation of transport such as hybrid (HEVs) and electric vehicles (EVs). Hybrid vehicles offer significant fuel savings and significantly reduced emissions compared to the vehicles with internal combustion engine through the use of an electric motor to propel the vehicle. The hybrid vehicle is classified according to a type of architecture. The traction chain of an EV is simplified compared to internal combustion vehicle; it consists of an electric motor, a source of electrical energy and a simplified mechanical transmission. Electric motors used for traction have better behavior at low rotational speeds and deliver higher power. This allows you to accelerate quickly during acceleration. In addition, electric motors have many advantages compared to internal combustion engines; they are lighter, reversible and have a very good performance.

Important parts of HEVs and EVs are power electronic converters. The study of new topology and their control is an especially importance for finding an optimal solution in different operation modes. The development of the mathematical model of multi quadrant DC/DC converter would contribute for examination of the proposed solution.

The main objective of this paper is to examine the acceleration and braking modes of an electric vehicle. The important contribution is to evaluate the energy which could be stored during the regenerative braking. This research is significant to determination of the efficiency and at the design of the system and the particular components.

In the paper a mathematical model with the differential equations and their implementation in MATLAB/Simulink and simulation results are presented. In Fig.1. a block scheme of HEVs is proposed. It consist of internal combustion engine, electric motor, inverters, rectifiers, DC/DC converter, mechanical transmission and batteries pack.

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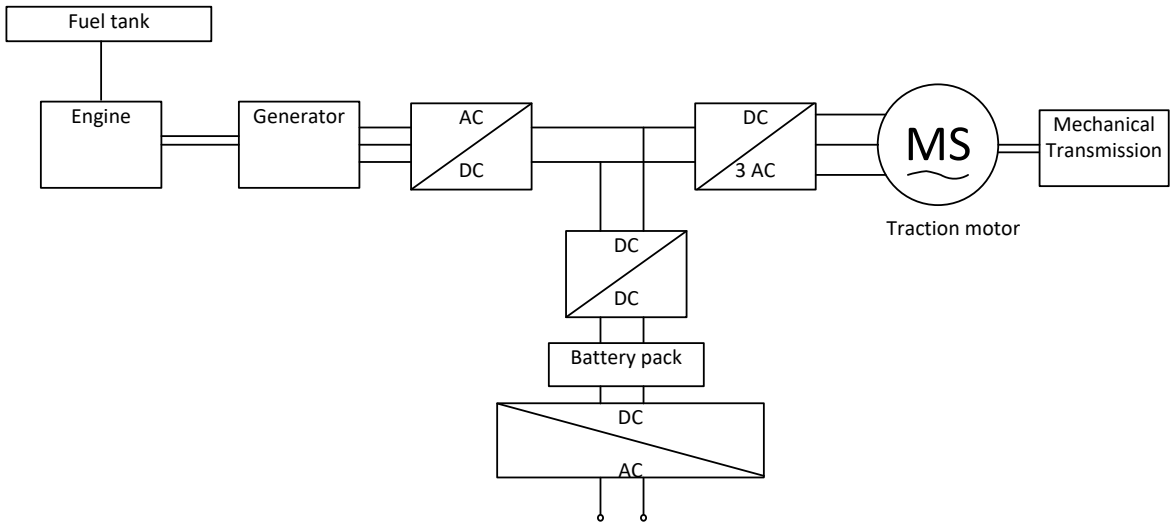

FIGURE 1. General configuration of a hybrid electric vehicle

MATHEMATICAL MODEL

In Fig. 2 a schematic of four quadrant DC/DC converter is presented. With the aid of the following equation are described the operation modes.

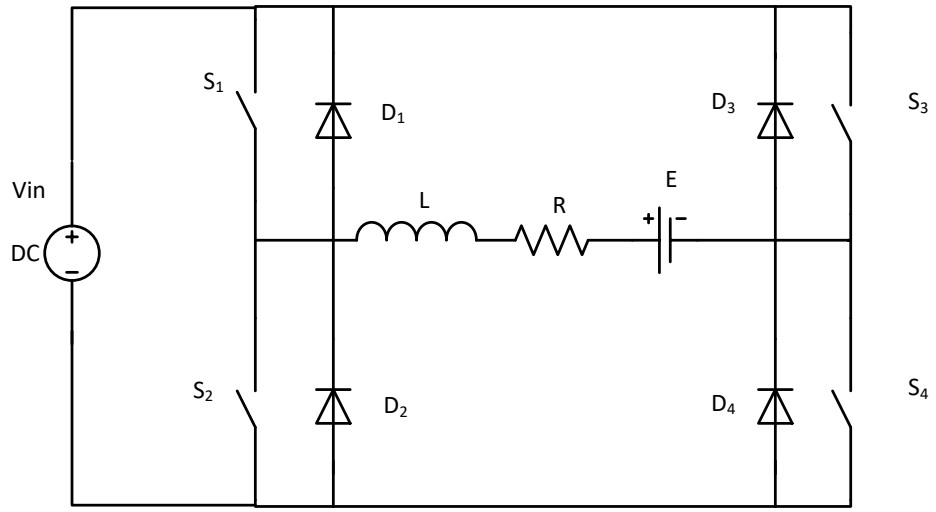

FIGURE 2. Four quadrant converter

This circuit operates as a two quadrant converter and it's obtain 4 modes of operations. When the switches S_1 and S_4 are turned on the input voltage is applied to the load and the instantaneous output voltage appearing across the load v_{out} is:

$$V_{out} = \frac{1}{T}\left[\int_0^{T_1} V_{in}\,dt + \int_{T_1}^{T}(-V_{in})\,dt\right] = \frac{V_{in}}{T}\left(T_1 - T_{off}\right) \tag{1}$$

$$T_{off} = T - T_1 \tag{2}$$

In Table I the parameters and the values of the used components are presented. The mathematical model is realized in MATLAB/Simulink environment and it's shown in Fig.3. In the scheme are connected a battery, a DC/DC multi quadrant converter, a load and a control system. The DC/DC converter is realized with two blocks implemented in MATLAB/Simulink. The DC motor is presented with equivalent circuit which consist of internal resistance, internal inductance and back electromotive force.

TABLE 1. Values of the components

Parameters	Values	Units
Voltage of the battery	300	[V]
Capacitor, *CH*	7.2	[mF]
Capacitor, *CL*	7.2	[mF]
Inductance, *L*	6.25	[µH]

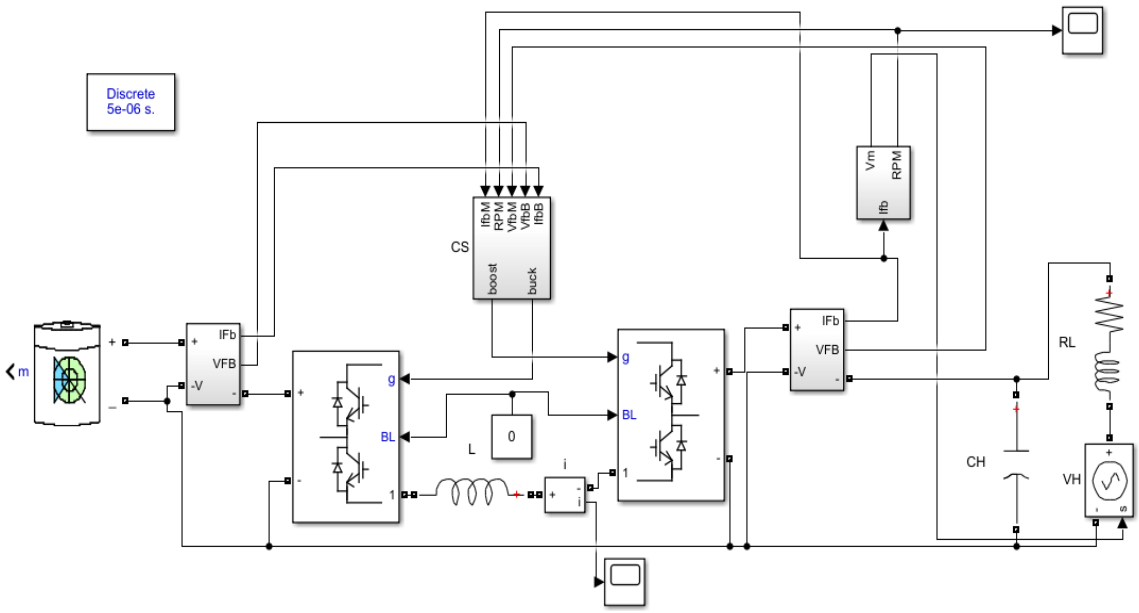

FIGURE 3. Schematic of the multi quadrant converter in MATLAB/Simulink

In Fig. 4. a control system of the proposed converter is presented. It is integrated in the block CS. The control is realized with two PI regulator. The first one regulate the tours in RPM which is set by the block "Imported Signal". The second one maintain the current of the converter.

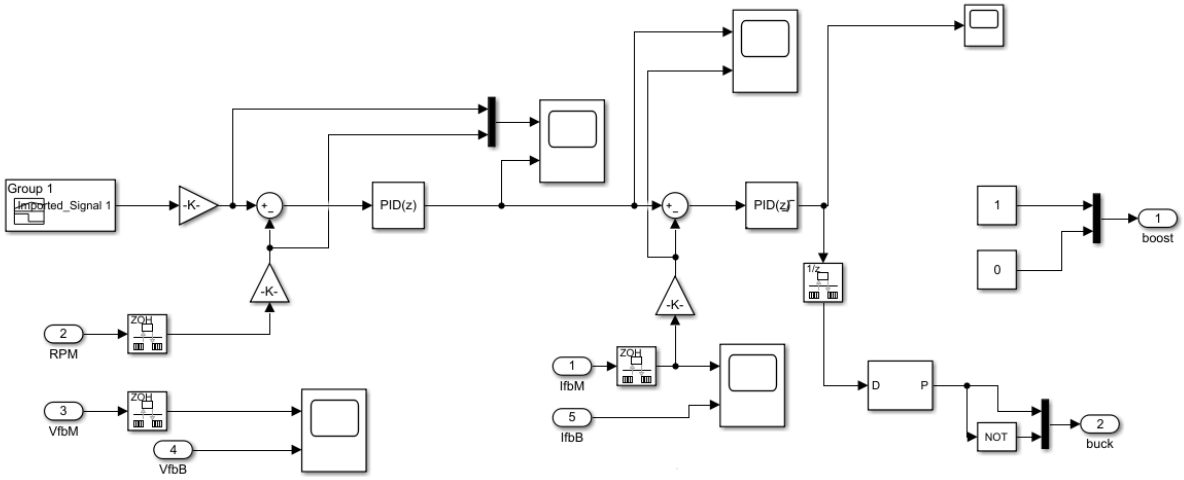

FIGURE 4. Control system

SIMULATION RESULTS

In Fig.5 a simulation results are presented. The first curve is the set for the RPM (yellow) and the second one (blue) is the real RPM.

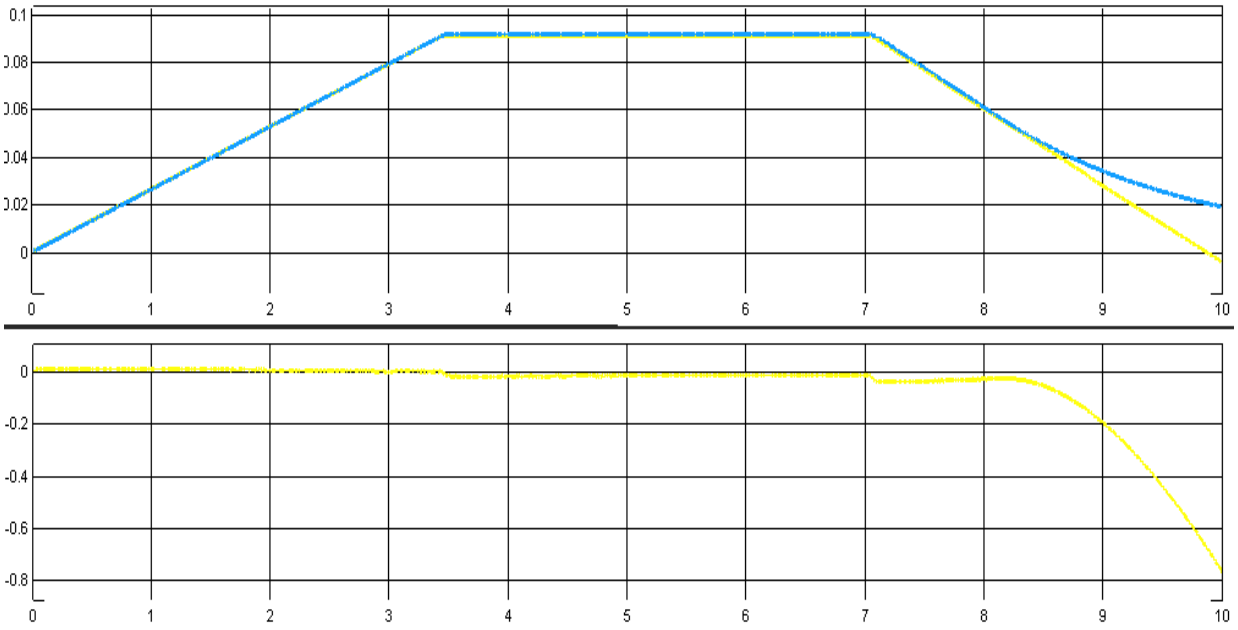

FIGURE 5. Simulation results

CONCLUSION

Having demonstrated the environmental and energy related advantages of the EVs, and noticed the prevalence of EVs with a DC/DC converter in their powertrain, the objective of this paper is to develop a solution for the powertrain DC/DC converter of an electric vehicle.

Several aspects of the solution have been examined. The first of them is the selection of an appropriate topology of DC/DC converter for the herein considered application, which finally is a multi-quadrant DC/DC converter.

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REFERENCES

1. Anurag M. Lulhe ; Tanuja N. Date, “A technology review paper for drives used in electrical vehicle (EV) & hybrid electrical vehicles (HEV)”, 2015 International Conference on Control, Instrumentation, Communication and Computational Technologies (ICCICCT).
2. Mehrdad Ehsani, Yimin Gao, Ali Emadi, Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design, Second Edition, CRC Press, Sep 21, 2009.
3. M. H. Rashid, Power Electronics: Circuits, Devices and Applications, 3rd edition, Pearson, 2004
4. V. R. Moorthi, Power Electronics: Devices, Circuits and Industrial Applications, Oxford University Press, 2007 M. P. Brown and K. Austin, The New Physique (Publisher Name, Publisher City, 2005), pp. 25–30.
5. Anju George, Surya Susan Alex, “Bridgeless buck-boost based power factor correction for multi quadrant operated brushless DC motor drive” 2017 International Conference on Intelligent Computing, Instrumentation and Control Technologies (ICICICT)
6. Nirav N. Senghani, G. Seshagiri Rao, “Multi quadrant operation of DC motor using hybrid topology with reduced number of switches”, 2014 Innovative Applications of Computational Intelligence on Power, Energy and Controls with their impact on Humanity (CIPECH).
7. I. Voss ; S. Schroder ; R.W. De Doncker, “Predictive Digital Current Control Using Advanced Average Current Sampling Algorithm for Multi-Phase 2-Quadrant DC/DC Converters”, APEC 07 - Twenty-Second Annual IEEE Applied Power Electronics Conference and Exposition
8. M.J. Jafarian ; J. Nazarzadeh, “Time-optimal sliding-mode control for multi-quadrant buck converters”, IET Power Electronics, 2011, Volume: 4, Issue: 1.
9. Y. Liu ; J. Arrillaga ; N.R. Watson, “A four quadrant multi-level back-to-back HVdc interconnector”, Proceedings. International Conference on Power System Technology, 2002, Volume: 1.
10. Omar Hegazy ; Joeri Van Mierlo ; Philippe Lataire ; Mohamed El Baghdadi, “Integrated Power Electronics Interface for Plug-In Hybrid Electric Vehicle Applications”, 2012 7th International Conference on Integrated Power Electronics Systems (CIPS).
11. A Sivaprasad , Jijo Joseph , S Kumaravel , S. Ashok, “Design and analysis of a dual input DC-DC converter for hybrid electric vehicle”, 2015 IEEE International Conference on Signal Processing, Informatics, Communication and Energy Systems (SPICES).
12. Dakshina M. Bellur ; Marian K. Kazimierczuk, “DC-DC converters for electric vehicle applications”, 2007 Electrical Insulation Conference and Electrical Manufacturing Expo.