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Converter used as a battery charger and a motor speed controller in an industrial truck

F.LACRESSONNIERE, B.CASSORET

Laboratoire Systèmes Electrotechniques et Environnement - Université d'Artois

Faculté des Sciences Appliquées, Technoparc Futura, 62400 Béthune, France

Tel. : +33 (0)3.21.63.72.03

E-mail : fabien.lacressonniere@fsa.univ-artois.fr

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«Asynchronous motor», «Battery charger», «DC power supply», «Power factor correction»

Abstract

This paper presents a bi-directional power converter used on one hand as a battery charger and on the other hand as a motor speed controller. Different possibilities are presented and a comparison of these structures is carried out. In battery charger mode, the power converter has to absorb a sinusoidal current with a unit power factor. According to the power range, two possibilities are presented : the isolated CUK converter with a 1,5kW DC motor and a pulse width modulation (P.W.M.) inverter/rectifier to supply a 6kW asynchronous motor.

Introduction

Nowadays, in an electrical industrial truck, there are two distinct power converters : the speed controller for the traction motor and the battery charger. According to the nature of the truck (pallet truck or fork lift truck), the power and the type of the traction motor are different. Generally, in a pallet truck, the traction motor is a DC machine with a power range of 1-2kW, this one is supplied by a chopper. On the other hand, in the fork lift truck, the power is higher (6-10kw) and the asynchronous machine is preferred and it is associated with a PWM inverter.

A second converter is used to recharge the battery. This one is connected at the single phase network for low power (<6kW) whereas for higher powers, it is connected at the three phase network. Between the network and the converter, there is a rectifier. Usually, this one generates some current harmonics in the network and a bad power factor. To reduce these harmonics, we use the Power Factor Correction (P.F.C) technique.

In order to decrease the weight and the cost of the battery charger, we use the same power converter for the traction and charger modes. The aim of this paper is to present different possibilities of converters for the two operations modes. According to some criteria, the isolated CUK converter and the P.W.M. inverter/rectifier are chosen for the pallet truck and the fork lift truck applications. The experimental results are shown for the CUK converter.

Power Converter for the electric pallet truck

Choice of the topology

A pallet truck is equipped with a lead acid battery which has a nominal voltage of 24V. The traction motor is a DC machine. Nowadays, in this truck, the nominal voltage of the DC machine and the battery are the same. Hence, a chopper (Buck converter) allows to control the speed of the truck. The problem of the DC machine is the damage of the brushes, especially when the voltage of the motor is low. To reduce this damage, the voltage of the DC machine has to be increased. Hence, a nominal voltage of 220V is chosen.

The nominal voltage of the battery is 24V and we use a 220V DC motor. In the speed controller mode, the power converter has to convert the DC voltage of the battery into a variable voltage for the DC

motor (0 – 220V). The system has to work in Buck or Boost mode. The power converters which have at the same time the Buck and Boost mode are indirect choppers (with intermediate storage of energy). In the battery charger mode, there is a rectifier between the network (220V/50Hz) and the converter. This one generate some current harmonics and reduce the power factor. To improve it, the converter has to be able to operate in PFC mode [1]. The galvanic isolation between low and high voltage is realised with a high frequency transformer, which operates at 20kHz.

There are two possibilities to include those two operations modes in the same converter :

- At first, an unidirectional converter (Fig. 1) can be used. In this case, the battery has to disconnect according to the operation mode : speed controller (1) or battery charger (2).

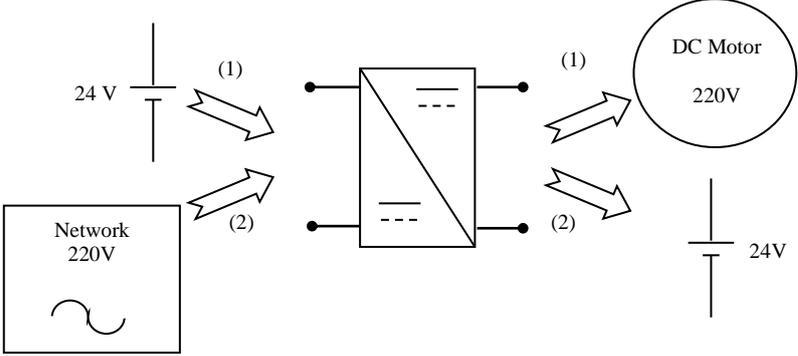


Fig. 1 : The configuration for an unidirectional converter

- The other possibility is to use a bi-directional converter. Then, the battery is always connected at the low voltage side (Fig. 2).

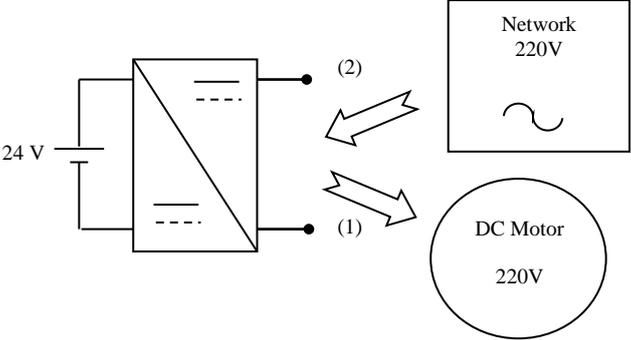


Fig. 2 : The topology for a bi-directional converter

The drawback of the unidirectional converter is the stress on the semiconductor components. That is to say, for the same power in both operations modes, the components have to support high currents and high voltages because the input and output voltages are different according to the operation mode. Then, the bi-directional topology are chosen.

In the speed controller mode, the converter has to convert the battery voltage into a variable voltage for the DC motor. In battery charger, the converter has to charge the battery with a unity power factor. To achieve those two operations modes, we have two possibilities :

- The Buck-Boost converter. The storage element is an inductor. The Flyback converter has the same topology with a galvanic isolation (Fig. 3).
- The Cuk converter. The storage element is a capacitor. Figure 4 presents this converter with a galvanic isolation (Fig. 4).

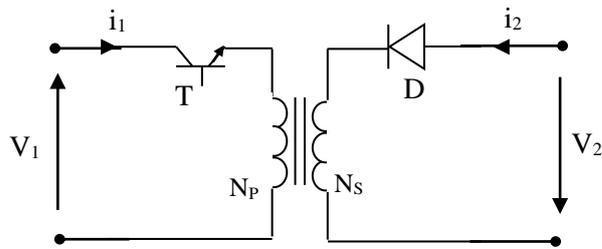


Fig. 3 : The Flyback converter

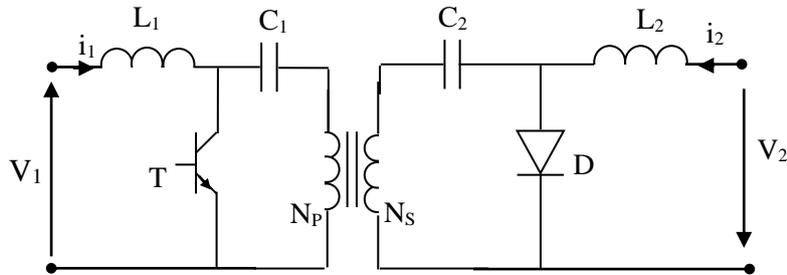


Fig. 4 : The Cuk converter

The main difference between these converters is the nature of the current. For the Flyback converter, the input and output currents are discontinuous whereas in the Cuk topology, they are continuous. Hence, at the nominal power, the maximal current in the semiconductors is twice higher in the Flyback converter. Moreover, the Cuk allows to work in PFC continuous mode [2][3] and so to reduce the input filter and conducted electromagnetic disturbances [4]. Then, the proposed DC/DC converter (Fig. 5) is based on the Cuk principle and only contains two transistors and two diodes for both energy flow directions.

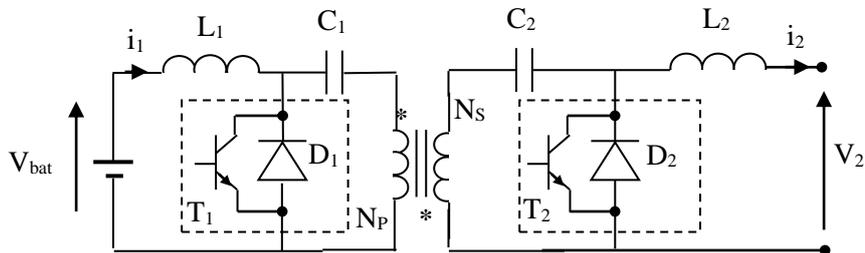


Fig. 5 : Bi-directional DC/DC Cuk converter

The final structure is given by the Fig. 6. The switch K allows to realize the connection according to the operation mode.

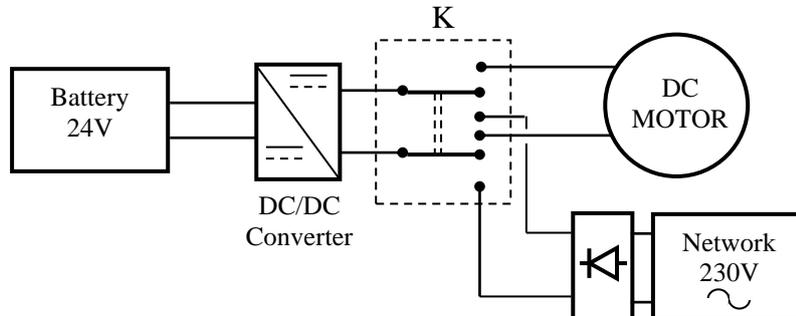


Fig. 6 : Structure for the pallet truck

Experimental results

The experiments was made with a 1,5kW prototype. At the low voltage side, the transistor T_1 is a MOSFET 130V-130A. At the high voltage side, T_2 is a IGBT 600V-50A. The operating frequency is equal to 20kHz. The UC3854 integrated circuit of Unitrode has been used for the command of the battery charger in PFC mode.

Fig. 7 shows the currents in the DC machine and in the battery during the start of the truck. A regulation was done in order to limit it. The maximal current in the battery at the nominal power is equal to 100A.

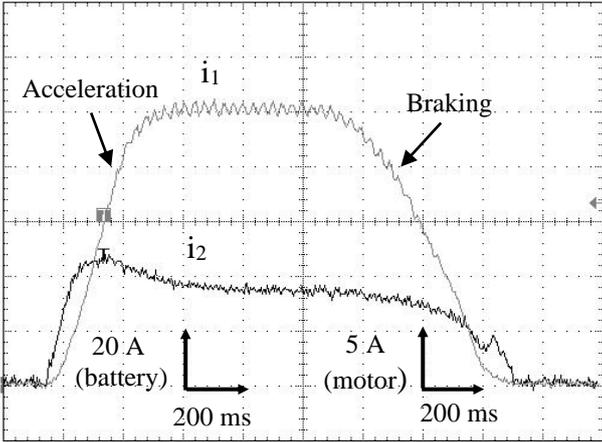


Fig. 7 : Battery and motor currents during the speed controller mode

In battery charger mode, the line current and voltage are shown in the Fig. 8 at the full load. The waveform of the current is approximately sinusoidal and it is in phase with the line voltage. Hence, the power factor of the battery charger is correct.

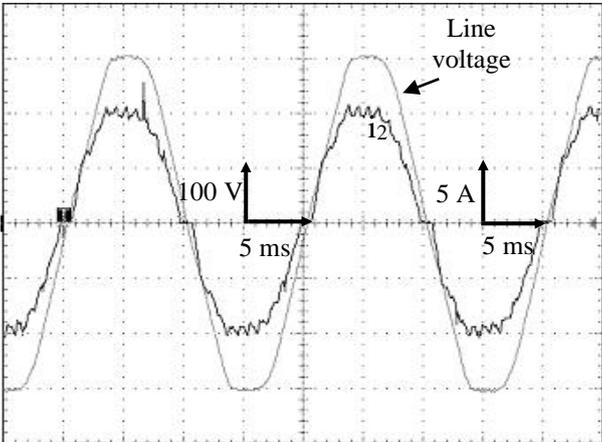


Fig. 8 : Line voltage and current in power factor correction mode

Fig. 9 shows the waveform of the battery current during this operation mode. This one is a typical waveform when a single converter are used which operates as a battery charger with an unity power factor and a sinusoidal input current. Then, its mean value is at the origin of the recharge of the battery [5]. The efficiency of converter is around 90%. This result has been obtained by the utilization of a soft switching snubber [3].

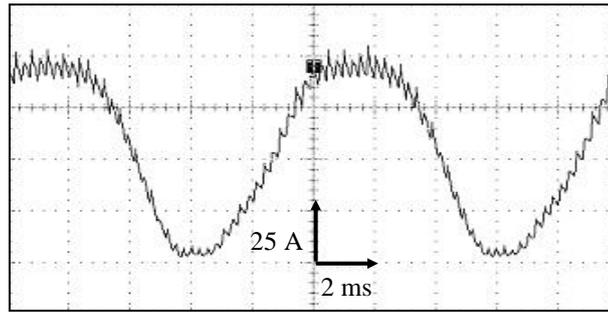


Fig. 9 : Battery current in battery charger mode

Power Converter for the fork lift truck

In this application, the nominal voltage of the battery is 48V and we use a three phased 48V asynchronous motor. To improve the efficiency of the traction system, the speed reducer between the shaft of the motor and the traction wheel has been eliminated. In the speed controller mode, a PWM inverter to supply the traction motor can be used and the space vector modulation strategy can be employed. In the battery charger mode, the inverter will be used as a PWM rectifier. The advantages of this converter are : bi-directional power flow, low harmonic distortion of the line current and the regulation of the input power factor to unity [6][7]. A transformer has to be placed in the structure to provide a galvanic isolation. To reduce its size and weight, the asynchronous motor are used like a transformer in the battery mode operation. The nominal power of the system is 6kW. The diagram of the system is given by the Fig. 10.

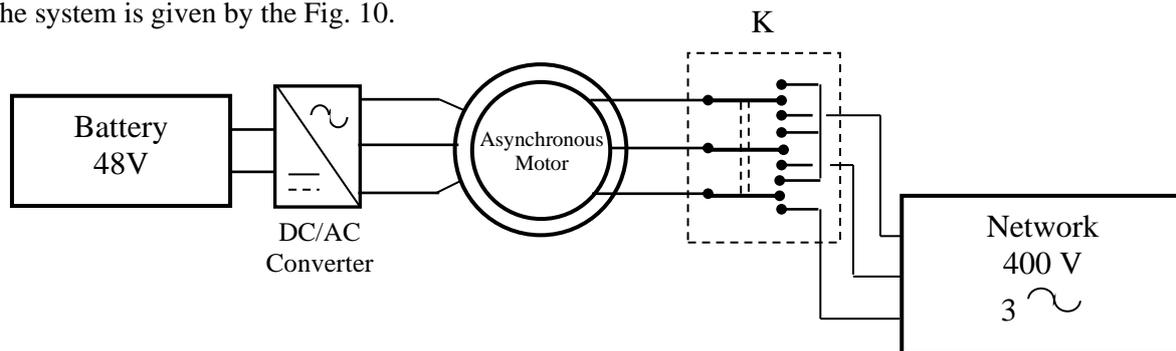


Fig. 10 : Structure for the fork lift truck

Characteristics of the asynchronous motor

The characteristics of the 6kW asynchronous motor described in detail in [5] are reported in the table I.

Table I : Technical data of the asynchronous motor

	Stator winding	Rotor winding
Arrangement	3 phase delta connected	3 phase star connected
Nominal voltage and current	48V phase to phase, 124A	400V phase to phase, 12A
Pole pair	8	8
Leakage inductance per phase	96 μ H	4,5mH
Resistance per phase	11,5m Ω	0,95 Ω

The outer diameter and the active length of the machine are equal to 45,8cm and 13cm. The weight of the machine is approximately equal to 125kg and its efficiency equal to 85% for the nominal power.

Combination of the asynchronous machine and PWM rectifier

During the battery charger mode, the rotor windings are connected to the 3 phase network. The stator windings are always connected to the PWM converter. The system of the battery charger is presented to the Fig. 11.

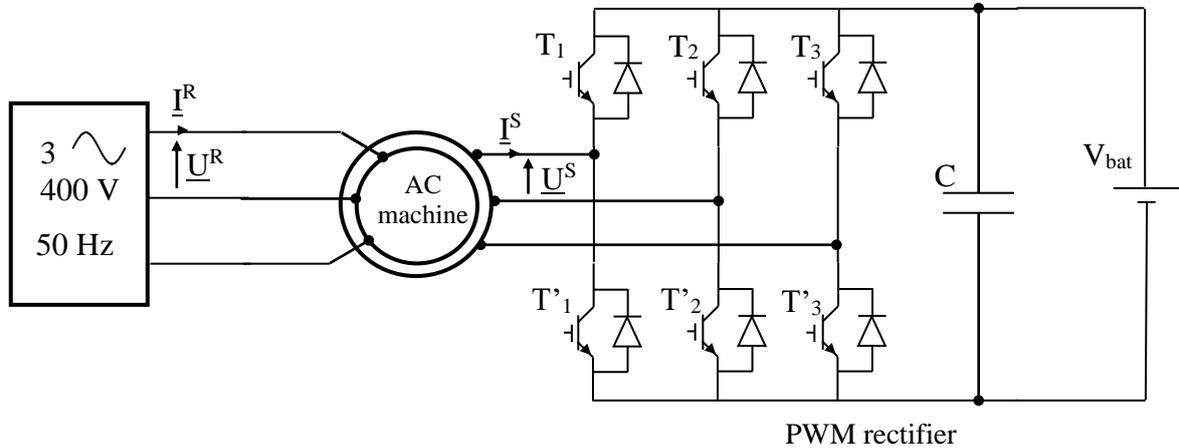


Fig. 11 : The battery charger topology

During the charging mode, the traction motor creates a torque. In order to the truck does not move, the rotor has to be blocked. The stator and rotor leakage inductances serve as filter inductance and the inverter operates as a PWM rectifier. This one allows to control the RMS value of \underline{U}^S and the phase shift between the control voltage \underline{U}^S and the source voltage \underline{U}^R . The phase shift between \underline{U}^S and \underline{U}^R is noted δ' . The RMS value of U^S is controlled by the parameter r :

$$U^S = r \frac{V_{bat} \sqrt{3}}{2\sqrt{2}}$$

The Fig. 12 presents the evolution of the parameters of the PWM rectifier according to the power of charge (P_{bat}) in order to obtain a unity power factor.

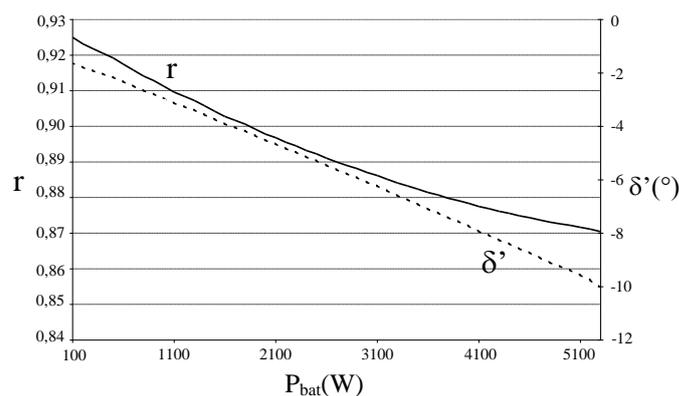


Fig. 12 : Evolution of r and δ' in battery charge mode

Conclusion

For a pallet truck and a fork lift truck, the speed controller and the battery charger can be realised with only one power converter. The proposed solutions allows to control the battery current during the charge, with a good input power factor. The cost, the size and the weight of the battery charger is reduced. The advantages and drawbacks of each possibilities have been shown.

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