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A new C-dump converter for performance improvement of SR motor drive: conceptual considerations and simulations

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In the article a new type of the C-dump converter type was presented, it was intended to supply switched reluctance drives, which is a modification of the configuration introduced in [1]. A structure and a principle of its working were discussed. In this construction independent supplying sections for each motor phase were used. Differences in construction and working both of the configurations and their influence on efficiency of the drive were discussed. Model results of simulation calculations of electromagnetic torque and phase current waveforms were presented. Applying the new system caused the increase in the efficiency of the drive.

KEYWORDS: switched reluctance motors, electrical drives, power electronics

1. Introduction

In electrical drives with the switched reluctance motors (SRMs) the power supply has the essential role in development of the output characteristics. This role is definitely more visible than, for example, in the permanent-magnet brushless machines. For that reason, there is a number of various converter topologies developed for these machines. The basic, and perhaps the most widely used, is one comprised of separate H-bridge converters feeding each phase winding of motor [3]. This converter, apart of a number of unquestionable advantages, does not allow, however to fully utilize a driving potential of the machine itself. In case of the SRM motor drives the best performance would be achieved when each out of a few phase windings was fed with the square current pulses during the motoring operation, and were completely switched off, respectively during the braking operation. However, in real systems, due to significant time-constants of the winding and high value of the back electromotive force, it is hard to achieve as the rotational speed increases. The solution of this problem could be supplying the motor from a current source, not the voltage source. This, however, leads to detraction from performance of the drive for a low-speed range. A good tradeoff is use of the C-dump converters where the capacitor functions as a dynamic power supply with increased voltage that allows speeding up the current rising and falling. Thanks to this, the current waveforms are closer to the ideal square pulse. Apart from these advantages, there are some drawbacks of this solution, like the need to switch between the power sources.

In this work we present a modification of the converter outlined in [1, 2, 5]. Via introduction of some useful changes into configuration of this type converter, we achieved a significant reduction of commutation losses for the low- and medium-speed ranges. Moreover, generation of the braking torque by the phase winding being switched off was reduced. The basic converter, presented previously as well as the new converter analysed here, are depicted in Fig. 1.

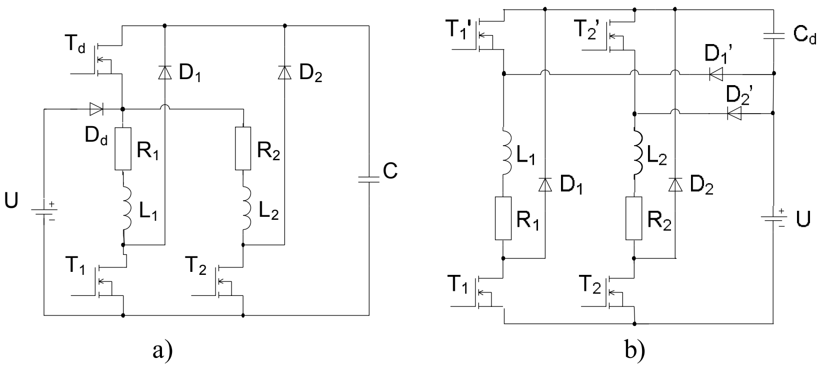

Fig. 1. Converter topologies: a) basic converter, b) proposed converter, both supplying a two-phase motor.

2. Description of operation of converters

The following modifications to basic structure were incorporated into the proposed system. In each out of two supplying sections the independent transistor connected with the capacitor was introduced, and the capacitor was connected to positive pin of the power source (in series with power source). In contrast, the basic converter [1] contains the common transistor for all sections and the capacitor is connected to negative pin of power source (quasi-parallel with source). Figure 2 depicts various operation states for both converters. The supplying state with the nominal voltage from source shown in Fig. 2a and Fig. 2b as well as the state of idle loop shown in Fig. 2g and Fig. 2h are identical in both converters. Significant differences exist, however in the remaining states of operation. In the supplying state with increased voltage in the basic converter the phase winding is supplied from the capacitor (Fig. 2c), although in the proposed system from the power source and capacitor connected in series (Fig. 2d). In addition to that, in the proposed converter, thanks to replacement of the common transistor with independent ones, all sections allow supplying a single winding with increased voltage as well as the return of energy from the unsupplied winding.

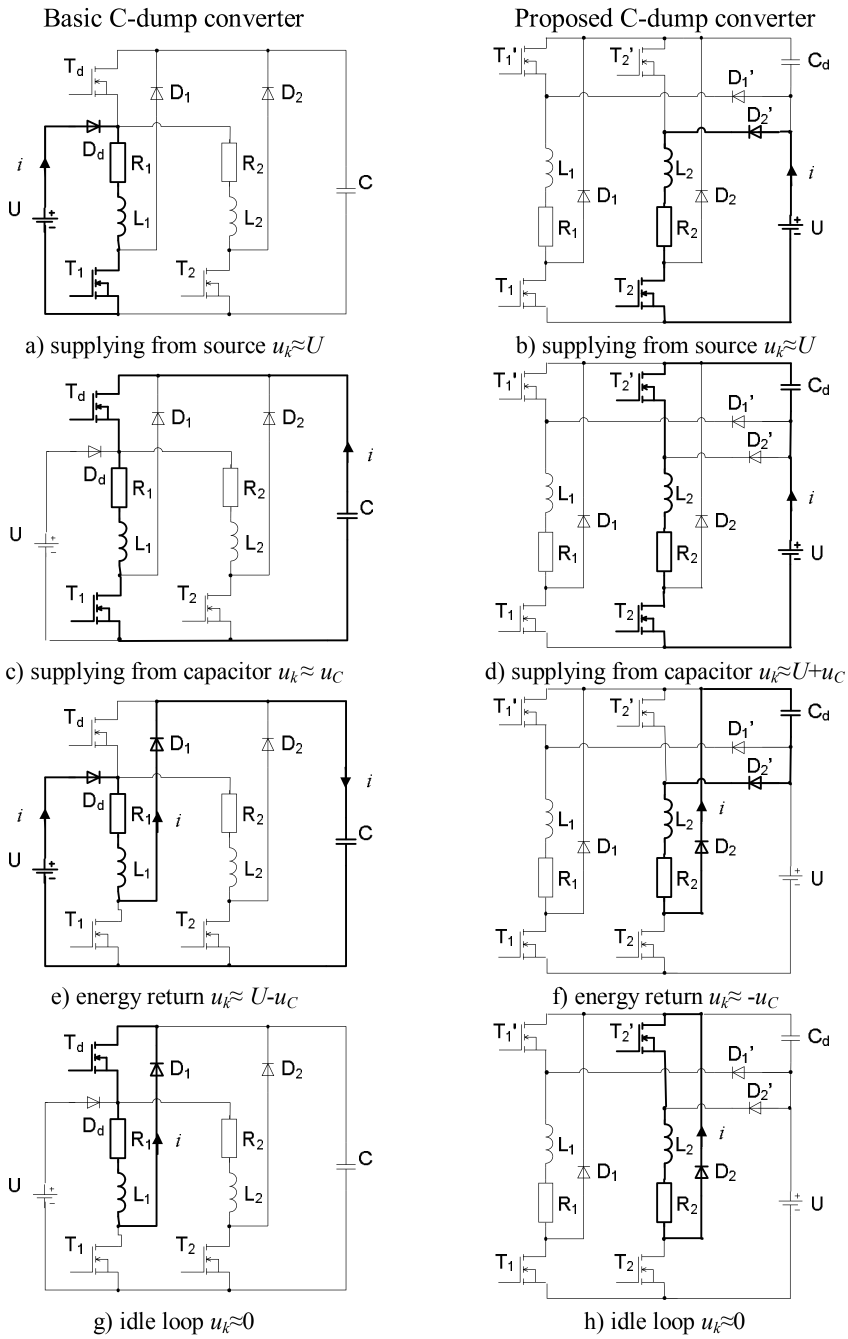

Fig. 2. Operation states of converters considered

In the basic converter (Fig. 1a) turning on the common transistor in order to supply a single winding with increased voltage disables the possibility to charge the capacitor with energy returned from other windings because this causes reconfiguration of the converter into operation state with idle loop (Fig. 2g). After turning off the transistors in the state with energy return (charging the capacitor) the current has a positive sense with source. As a result the energy is taken of the source. In the same time the voltage across the source and that across the capacitor have different senses. This reduces the resultant voltage across the phase winding of motor during the energy return state by voltage across the power source. As a result the current falling time is longer than during the state of supplying with increased voltage. The time of energy discharge from the windings is also increases. In the proposed converter (Fig. 2f) there exists a similar phenomenon related with reduction of voltage across the winding because the energy is returned only to capacitor and during the supplying state it is taken from power source and capacitor connected in series. However, in the proposed converter the current flow through the power source during the energy return state has been eliminated. For that reason the additional energy is not taken from the capacitor which would increase the current falling time.

3. Simulations

To support the above presented theoretical considerations, the computer simulations of the drive, using Matlab/Simulink/Plecs and model outlined in [4] were carried out. The computations were carried out for a two-phase motor with the following specification: nominal voltage 36 V, maximum current 90 A, and maximum torque generated equal to 3,5Nm at 3600 rpm. These ratings are, however attributed to operation with the basic converter, and not with a C-dump converter considered further. As a result of computer simulations the steady-state characteristics as well as the waveforms of phase voltages and currents, and torque were determined (Fig. 3). In case of the basic converter the increased voltage was applied to the motor during the first 10 degrees of the phase winding supplying angle. Afterwards, the phase winding was supplied with a nominal voltage so as to disable energy discharge from windings and to enable charging the capacitor.

In the proposed system, for the range of low speed, the transistors that commutate the increased voltage were turned on for the entire range of supplying angle of the winding. Thanks to this, when the current control mode is considered, the capacitor is charged only partially during the initial phase of conduction cycle.

When the given level of current is achieved by the phase winding and when it is switched off, the energy is passed directly to the next phase winding that is turned on.

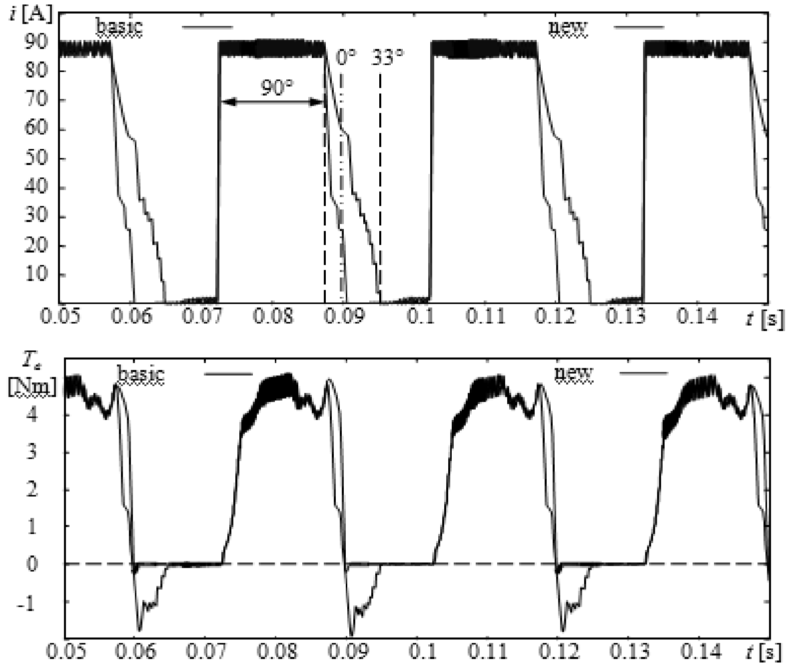

Fig. 3. Computed steady-state waveforms of phase current and torque generated by single phase winding for (current turn on angle θ_{on}=-105°, and current turn off angle θ_{off}=-15°)

Thanks to this, for this range of speed, the average value of voltage supplying the phase winding is lower than in the basic converter, where the capacitor has to be charged in order to speed up the energy discharge process. This leads to reduction of switching losses in transistors. Transistors T_k' that commutate the increased voltage do not produce any losses, however transistors T_k that commutate form the side of the pin of ground produce power losses that are lower than those in the basic converter due to reduced value of the voltage during commutations. Moreover, shortening of the winding energy discharge time (thanks to elimination of current flow through source) reduces braking torque as well as conduction losses. This causes rise of average torque value and so, improves efficiency of the drive. In the considered case, at the end of operation range with constant torque corresponding with rotational speed equal to 5000 rpm the computed values of efficiencies were: 72 per cent and 77 per cent for the basic converter, and for the new converter analysed here, respectively.

4. Conclusion

Use of power converters with capacitors for energy dump for the switched reluctance motor drives allows significant improvement of overall performance of the drive related with rise of rotational speed as well as increase of the output power of the drive. A drawback of this solution is a rise of power loss related incorporation of additional components into the converter structure. In the converter discussed in this work the number of switching elements has not been increased in comparison to the basic configuration based on the half-bridge converters. Application of the proposed converter allows reduction of the number of commutations per cycle of operation as well as the value of voltage during commutations. Additionally, this system allows for reduction of energy discharge time when it is necessary, which also improves operation of the drive.

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