THE APPLICATION OF SUPERCAPACITOR ENERGY STORAGE DEVICES IN DC DRIVES

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Abstract. The article looks on actual theme about improoving of energetic efficiency of exploitated DC traction drives. There are developed the separate schemes for DC motor starting and braking regimes by using the supercapacitor energy saving devices for motor armature shunting. The starting device allows to decrease the motor torque jerks at the beginning of transient process thus providing the elimination of consumed energy and drive system mechanical wear. There is given the saved energy calculating equivalent circuit and expression. By varying the subtitution scheme shunting and ballast resistance values, the mechanical time constant changes with increasing the speed of transient processes. The estimated DC motor control device with supercapacitor battery allows to eliminate the need for ballast resistor. The decreasing of consumed energy is achieved in such way because the electrodynamic braking has realized simultaneosly with shunting of DC motor armature with the help of capacitor energy saver which decreases the armature voltage to provide the stable boost converter operation. The braking scheme with two converters transfers the energy saved in the filter capacitor to the supercapacitor energy saver independently from the filter capacitor voltage oscillation value. The new device has higher efficiency factor.

Key words: ballast resistor, DC motor, supercapacitor, transient processes.

Introduction

DC drives still are used in transport and industrial applications due to the competitive price and long lifetime of the existing drive system mechanical part. They are favorably-priced and efficient retrofit solution for most industrial applications as well as for the modernization of old plants and transit systems without significant expenses.

However the efficiency of typical industrial DC drive system with uncontrolled rectifier and DC/DC converter is lower than induction drive because they lack regenerative braking feature. The introducing of controlled rectifier scheme worsens the converter power factor. The multiple DC motor regenerative braking to one DC network requests either connect the inverter parallel to rectifier or utilizing the contactors for converter DC bus polarity switching.

The large reconstruction of 191 T3A type tramcars and the renewing of 30 T3M (T6B5) cars took place in Riga city from the 1998 to 2007. As the result of such work the lifetime of the tram is extended for 10-20 years. The tendency to continue exploitate the heavy and light rail vehicles equipped with DC traction motors is observed not in Eastern Europe and the Baltic States only, but also in Western Europe.

All Baltic tram systems – Riga, Liepaja, Daugavpils and Tallinn currently are not using rolling stock with induction traction motors. In Eastern Europe and even old EU countries as well for many decades old trams with DC traction drive are still in use due to the reasons, that the rail electric transport rolling stock mechanical part exploitation resource mostly is 30-50 years and new car cost is aproximately 1 millione Euros per unit, which cause difficulties for a lot of transport operator companies to renew the old fleet before complete physical wearing.

Although the best energy saving and tramcar performance improving could be achieved changing DC drive with asynchronous drive, the raise of electrical part cost seldom pays off in the tramcar rest 10-20 postreconstruction years, which forces restrict the renovation with the rheostat and thyristor control systems changing by transistor ones, leaving old existing DC traction motors [2].

The modern variable speed AC motors are the most frequently drives encountered in industry, however their converters are more complicated and expensive than DC motor converters. Due to the greater inverter cost the total cost of AC drive is greater than for DC drive, which considerably lowers the renovation efficiency and payback.

DC drives also continue to be an attractive alternative for machine suppliers, because millions of motors are still in use and thousands more are being produced every year and the modern DC converters are easy to operate, compact and low in maintenance.

DC drive modernization possibilities

Therefore, the reconstruction of vehicles and benches have been made to prolong their exploitation period with replacing the control equipment by newer and more energy-efficient one, providing regenerative braking that allows 20-40 % of the consumed energy to be returned [1]. However the real energy saving strongly depends on its efficient consuming by giving to other consumer connected to the same power supply or sending back to power grid.

The instantly regenerative energy consumption often is impossible at low traffic density on weekdays off-peak hours and easy loaded lines because in the single traction substation overhead supplying zone during one tram braking other trams could not utilising the energy in traction mode or even not located in this net feeding zone. The industrial bench and elevator drives often have single motor connection to the power supply, which do not allows the regeneration mode.

Although the power system possibility of instant regeneration energy consuming is large enough due to the relatively small amount of the latter, however because of necessity to place the additional rectifier-inverter block it is technically difficult and expensive to be realized in comparison with conventional traction substation electric equipment which almost doubles the substation price. The AC grid inverters have lower power factor and the energy transfer from tramcar to substation at distance from severe hundred meters up to few kilometers is coupled with energy losses. Long overhead line's internal resistance between tramcar and substation caused power losses decreases the power saving even for 10 % [1]. The same problem occurs in industry, when the consumer locates in a significant distance from power supply. Due to the above mentioned drawbacks the most of world's public transport power substations and those in Riga are non-reversible therefore in the case of lack of consumers the excessive amount of regenerative energy is unefficiently lossed in the tramcar brake resistors.

For achieving the minimum renovation cost, the general modernization tendency is to left unchanged the field weakening circuit with contactors. In this case it is impossible to restrict the motor counter electromagnetic force rising above the power supply voltage. For providing the stable DC boost converter operation during the motors regenerative braking mode, their EMF is decreased by the ballast resistors, in which the part of regenerative energy is unefficiently lossed. As show the practical experience of high speed railway drive exploitation, the large power AC motors also could not sufficient operate without additional braking resistors. The actual problem is DC drive starting energy maximum, which is twice more than motor continous regime power [2].

The reducing of starting and braking torque could be achieved by armature shunting and connecting additional series resistance, that causes significant power losses, which could be eliminated by using the supercapacitor storage device instead of rheostats. This reduces the drive mechanical stresses in beginning of motor mode and allows operate without series ballast resistance in braking mode. To obtain the usefull utilisation of regenerative energy, it should be saved in special energy accumulator until the correspondent power consumer is connected to the DC line. One of the most perspective energy storage devices is a supercapacitor battery of large capacity. In comparison with chemical accumulator batteries and rotating fly-wheels the supercapacitors have high-speed operation in dynamic charge and discharge modes that allows quicker receiving and returning bigger amount of energy in a short time despite the smaller total energy capacity. The supercapacitor advantages are also independence on the environment temperature, smaller weight, cost and dimensions than other types of storage device type.

Starting device with energy storage equipment

The new scheme (Fig. 1) with supercapacitor storage [3] was elaborated for the DC motor start losses reduction and operates in following. At the motor 3 with series excitation winding 2 starting process the DC buck converter 1 works with pulse width modulation. Simultaneosly for the stabilising of motor dynamic torque value the energy is supplied to the first storage capacitor 6 through the filter choke 5 and adjusted by additional controllable switch 4. This allows to decrease the consumed electrical energy in starting process up to the achieving the necessary rotation speed.

The electrical energy stored in the first energy storage capacitor 6 is supplied to the second energy storage capacitor 8, which operates as accumulator, through the DC/DC converter 7 independently from the voltage oscillations.

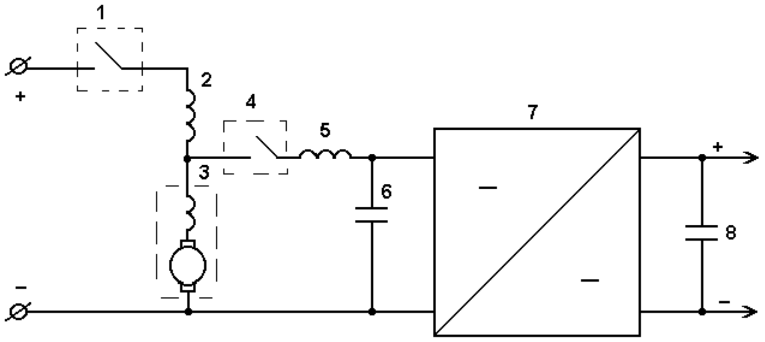

Fig. 1. **DC motor starting device**

From the motor torque expression (1) is obtained the motor rotation speed equation in the linear part of characteristics (2):

$$M_{din} - M_{st} = \frac{GD^2}{375}\frac{dn}{dt}, \tag{1}$$

$$n = n_{st}\left(1-e^{-\frac{t}{T_M}}\right)+n_{s\bar{a}\bar{a}}e^{-\frac{t}{T_M}}, \tag{2}$$

where T_M – mechanical time constant.

It is joined with motor parameters through the equation (3):

$$T_M = \frac{GD^2}{375}\frac{(R_a + R_p)}{c_e c_m \Phi_{dz}^2}. \tag{3}$$

From here is seen that the motor rotation speed could be impacted by varying the additional resistance R_p value, however the resistor voltage drop causes big power losses [4]. By substituting this resistance with capacitor storage, the previously to the resistor connected voltage is supplied to the capacitor battery, which allows to store energy ammount

$$\Delta A = \int_0^{t_{pal}} I_{pal}^2 R_\Sigma dt, \tag{4}$$

where $R_\Sigma = R_a + R_p$ – total value of armature and additional resistor resistances;

$R_a = r_a + r_{pp}$ – armature resistance, which is determined by the sum of armature winding and additional poles resistances.

The charateristics of electromechanical transient proceses are shown in Fig. 2., where the curve 1 coresponds to the operation mode without capacitor storage, curve 2 – with supercapacitor energy storage.

The scheme with energy storage device provides the armature circuit bypass (Fig. 3.), restricting motor starting torque, which decreases the transmission wear [5]. The performing of such control by the help of active bypass resistance R_{ekv} and additional resistance R_p is uneconomical.

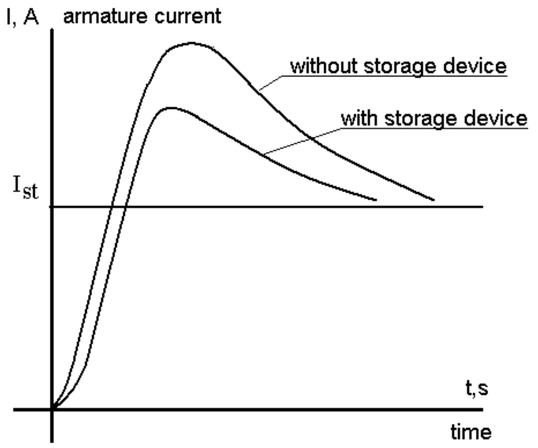

Fig. 2. **Electromechanical transient process**

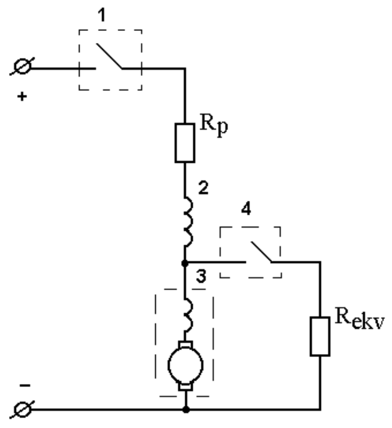

Fig. 3. **Motor control equivalent circuit**

Braking scheme with energy storage

By connecting the motor armature winding to the supercapacitor storage, the generator mode voltage should be limited without additional ballast resistance in armature circuit for providing the stable operation of braking mode DC boost converter when its input voltage must be lower than power supply voltage value. For this purpuse the scheme shown in Fig. 1. is supplemented by braking rheostat 10 and its electronical switch 11, braking boost converter diode 13 and additional converter 9 with diode 12. During the motor torque change in motor and generator modes the additional controllable switch 4 commutates LC circuit, storing electrical energy in this circuit capacitor 6. It allows the possibility to transfer this saved energy to the storage capacitor 8 independent from the capacitor 6 voltage oscillations. In the braking mode the pulse converter switch 1 disconnects the motor from network and together with diode 13 operates as voltage boost converter as shown in Fig. 4. with dotted line. The braking mode controllable switch 11 is switched on. Part of the motor electrical energy is dissipated in the powerful resistor 10 and motor active resistances, but other part transfered to the storage capacitor 8 through the braking mode converter 9. By adding the second capacitor storage device with pulse converter parallel to resistor 10 and switch 11, all regenerative braking energy could be stored in the case of other consumers abscience during the braking.

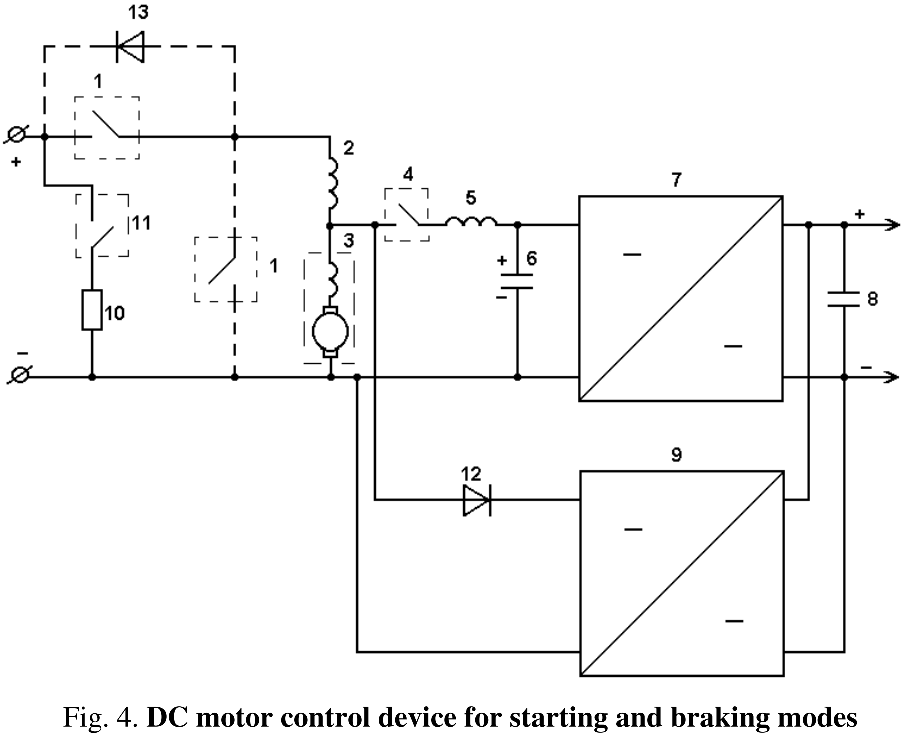

Fig. 4. **DC motor control device for starting and braking modes**

Conclusions

1. The supercapacitor storage device improves the DC motor electromechanical transient process, eliminates motor start jerks and power losses in braking ballast resistance, which allows to reduce the DC motor voltage in generator mode without great power losses.
2. This device can save the excessive transient process energy. The amount of stored energy could be calculated from the substitution scheme.
3. The transient process forwarding is possible by equivalent resistances values varying, which affects the mechanical time constants.

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