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INVESTIGATION OF A DC TRACTION MOTOR IN THE SERIES EXCITATION GENERATOR MODE

The article analyses electrical braking systems with direct current motors. It develops an experimental setup for studying the self-excitation of a traction motor. The research demonstrated the feasibility of implementing electrical braking systems with motors operating in the series excitation generator mode.

Keywords: *electric motor, excitation windings, electrical braking, series excitation generator, DC-DC converter.*

Introduction

Nowadays, with a significant deficit of electrical energy in Ukraine and frequent disconnections of individual city neighbourhoods from power consumption, ensuring the safe operation of electric transport is a pressing issue. In numerous cases, even traffic lights may not function, necessitating reliable operation of the electric braking system in the absence of electrical voltage in the network to ensure timely stopping of the vehicle. Notably, traction electric motors of urban electric transport typically employ series excitation direct current motors. Until recently, the most common braking systems have been those where traction motors operated as separately excited generators. It meant connecting the excitation windings to the power supply network and the armatures to braking resistors. If there was no voltage in the power network, such a braking system did not work.

Addressing this issue necessitates an autonomous energy storage unit to supply the excitation of traction motors in braking mode or to ensure their self-excitation when operating in the series excitation generator mode. Implementing an autonomous energy storage unit on a vehicle requires significant investment. As for the latter option, some technical solutions are available, but there is no information about their application in vehicles.

Literature Review

To date, implementation of electric rolling stock is taking place, utilising traction electric drives with direct current motors connected to pulse voltage converters employing IGBT transistors [1–8]. The standard electrical scheme by firms such as Cegelec, Ganz Ansaldo, and others includes a pulse converter with four IGBT transistors (VT3–VT6) with reverse diodes to reverse the series excitation winding and two IGBT transistors (VT7, VT8) for the armature.

This electrical scheme provides independent regulation of the excitation current and armature current, implements energy recuperation during braking, and contactless reversal of the excitation circuit. However, the electrical scheme contains six powerful IGBT transistors, and its characteristics are significant electrical energy losses in the transistors. Additionally, the motors function as separately excited machines in both traction and braking modes.

In our urban electric transport conditions, energy recuperation during braking into the grid is almost impossible due to using uncontrolled rectifiers at traction substations. However, during braking, electrical energy from the grid is supplied to the excitation windings of the motors, which operate as separately excited generators.

Several studies [9–10] present electric braking systems in which traction motors operate as series excitation generators. A combined method of electric braking and an electric braking system with a variable structure can serve as a general approach. These methods provide braking at the initial stage by using the traction motors as series excitation generators, followed by automatic regulation of the excitation current of the generators using a pulse converter by shunting the excitation windings’ input of this converter. This approach leads to the formation of braking characteristics close to those with independent excitation. Additionally, there is no need to consume electrical energy from the grid for motor excitation, and the converter output energy remains available for internal use.

Research Aim

The study aims to investigate the self-excitation of a series excitation generator to enable the implementation of an electric braking system independent of the voltage presence in the network.

Discussion of Results

During the development of the test bench, series-excited DC traction motors of the TE-022 type, manufactured in Czechoslovakia, were used. These motors have a power rating of 45 kW, a nominal current of 150 A, a nominal voltage of 300 V, and a nominal rotational speed of 1750 rpm. We installed such TE-022 motors on Tatra T3 tramcars as traction motors, arranged in pairs in series. The test bench employs four of these traction motors paired up. In each pair, the motors connect with shafts. The test bench allows for using either one or two pairs of motors.

Fig. 1 shows the external view of the test bench for investigating a series-excited DC traction motor operating in generator mode.

Fig. 1. External view of the test bench for investigating a series-excited DC traction motor operating in generator mode

We used one pair of traction motors, with one operating as a motor and the other as a generator, to investigate the self-excitation of the traction motor in series-excited generator mode.

The used power source was a three-phase controlled rectifier, with its input connected to a 380 V, 50 Hz network.

Fig. 2 shows the simplified electrical diagram of the test bench for investigating the self-excitation processes of series-excited generators.

The drive motor draws power from a three-phase thyristor converter. A manual potentiometer regulates the voltage on the drive motor. A tachogenerator of the ET-4 type mounted on the shaft of the tested motor measures the rotational speed. The test bench allows for the automatic short-circuiting of the generator power circuit or the connection of a resistor with different resistance values in the circuit.

We recorded transient processes in the power circuit and the motor rotational speed during the experiments using a USB Autoscope III oscilloscope and a laptop.

The experiments used various resistance values of the resistor in the power circuit.

To determine the minimum critical speed of the tramcar, which makes self-excitation of the series-excited generator possible, we gradually increased the voltage on the drive motor. Recording the self-excitation process of the generator and the motor's rotational speed involved an oscillogram.

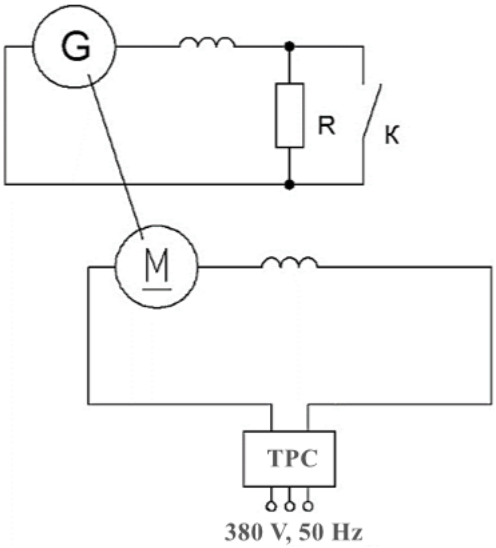

Fig. 2. Simplified electrical diagram of the test bench for investigating the self-excitation processes of series-excited generators

The self-excitation process from residual magnetisation in the series-excited generator, even with the windings short-circuited at the initial stage, progresses slowly, as seen from the oscillogram in Fig. 3. Only when the rotational speed reaches 227 rpm does an intense increase in the braking current in the generator power circuit occur, reaching a value of I = 130 A, and forming a braking torque proportional to the square of this current:

$$M = C \cdot \Phi \cdot I \equiv I^2. \quad (1)$$

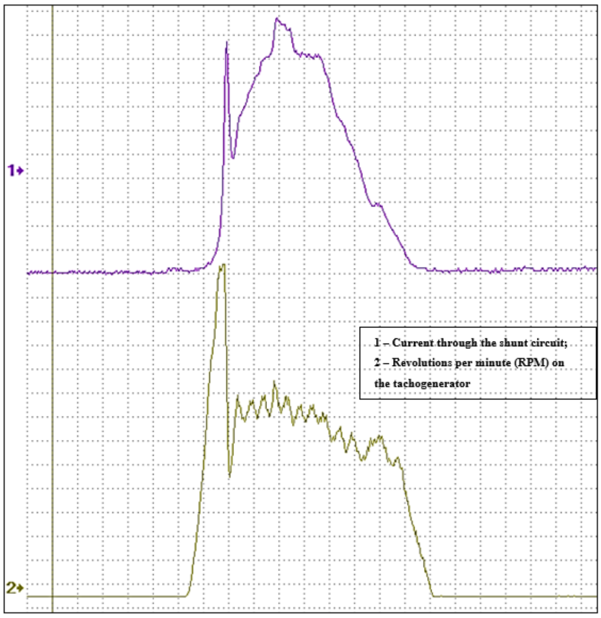

Fig. 3. Oscillograms of the self-excitation of the traction motor in generator mode with short-circuited windings

As a result, the rotational speed and, consequently, the braking torque decrease significantly. With a further increase in voltage on the drive motor, the rotational speed does not rise substantially because the braking current and braking torque increase again.

Thus, we can conclude that the self-excitation process of the series-excited generator occurs intensively with a rapid increase in current and torque. Therefore, it is necessary to decrease the excitation current for controlled self-excitation.

Fig. 4 shows the oscillogram of the generator's self-excitation, including R_g = 0.2 Ohms in the generator's power circuit. As seen from the oscillogram, the self-excitation process of the generator occurs at a speed of 330 rpm, and the increase in current is less intensive, reaching I = 80 A with an increase in voltage on the drive motor.

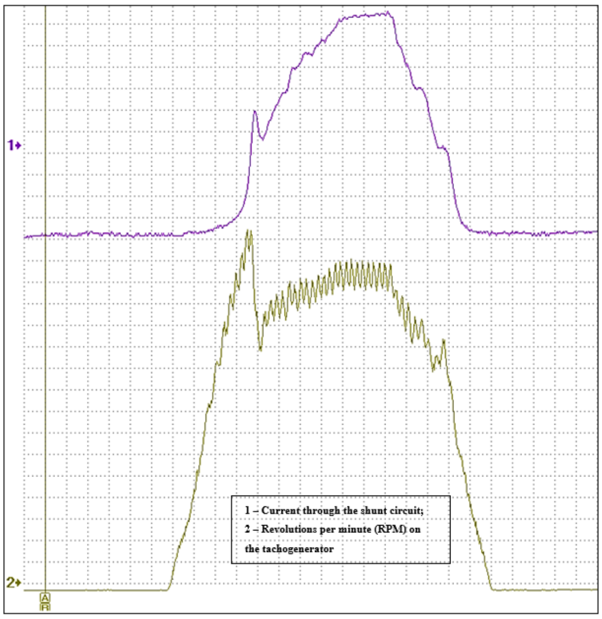

Fig. 4. Oscillograms of the self-excitation of the traction motor in generator mode with R_g = 0.2 Ohms included in the generator circuit

Introducing the braking resistor slows the generator's self-excitation process in the second braking stage.

The oscillograms of the self-excitation of the traction motor in generator mode with the resistor R_g = 2.1 Ohms included in the generator circuit are shown in Fig. 5. As seen from the oscillogram, the self-excitation process of the generator occurs at even higher speeds, reaching 410 rpm, and the increase in current reaches I = 75 A with an increase in voltage on the drive motor.

Based on the obtained results, we calculated the dependency of the critical speed on the braking resistor resistance.

The critical speed we calculated based on the corresponding motor revolutions:

$$V = \frac{3{,}6 \cdot \pi \cdot D_w \cdot n_{en}}{60 \cdot i_{red}}. \qquad (2)$$

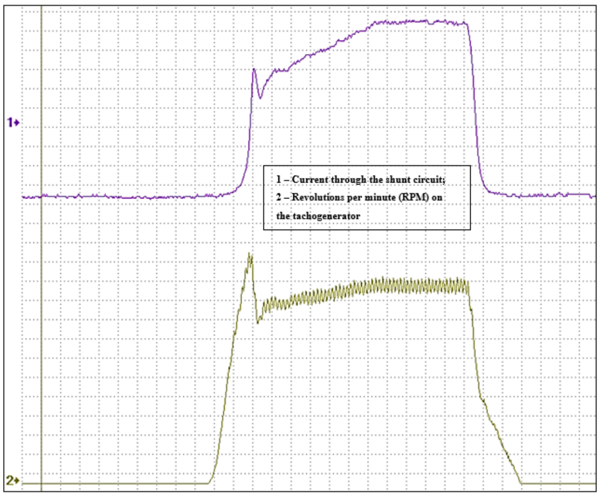

Fig. 5. Oscillograms of the self-excitation of the traction motor in generator mode with the resistor R_g = 2.1 Ohms included in the generator circuit

Thus, as a result of the research, it has been established that the critical speed decreases with the reduction in the braking resistor resistance R_g. Introducing the braking resistor into the series-excited generator circuit reduces the current surge and braking torque. For controlled self-excitation, it is necessary to decrease the excitation current of the generator.

Fig. 6 shows the dependency of the critical speed on the braking resistor resistance.

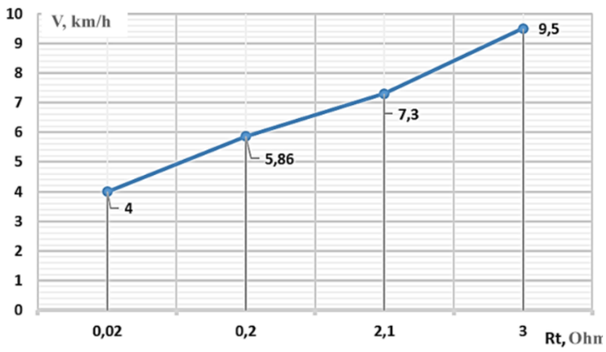

Fig. 6. Dependency of the critical speed on the braking resistor resistance

Conclusions

The paper analyses electric braking systems for vehicles with direct current motors, revealing systems where motors operate as generators. However, information regarding their implementation is lacking.

We developed an experimental full-scale test bench to investigate the self-excitation of traction motors in the series excitation generator mode.

The investigations on the self-excitation of the traction motor in the series excitation generator mode have demonstrated the feasibility of implementing electric braking systems with motors operating in the series excitation generator mode.

The study obtained dependence of the critical speed on the braking resistor resistance.

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ДОСЛІДЖЕННЯ ТЯГОВОГО ЕЛЕКТРОДВИГУНА ПОСТІЙНОГО СТРУМУ В РЕЖИМІ ГЕНЕРАТОРА ПОСЛІДОВНОГО ЗБУДЖЕННЯ

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У складі тягового електропривода наземного електричного транспорту використовуються тягові електродвигуни постійного струму послідовного збудження. До недавнього часу найбільш поширеними були системи електричного гальмування, в яких тягові двигуни працювали генераторами незалежного збудження. У цьому разі обмотки збудження підключались до мережі живлення, а якорі включались на гальмівні резистори. При відсутності напруги в мережі живлення така система гальмування не працює.

Для вирішення цього питання необхідно або мати автономний накопичувач електричної енергії для забезпечення збудження тягових електродвигунів в гальмівному режимі, або забезпечити їх самозбудження при роботі в режимі генератора послідовного збудження. Впровадження автономного накопичувача електричної енергії на транспортному засобі потребує значних затрат. Для останнього варіанта є технічні рішення, але відсутні відомості про застосування їх на транспортних засобах. Тому дослідженню самозбудження генератора послідовного збудження для забезпечення можливості впровадження системи електричного гальмування, не залежної від наявності напруги в мережі, і присвячена ця робота.

У роботі проведено аналіз систем електричного гальмування з двигунами постійного струму. Розроблено експериментальний натурний стенд для дослідження самозбудження тягового електродвигуна. Проведені дослідження, які показали можливість впровадження систем електричного гальмування з двигунами в режимі генератора послідовного збудження.

На основі отриманих результатів розрахована залежність критичної швидкості від опору гальмівного резистора. У результаті проведених досліджень встановлено, що критична швидкість знижується зі зменшенням опору гальмівного резистора. Введення гальмівного резистора у ланцюг генератора послідовного збудження зменшує кидок струму та гальмівного моменту. Для регульованого самозбудження необхідно зменшувати струм збудження генератора.

Ключові слова: *електродвигун, обмотки збудження, електричне гальмування, генератор послідовного збудження, DC-DC перетворювач.*