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INNOVATION OF TRACTION DRIVES

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1. Introduction

The choice of traction drives has been done from a historical viewpoint of demanded traction characteristic for the traction motor. That was demanded torque characteristics given by demand of constant power utilization

$$F = \frac{P \cdot 3,6}{v} = \frac{k}{v} \quad [\text{kN}; \text{kW}; \text{km/h}], \quad (1)$$

where the traction force depends on torque, i.e. $F = k \cdot M$ and the velocity is a function of motor revolutions $v = k \cdot n$.

Equation (1) has expressed ideal requirement derived from vehicle traction characteristics, namely hyperbolic dependence between traction force and speed. Dynamic and control properties were the second requirements. Considering that viewpoint demanded properties were shown especially by the commutator motors designed as either direct-current series motors fed by direct-current power network or single-phase series commutator motor fed by single-phase power network with the lower frequency of 16 2/3 Hz. Therefore, that obtained the dominant position for traction drives.

The selection of traction motor governed even the choice of traction systems. The common properties of commutator motors were the problem of rotary converters, i.e. mechanical commutators, which were the limiting design part of these motors from point of view of current loading. The negative properties of these motors were the proper commutation effects, which have not been practically solved up to date. The idea of utilization of simple induction motor without commutator for traction vehicle drives was topical from invention of this motor by Slavonic inventor N. Tesla (1896), who dwelt in the USA at that time. The proper design of that drives was connected with contemporary used control technology. In comparison with commutator motors, the main advantage of induction motors is the simple designs and smaller geometrical dimensions, as commutators occupy about a third of machine length, which is important from point of view of space placement of traction vehicle. The second advantage is the torque and current overloading and the last but not least advantage is the lower production cost. The disadvantage of induction motor was that it was not possible to control the motor revolutions using simple lossless method. At that time, control means of these motors did not allow to achieve the comparable control properties as for commutator motors practically up to now. Nevertheless, the solutions of these motor utilizations sometimes occurred at that time (Italy and Hungary railroads - Kandó system) but these solutions were not prospective from point of view of broader utilization.

Only the development of power semiconductor electronics and microelectronics has allowed utilization of the higher control type.

2. Power electronic control

The development of power semiconductor electronics and microelectronics has allowed utilization of new principles. Firstly, the power electronics has been used for commutator motors of direct current traction, where the switching devices (thyristors) have solved earlier loss resistor method of control by using lossless pulse control. The exceptionally previously-used series-wound motors are gradually replaced by separate-excitation motors. The reasons are the better dynamic properties used for automatic control (locomotive type 163, 162, 363). The modernization of vehicles with the conventional resistor controls, which are contemporary used, uses direct-current motors and the control systems are modernized using new generations of modular pulse converters, fitted with new switching devices. That simplifies the converters and diminishes their dimensions. The example of modernized vehicles with original motors is renovated subway vehicle or alternating-current pantograph unit, type 560, where thyristors IGCT are used as switching devices. The modernized traction circuit of subway vehicle, where the pulse control with new IGBT switching devices is used, is shown in **Fig. 1**. The vehicle is equipped with both resistor braking and recuperation. The original motors use separate-excitation regimes.

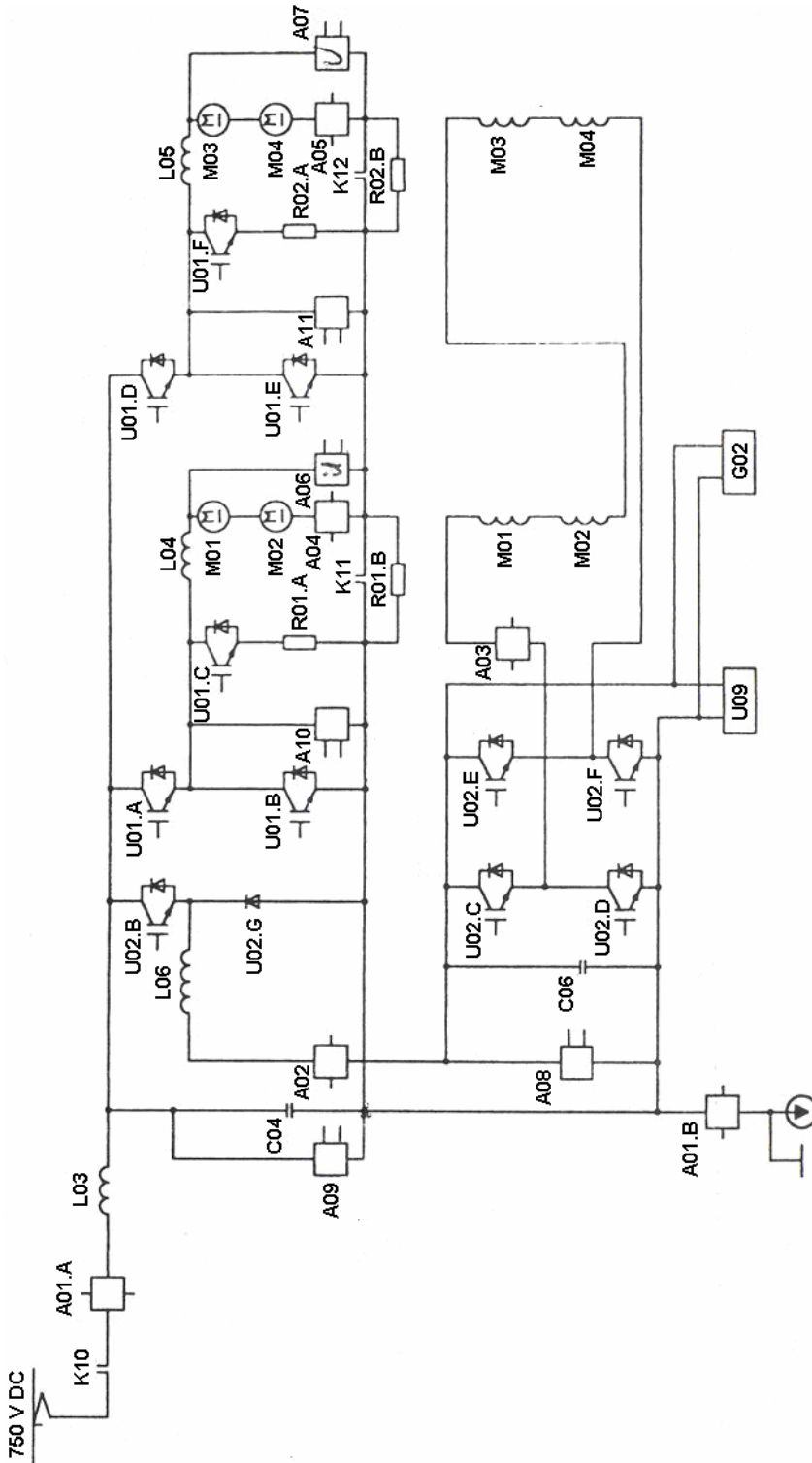


Fig. 1 Traction circuit of reconstructed subway vehicle

When the new switching devices (thyristors GTO, IGCT and switching transistors IGBT) have been especially used for frequency controlled inverters, favorable conditions for their broader application have been created especially for induction motor control area. From technical point of view, the long-lasting problem of mentioned mechanical commutator has been solved. It is interesting that for all drives with variable revolution control, the current commutation is the limiting factor regardless of current and motor types. From this point of view, the difference between commutator motors and frequency controlled non-commutator motors is given by the fact, that commutation is done by mechanical commutator or static converter for induction motor, where these problems are reliably solved today. The substantial simplification of frequency converter has been done during a short development period. That causes the reduction of power losses and dimension minimization. That is very important especially for small traction vehicles such as tramways, trolleybuses and motor units.

The up-to-date traction drives with non-commutator motors basically possess two parts, namely power and control units. The power unit is formed by induction motor with squirrel cage, which change energy practically lossless. Recently, an alternative solution of proper drive with non-commutator motor with permanent magnets has been suggested. New production technologies of permanent magnets using rare earth, mostly alloys such as neodymium – iron – boron or samarium – cobalt, where the higher value of magnetic saturation can be reached, allow the design of these motors. Synchronous motors with permanent magnets possess additional advantages in comparison with induction motors. Firstly, that are higher torques per motor weight, lower moments of inertia and lower temperature rises. The next advantage is that can produce maximum torque even for rest position, which is important property for traction drives. Contemporary, designers are able to build up these motors with power up to 180 kW. The designs of these motors considering their traction characteristics allow even the solution of gearless drives. The prospective utilization of these motors can be expected considering the realized powers especially for so called light transport systems such as electrical automobiles, electrical scooters but even light railroad vehicles, where the possibilities of direct individual wheel driving is suggested. That allows low-floor vehicle design. Considering the motor control the similar control algorithms as for induction motors are applicable. The idea of traction drive designs with induction motor or possibly synchronous motors has started from variant of voltage indirect converter (controlled inverters) shown in *Fig. 2*.

The proper circuit consists of direct-current intermediate circuit formed by capacitor. The voltage intermediate circuit is fed with direct-current line using input filter by either directly or through pulse converter controlled required voltage level. Additionally, the braking circuit is connected in parallel to direct-current circuit. It forms the pulse converter PM with braking resistor R_b , which consumes the power in the case of generator regime of induction motor or possibly this power can be recuperated into traction lines and consumed by another traction vehicle, which asks for additional circuit

modification. The proper converter of the basic design is shown in **Fig. 3**. That consists of six switching devices (GTO, IGBT, and IGCT) and six anti-parallel-connected diodes, through which the transient current is closed during changing-over of switch devices or that act as rectifiers for reverse power flow from motor into intermediate circuit.

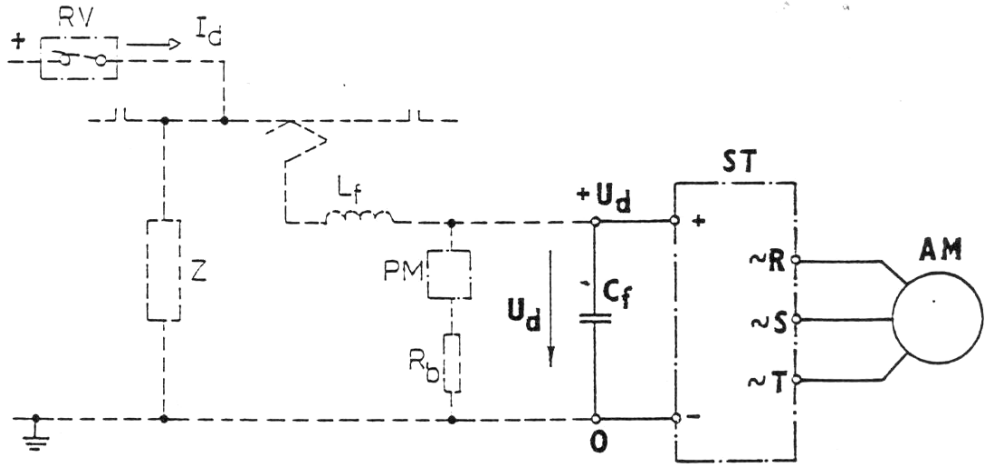


Fig. 2 Principal design of induction motor with voltage converter

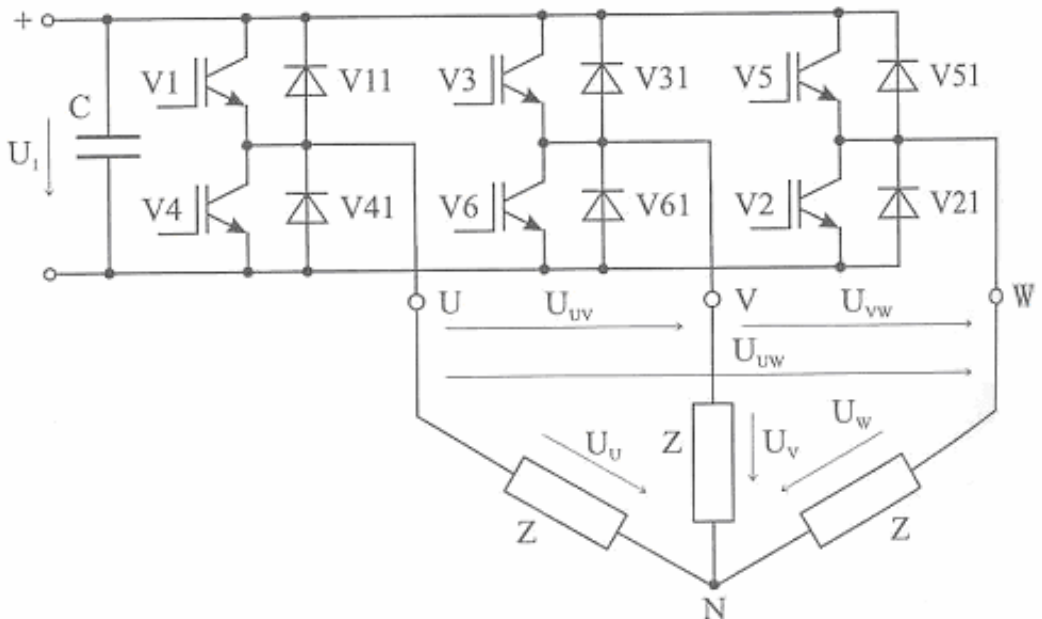


Fig. 3 Two-level converter connection

To obtain the demanded motor torque and revolutions, power converter devices are switched according to given algorithms in such a way that the demanded function of

U and f are accomplished. Various control methods have been worked out due to microprocessor development. Today, they are named as vector control methods, which are preferred by the Siemens firm or torque direct control method, which are preferred by the ABB firm. That is more complicated problem, which cannot be explained in the framework of this paper. The proper control of voltage and frequency, where the demanded function of U and f should be kept according to the certain algorithms, has been done separately for the converters of generation one. The example of that solution was the first Czech locomotive "Asynchron". The change of frequency and output RMS voltage values for today converters is achieved by pulse-width modulation (PWM method). In case of alternating-current feeding (15 kV, 16 2/3 Hz or possibly 25 kV, 50 Hz), the direct-current intermediate circuits are fed with rectifiers. Circumstances will be more complicated, when motors would be used as generators for electro-dynamic braking. The reverse power of motor – generator would be accumulated in the direct-current intermediate circuit, where it would be consumed by braking resistor similarly as for direct-current traction or possibly this power can be recuperated into traction lines. In that case, the power should be changed using converter. That would be frequency converter inversely connected with the given control algorithms and PWM. Then that is termed four-quadrant converter. The simplified block diagram of traction circuit design for multi-system vehicle of motor unit of type 681 – Pendolino is shown in **Fig. 4**. During run regimes, intermediate-circuit voltages of direct-current systems are controlled by pulse converters, which maintain the demanded voltage. Then any pair of bogies is fed using separate converters. When the regime for alternating-current system is used, the intermediate-circuit is fed by four-quadrant converter, which is used as a rectifier.

During brake regime, if conditions for recuperation are not fulfilled, power is consumed in the brake resistor, where the value of brake current is controlled by switching device PM. During recuperation for alternating-current system, power flows through pulse rectifier and transformer backward to power network.

In conclusion, it is necessary to stress that in addition of proper power consumption, it is necessary to solve electromagnetic compatibility (EMC) problems for new control systems. That means backward conductive effects of power consumption on power network from power factor viewpoint, current harmonics arising due to any switching devices and effects on safety systems, which can be interfered. Moreover, that can form the radiation of electromagnetic interference fields as sections of power network can act as transmission line stubs and magnetic or electric dipoles. Therefore numerous measures should be considered during design including various filters and shielding.

The utilization of frequency controlled converters into vehicle traction drives for dependent traction has developed an idea to replace direct-current series motors even for transmission systems of motor traction, where that were previously exclusively used, by simple design using induction motor.

The traction circuits are conceptually solved in such a way that alternating-current generators SG feed the direct-current intermediate circuits, which is formed by capacitors and switched brake resistors BS again, through controlled rectifiers GR. The controlled converters WR, which feed three-phase induction motors, are fed by intermediate circuits. The control algorithms are similar to converters for dependent traction. The design block diagram of traction circuit is shown in *Fig. 5*.

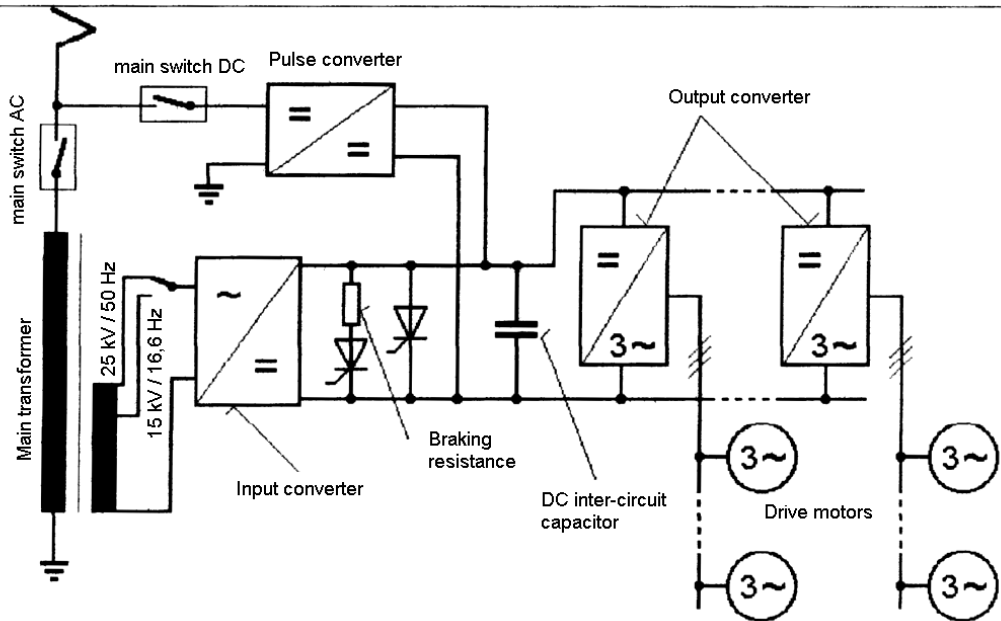


Fig. 4 Block diagram of three-system traction vehicle of type 681

3. Conclusions

The modernization of vehicle traction drives for dependent and independent traction is described. The generation development of proper traction drives and controls from viewpoint of application for railway vehicles is given. New application drives with synchronous motors with permanent drives, which are especially used for drives of light railroad vehicles but mostly for road vehicles, where their advantages are applied.

The development of power semiconductor electronics and microelectronics has allowed utilization of the higher control type. That has created favorable conditions for their broader application for both direct-current and alternating-current motors, especially for squirrel-cage induction motor control area. Recently, an alternative solution of proper drive with non-commutator motor with permanent magnets has been suggested, which offers additional advantages in comparison with induction motors.

In conclusion, it is necessary to stress that in addition of proper power consumption, it is necessary to solve very important electromagnetic compatibility (EMC)

problems for new control systems. That means backward conductive effects of power consumption on power network from power factor viewpoint, current harmonics arising due to any switching devices and effects on safety systems, which can be interfered. Moreover, that can form the radiation of electromagnetic interference fields as sections of power network can act as transmission line stubs and magnetic or electric dipoles. Therefore numerous measures should be considered during design including various kinds of filters and shielding.

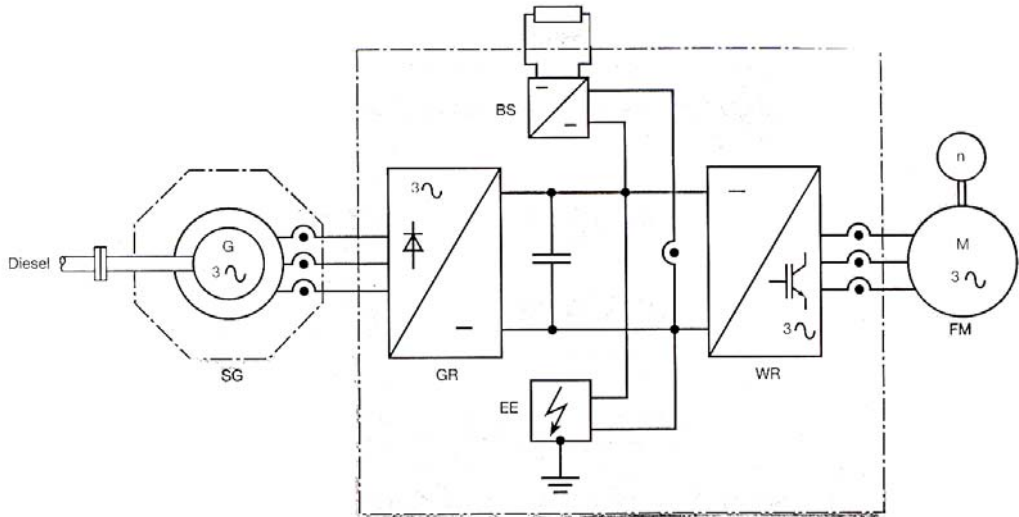


Fig. 5 Control block diagram for motor traction vehicle with induction drive

Lektoroval: Prof. Ing. Viktor Valouch, CSc.

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Resumé

MODERNIZACE TRAKČNÍCH POHONŮ

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Článek pojednává o modernizaci trakčních pohonů vozidel závislé a nezávislé trakce. Je zde uveden generační vývoj vlastního trakčního pohonu a jeho řízení z hlediska aplikačního užití na kolejových vozidlech. Pojednává se zde i o novém aplikačním pohonu se synchronním motorem s permanentními magnety, který nachází zejména uplatnění v pohonu lehké kolejové techniky, ale především u silničních vozidel, kde se uplatní jeho přednosti.

Summary

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The modernization of vehicle traction drives for dependent and independent traction is described. The generation development of proper traction drives and controls from viewpoint of application for railway vehicles is given. New application drives with synchronous motors with permanent drives, which are especially used for drives of light railroad vehicles but mostly for road vehicles, where their advantages are applied.

Zusammenfassung

MODERNISIERUNG DER TRAKTIONS-TREIBANLAGEN

Stanislav GREGORA, Jaroslav NOVÁK, Vladimír SCHEJBAL

Dieser Aufsatz beschreibt Modernisierung von Traktions-Treibanlagen der Fahrzeuge in abhängiger sowie unabhängiger Traktion. Die Entwicklung in „Generationen“ von eigenen Traktions-Treibanlagen ist hier beschrieben, sowie seine Durchführung vom Standpunkt der Applikation an Gleisfahrzeugen. Ein neues Applikations-Treibsystem mit Synchronmotor mit Permanentmagneten ist hier diskutiert. Dieses Treibsystem ist vor allem in leichter Gleistechnik, sowie bei Strassenfahrzeugen mit Vorteil anwendbar.