# MODERNÁ ELEKTRICKÁ TRAKCIA VOZIDIEL ŠKODA PLZEŇ
# MODERN ELECTRIC TRACTION OF ŠKODA PLZEŇ VEHICLES

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**Abstrakt** Výrobca elektrických hnacích vozidiel ŠKODA Plzeň – Transportations vyvíja a vyrába elektrické trakčné pohony na špičkovej technologickej úrovni. Elektrické vozidlá dodáva pre dopravné inštitúcie v ČR aj v zahraničí. Na tejto úspešnej činnosti sa podiela veľa absolventov inžinierskeho a doktorandského štúdia na Žilinskej univerzite v Žiline.

**Summary** The electric traction vehicle producing plant ŠKODA Plzeň – Transportations develops and produces electric traction drives with the top techological niveau. Electric vehicles are delivered to transport institutions in Czech Republic as well as abroad. Many Ma. and PhD. graduates of the University of Žilina take part in this successful activity.

## 1. INTRODUCTION

Today's producing plant ŠKODA Plzeň Transportation had been producing many thousands electric traction vehicles (ETV) during last about 80 years for railways, coalmines and city public transport. These vehicles are in service from the Pacific Ocean coast in Russia over Asia, Europe to the Pacific Ocean west coast in USA.

The successful ETV production is determined by the ŠKODA-staff great experience and by application of innovative technologies. It must be said that many MSc. and PhD. graduates of today's University of Žilina had been taking part in the modern traction drives ŠKODA development.

The electric traction drives ŠKODA development can be divided into 3 categories shown in Table 1.

*Tab. 1 ŠKODA electric locomotive drives classification*

| Category | Power control | Power control principle by DC supply systems | Power control principle by AC supply systems |
|---|---|---|---|
| **1st generation** | Contact, DC TM | Resistance voltage control +field weakening | Transformer voltage control + diode inverter + resistance field weakening |
| **2nd generation** | Inverter, DC TM | Thyristor chopper control + field weakening | Thyristor controlled rectifier + field weakening |
| **3rd generation** | Inverter, AC TM | GTOT/IGBT-VVVF inverter control and field weakening | GTOT/IGBT-VVVF inverter control and field weakening |

In this contribution, the development of the **3rd generation** ŠKODA electric traction drives and vehicles with asynchronous traction motors will be shortly described.

## 2. ELECTRIC LOCOMOTIVES 3rd GENERATION ŠKODA

### 2.1 Electric 3 kv dc locomotive škoda 85 e0

Two prototypes of electric locomotive (EL) 85 E0 were designed and built in 80th years: one of them with gearless asynchronous traction motor (ATM), see Fig. 1, the second one with gearbox and high revolutions ATM.

Main EL data:

Axle arrangement Bo'Bo'
EL mass 84 t
Maximum speed 120/160 km/h
Continuous traction power 3000/4000 kW

Resistance EDB max. braking output 3170 kW

Main 3-phases ATM data:
Continuous power 750/1000 kW
1-phase nominal voltage 1200 V
Continuous revolutions 317/443 r/min
Max. revolutions 417/736 r/min
Fully spring-mounted

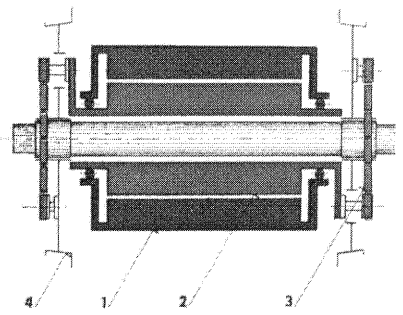



*Fig. 1 Gearless 85 E0 ATM: 1 – stator, 2 – rotor, 3 - coupling, 4 – driven axle*

The traction circuit of 85 E0 designed in 80th years was set up from:

- input voltage control thyristor choppers,
- DC intermediate circuit,
- DC/AC 3-phases current inverters with frequency control,
- four squirrel-cage 3-phases ATM.

Always two asynchronous traction motors (ATM) in one bogie were fed from one scalar controlled DC/AC inverter. The inverter control was re-constructed on the vector control later.

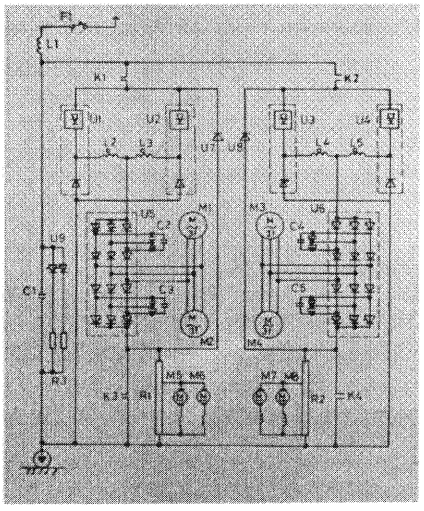


*Fig. 2 The first "asynchronous" ŠKODA locomotive 85 E0 traction circuit*

Both the 85 E0 are in service on ČD (Czech Railways) but the series production of them had not started because
the technology development, mostly in the inverter control technology and IGBT characteristics improving, enabled
to design the modern voltage inverters with both voltage and frequency (VVVF – Variable Voltage Variable Frequency) control.

### 2.2 Electric 3 kV DC shunting/universal ŠKODA 90 E

The 90 E, Fig. 3, was designed for shunting operations and as a light universal locomotive for railways. 4 pieces of the 90 E were built and sold to Severočeská uhelná (Northern Bohemia Coil Co.) till 1996.

*Fig. 3 The Bo'Bo', 1600 kW nominal output EL 90 E*

This Bo'Bo' EL was the first ŠKODA "asynchronous" locomotive with an own ŠKODA microprocessor traction drive control and with GTO-thyristors DC/AC inverter. Because of lower allowed reverse GTO-thyristors voltage had to be used an input chopper decreasing the up to 3600 V input supply voltage.

The traction circuit consists of the input chopper decreasing continuously the voltage for the intermediate DC circuit 2400 V and two VVVF GTO-inverters supplying each of them two in parallel connected 400 kW, 3-phases squirrel-cage asynchronous traction motors.

### 2.3 Electric equipment of the 3 kV DC emu seriec 471 ČD

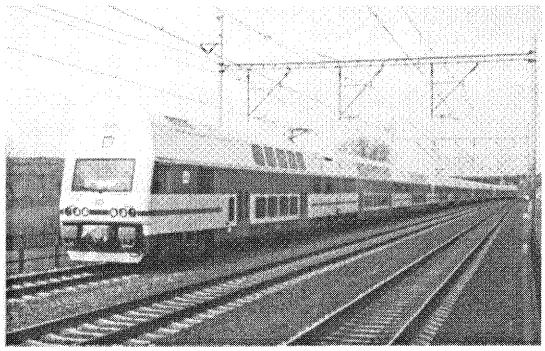


*Fig. 4 A train consisting of more 471 EMUs*

Characteristics of the 471 EMU were described in detail in [1]. The unit can consist of following vehicles:

- 471 series driving trailer,
- 971 series steering coach,
- 071 series intermediate passenger coach.

Main vehicles characteristics are given in Table 2.

*Tab. 2 Vehicles technical data*

| | |
|---|---|
| Track gauge | 1 435 mm |
| Traction supply system | 3 kV DC |
| Maximum speed (variants) | 140 (160, 120) km/h |
| 471 rated output | 2 000 kW |
| EDB output res./regenerative | 1 700/2 000 kW |
| Maximum traction effort | 180 kN |
| Maximum braking effort | 145 kN |
| Axle arrangement 471/071/971 | Bo'Bo'/2'2'/2'2' |
| Total vehicle length (by all) | 26 400 mm |
| Total width (by all) | 2 820 mm |
| Total height over rail head | 46 535 mm |
| Maximum axle load mass | < 20 t |

Every of vehicles have its own maximally autonomous operation/diagnostics control provided by "central vehicle computer", see Fig. 5. Only functions common for all vehicles in the train are controlled from "master" computer in the driver vehicle (471 or 971) via WTB connection. Other central vehicle computers work in "slave" regime in this case. A longer train can be set up from more EMU's and centrally controlled by driver. Also the automatic train operation (ATO) is controlled from the "master" central vehicle computer in driver's driving trailer (471) or steering coach (971) securing required automatic train movement, automatic target braking (ATB) and energy consumption optimisation (ECO).

This ČD unique automation system had been developed by VÚŽ Praha and digitalised by AŽD Praha by PhD. study graduates of Dpt. of Electric Traction University of Žilina Dr. Ing. A. Lieskovský and Dr. Ing. I. Myslivec.

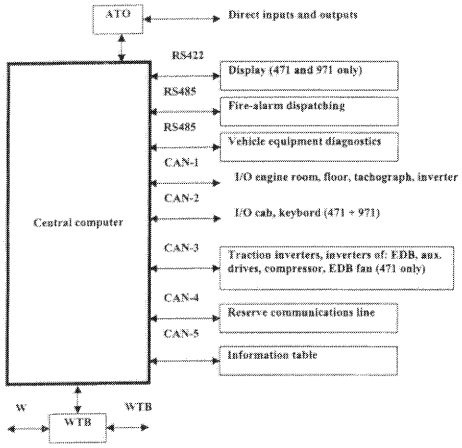



*Fig. 5 The microprocessor control and diagnostic system of EMU 471one vehicle*

The traction drive circuit (described more in detail in [1]) consists of:

- 3 kV DC supply via the main circuit breaker and the input filter inductivity,
- two intermediate DC 1,5 kV in series connected voltage circuits,
- four water-cooled inverters IGBT-VVVF 1,5 kV DC/3 x (0 ÷ 1130 V, 0 ÷ 200 Hz),
- four squirrel–cage 3-phases asynchronous traction motors with 2 stator windings fed – ever of them – from two different VVVF inverters with 1,5 kV input voltage. The motors have 4 x 500 kW output power. Traction circuit is in Fig. 6.

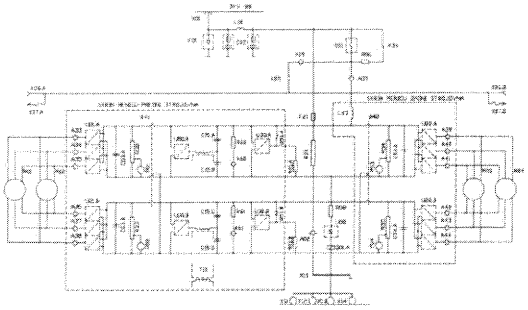
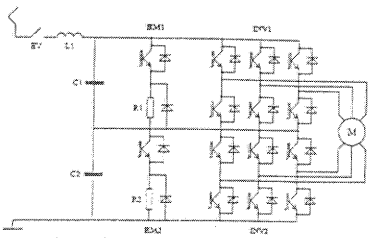


*Fig. 6 The 471 traction circuit*



*Traction circuit with asynchronous motor (double star connection) and IGBTs.*

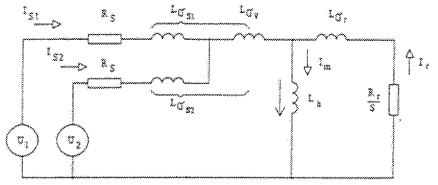


*Fig. 7 EMU 471 traction drive principle scheme and its substitution diagram*

The primary traction transformer winding can be switched over both for 25 kV and 15 kV systems. By the 3 kV DC supply system, the secondary traction transformer windings are utilized like inductors of the locomotive input current filter. Four traction motors are asynchronous three-phases ones with two in double star connected stator windings. The rated output on the motor shafts is 4 x 1 600 kW. Locomotive both traction and auxiliary asynchronous drives are processor-controlled enabling the multiple control of coupled locomotives from one locomotive or steering vehicle stand.

The double-deck passenger rooms are air-conditioned and divided to 1st and 2nd class departments. The central vehicle computer informs passengers both by electronic panel and sound announcement.

Totally 15 three-vehicles EMU's series 471 operate on suburban ČD routes today. Another 15 EMU's are ordered and will be delivered till 2007.

### 2.4 3-systems express locomotive 109 E

The locomotive is intended to haul EC/IC and express train in Czech Republic, Slovakia, Germany, Austria, Poland and Hungary as well as for the transport on EU "corridors" electrified by 3 kV DC, 25 kV/50 Hz and 15 kV/16,7 Hz supply systems.

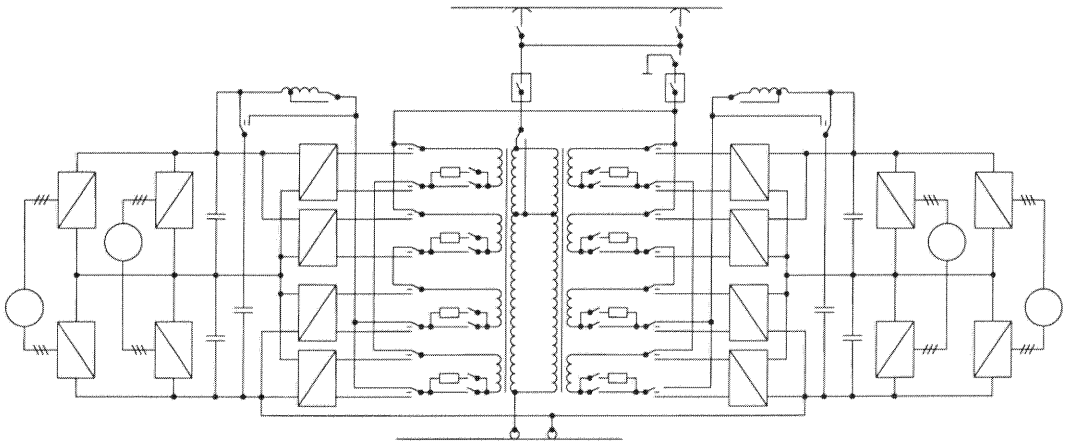


*Fig. 8 The principle traction circuit scheme of the 109 E 3-systems locomotive*

Totally 20 locomotives 109 E were ordered by ČD. The locomotive electric equipment is under construction and ought to be tested mounted into the mechanical part one of 85 E0 locomotives during the year 2005.

Main 109E technical parameters

Gauge 1 435 mm

Axle arrangement Bo' Bo'
Max. speed 200 km/h
Draw-hook continuous power 6 050 kW
Speed at the continuous power 102 km/h
Draw-hook traction effort
by the continuous power 213 kN
Max. draw-hook traction effort 274 kN
Max. one traction motor phase

acceleration current 647 A
EDB power at the wheel-rim:
regenerative brake 6 963 kW
resistor brake 4 700 kW
Max. EDB braking effort 226 kN
Vehicle length over buffers 18 000 mm
Diameter of (new) wheels 1 250 mm
Locomotive max. width 3 070 mm
Locomotive max. height above the top of rail 4 280 mm
Total mass 86 t (+3%, -1%)
Axle load 21.5 t
Bogie mass 15.8 t
Min. curve radius 120 m

## 3. TRAMWAYS ŠKODA

The rapidly decreasing orders of new electric locomotives after the social changes in the Middle Europe and Soviet Union made the plant ŠKODA to fetch a new production and trade branch. It was found in the production of modern tramcars with asynchronous traction drives for Czech cities and for the export, i.e. to the USA.

The first tramcar called ASTRA was originally equipped by firma ELIN traction drive with 3-phases asynchronous TM and air-cooled IGBT voltage VVVF inverters connected directly to 600/750 V DC supply voltage.

Maximum deceleration value (normal operation) 1,3 $m/s^2$
Vehicle floor height over the rail top:
in lower part 350 mm
in taller parts 780 mm
Vehicle body length 20 090 mm
Vehicle mass – empty 24 200 kg ± 5%
Vehicle mass – fully occupied 39 740 kg
Passengers max. number 221
Traction output: rated/max. 4 x 90 kW/500 kW
Regenerative/resistance EDB output 750 kW
Emergency brake: 4 jaw type rail brake

Since 2000, trams ASTRA and following tram types are produced with own ŠKODA inverters IGBT-VVVF controlled by ŠKODA microprocessor system.

### 3.1 Three-sectional low-floor tram ŠKODA 03 T ASTRA

The three-sectional low-floor tramway car ŠKODA of the 03 T type can operate either in the "classic" city rail transport or in the rapid city/suburban transport. Thanks to the arrangement of cabling and the use of materials with the attestations of incombustibility, it is suitable also for use in tunnels. The middle low-floor part of the tramway car makes possible the comfortable entrance and exit for passengers with a reduced mobility. The disengaging platform makes easier the transportation of the passengers with a reduced mobility with a wheel chair or with a buggy.

Main vehicle data:

Axle arrangement Bo'Bo'
Max. speed in city/rapid transport operation 50/70 km/h
Maximum construction speed 75 km/h
Maximum service speed 70 km/h
Maximum acceleration value 1,5 $m/s^2$
Emergency brake max. braking effort 4 x 70 kN (≅ up to ca 6 $m/s^2$ deceleration value.

### 3.2 Five-sectional low-floor tram ŠKODA 05 T – VEKTRA

Semi low-floor tramcar vehicle VEKTRA consists of five sectional car bodies mounted on three traction two-axle bogies. The vehicle was developed as a functional sample on basis of tram SKODA 03 T. Vehicle is driven by asynchronous traction motors powered by two traction inverters using IGBT SKIIP modules. Vehicle is equipped by both transparent visual and acoustic microprocessor controlled info system. Tram is also equipped for easy transport of disabled passengers.
Tram VEKTRA has the axle arrangement Bo'Bo'Bo'. The not driven sections both by VEKTRA and ASTRA are hung-up without bogies. At the moment, a VEKTRA
variant for Prague city transport is prepared where 20 vehicles were ordered. Another 6 vehicles are built for Cagliari (Italy).

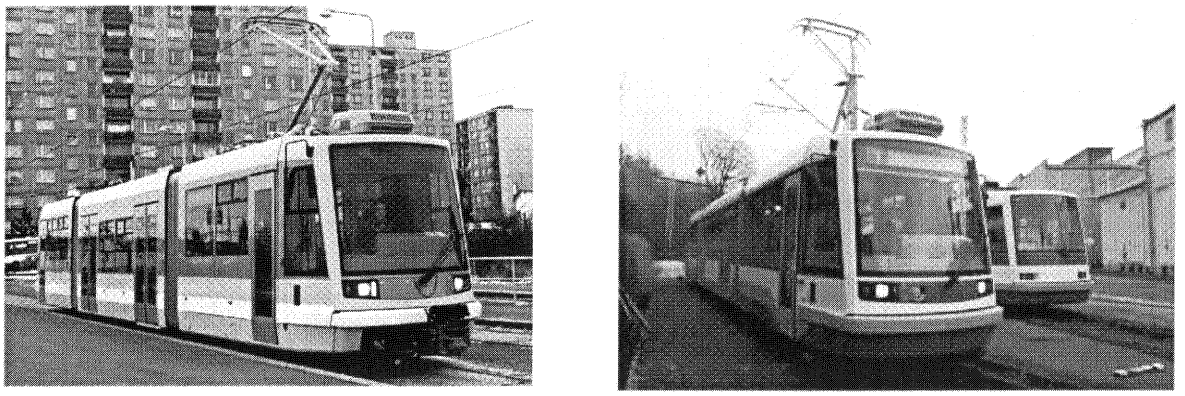


*Fig. 9 Tram ASTRA in Plzeň (left) and in Ostrava (right), CZ*

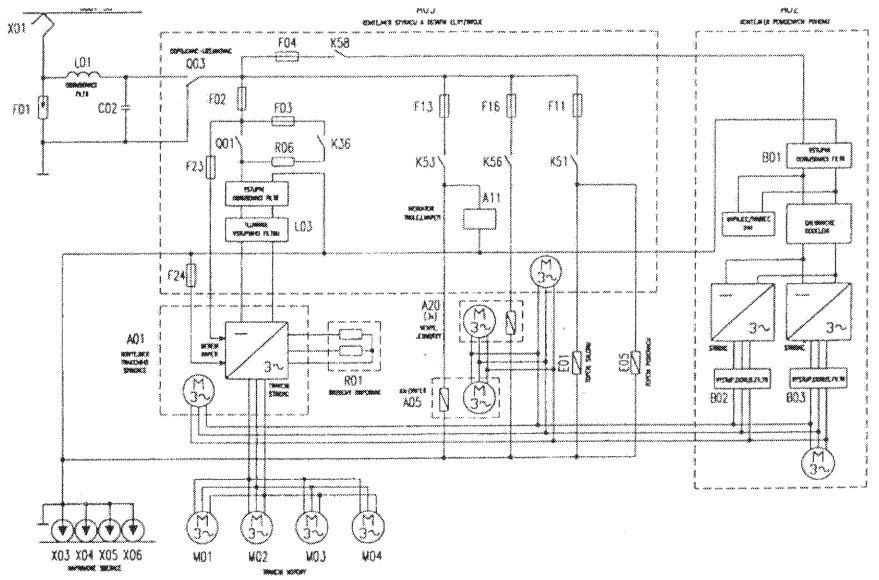



*Fig. 10 Tram ASTRA traction circuit*

*Fig. 11 Tram VEKTRA tested in city transport in Plzeň*

### 3.3 Three-sectional bi-directional low-floor tram ŠKODA-INEKON 10 T

The design of ŠKODA-INEKON 10 T was developed from the tram ASTRA design with some upgraded parameters. Asynchronous traction motors and processor-controlled IGBT-VVVF voltage inverter enabling the regenerative EDB reduce the energy consumption demand and the maintenance costs. The vehicle will conform to the requirements of us both in the classic urban public transport systems and on the rapid transport lines.

These trams are exported to Portland and Tacoma, USA, see Fig. 12.

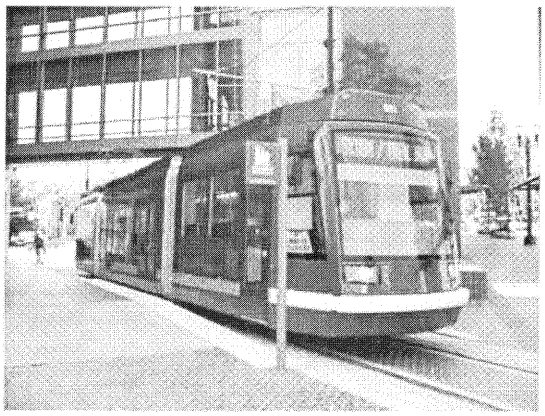


*Fig. 12 Tram ŠKODA 10T in Portland, USA*

Main vehicle parameters

Wheel set arrangement Bo'Bo´
Maximum operation speed 70 km/h
Construction speed 75 km/h
Body length 20 130 mm
Floor level above the rail surface:
low-floor section 350 mm
higher level floor section 780 mm
Wheel diameter new/worn 610/530 mm
Empty vehicle mass 28 800 kg
Normally loaded vehicle with a driver 39 060 kg
Continuous output 4 x 90 kW
Maximum acceleration output 645 kW
Maximum breaking output 960 kW

### 4. TROLLEYBUSES ŠKODA 24 Tr AND 25 Tr

The asynchronous drive with IGBT-VVVF inverter was used also by trolleybuses ŠKODA 24 Tr (solo vehicle) and 25 Tr (articulated two-sectional vehicle). Both the vehicles are maximally unified one to another and together with buses IRISBUS produced in co-operation KAROSA (CZ)/RENAULT (F) for CZ as well for the export. This minimized the needed spare parts number in city public transport corporations where both buses and trolleybuses operate.

*Tab. 3 Trolleybus ŠKODA 24 Tr main characteristics*

| | |
|---|---|
| Continuous motor power | 210 kW |
| Length/width/height | 11 990 / 2 500 / 3 500 mm |
| Length with collectors pulled down | 12 860 mm |
| Platform height of all doors | 320 mm |
| Outer turning circle diameter | 22 600 mm |
| Vehicle mass | 11 500 kg |
| Maximum vehicle speed | 65 km/h |
| Seating passengers | 30 persons |
| Standing passengers | 69 persons |

*Tab. 4 ŠKODA 25 Tr main characteristics*

| | |
|---|---|
| Continuous motor power | 240 kW |
| Length/width/height | 17 800 / 2 500 / 3 580 mm |
| Length with collectors pulled down | 18 400 mm |
| Platform height of all doors | 320 mm |
| Outer turning circle diameter | 23 400 mm |
| Vehicle mass | 17 700 kg |
| Maximum vehicle speed | 65 km/h |
| Seating passengers | 40 persons |
| Standing passengers | 110 persons |

The greatest part of the vehicle electric equipment is placed under the vehicle roof, i.e. traction IGBT-VVVF inverter, auxiliary drives inverter, vehicle battery charging inverter, vehicle room heating (and – optionally – air- conditioning) inverter, main switches and fuses and inverter control units. Vehicles have regenerative and resistance EDB and

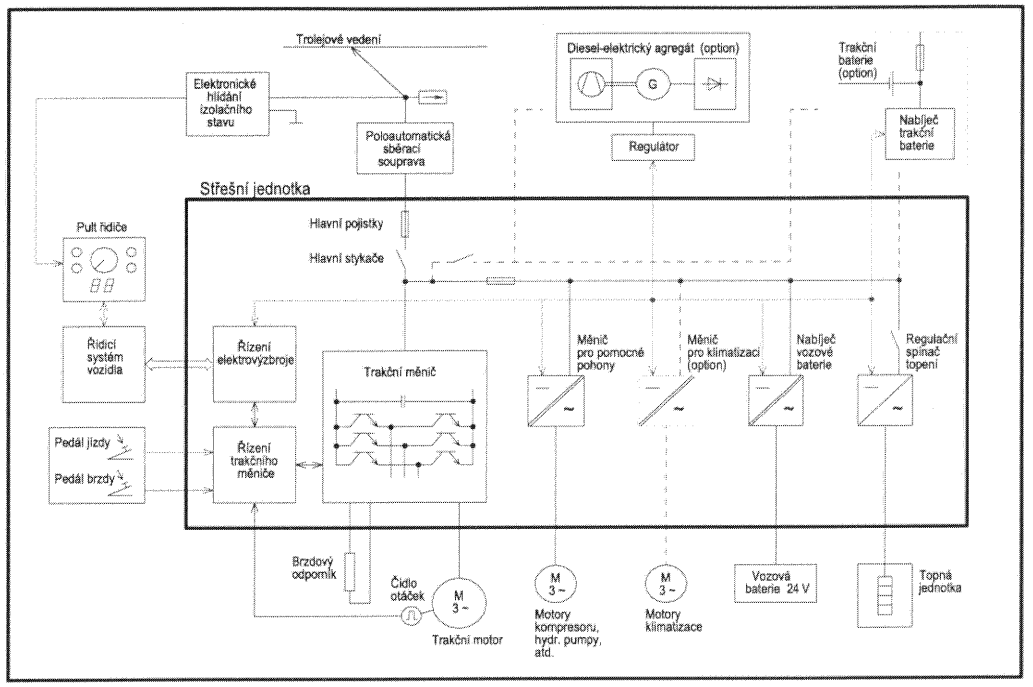



*Fig.13 The trolleybuses 24 and 25 Tr main circuits*

continuous electronic isolation diagnostics. Either the diesel-electric or traction battery auxiliary traction supply enabling to overcome a short route parts without trolley supply can be delivered optionally.

*Table 5 ŠKODA 25 Tr traction inverter main data*

| | |
|---|---|
| Continuous rated output | 225 kVA |
| Nominal DC supply voltage | 600 V |
| Output AC voltage | 3 x (0 ÷ 420 V) |
| 1-phase output nominal/max. Current | 310/500 A |
| Output frequency | 0 ÷150 Hz |
| Modulation frequency | 2 kHz |
| Input capacitor capacitance | 12 mF |
| Nominal power losses by 50 Hz | 3,9 kW |


*Fig. 14 The first articulated trolleybus for Boston tested in Plzeň*

Trolleybuses ŠKODA are delivered not only for Czech cities. Totally 150 vehicles were delivered to California, USA, in last years. Total 28 sets of electric equipment for „solo" trolleybuses were delivered in 2004 and 32 sets for articulated trolleybuses are produced and tested for Boston, see Fig. 14.

The vehicles are completed in Boston in co-operation with the body producing firma NEOPLAN – USA.

## 5. FINAL NOTES

The division ŠKODA Transportation Plzeň has adapted its production strategy after the great political, social and economical changes in the Middle Europe in 90$^{th}$ years. The serial production of hundreds electric locomotives – mainly for the Czechoslovak and Soviet Railways - had to be replaced by the production of smaller series more technologically exacting electric traction vehicles inclusive trams and trolleybuses.

The successful development of own asynchronous drive design and its microprocessor control system enables the SKODA to compete with its products to world-known producers on international markets.

## REFERENCES

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