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Activity 3.6. Work visit at Technical University of Moldova

Scientific and Research Activities on TUIASI over the Project:

“Improving the cross-border public transportation using electric buses supplied with renewable energy”

Project EMS-ENI code 2SOFT/3.1/54

„Gheorghe Asachi” Technical University of Iasi, Romania (TUIASI)

Research Expert 2, Ș.l.dr.ing. Gabriel Chiriac

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G.A. No. 3.
Analysis of the electric bus optimal functionality.

Activity 3.1. Analysis of the electric buses.

Activity 3.2. Analysis of the auxiliary loads.

Output 3.1.

Increasing the energy efficiency of the auxiliary loads.

Output 3.2.

Increasing the overall energy efficiency of the electric bus

Activity 3.1. Analysis of the electric buses

Description and methodology

An overview related to the electric vehicles in general, and to electric buses, in particularly, with benefits of using of the electric power supply instead of traditional fuels and the impact on the environment.

A research and analysis regarding the functionality and the energetical aspects of the electric buses: the structure of the bus, the drive system, the auxiliary system and its equipment, efficiency, the traction motor.

Realization of a test bench (TUIASI) including an electric motor and generator as variable load.

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Outputs on the Activity 3.1. Analysis of the electric buses

1. The benefits of using of the electric power supply instead of traditional fuels and the impact on the environment.
2. **Perspectives for fully electric buses in the EU.**
3. Technical limitations of using the electric buses.
4. **Electric buses types to use in urban and interurban transportation.**
5. Electric buses technology configurations.
6. **The drive system and the optimization of the electric buses operating.**
7. The auxiliary equipment used on the electric buses: main equipment, energy consumption and optimization.
8. **Electric motor used to drive the electric buses.**
9. **Test bench achievement**: the drive system of the electric bus accomplished in the laboratory: it permits to study the operating drive system, the energy consumption, speed, braking time, energy to be recovered.
10. Electric buses operating at variable loads. Studies and experiments on the test bench in laboratory.

Activity 3.1. Analysis of the electric buses

1. The benefits of using of the electric power supply instead of traditional fuels and the impact on the environment.

Within the European Union the road transport is the second largest producer of carbon dioxide (CO2), one of the greenhouse gases responsible for climate problems.

Fully-electric buses have potential to significantly **reduce carbon dioxide emissions,** up to 75%.

Advantages that electric buses offer beyond the cost consideration:

Increasing urban quality of life: **lower air pollution** and **lower noise** , Attractive to the people, **Using renewable energy**, Energy security , Stimulating European industry.

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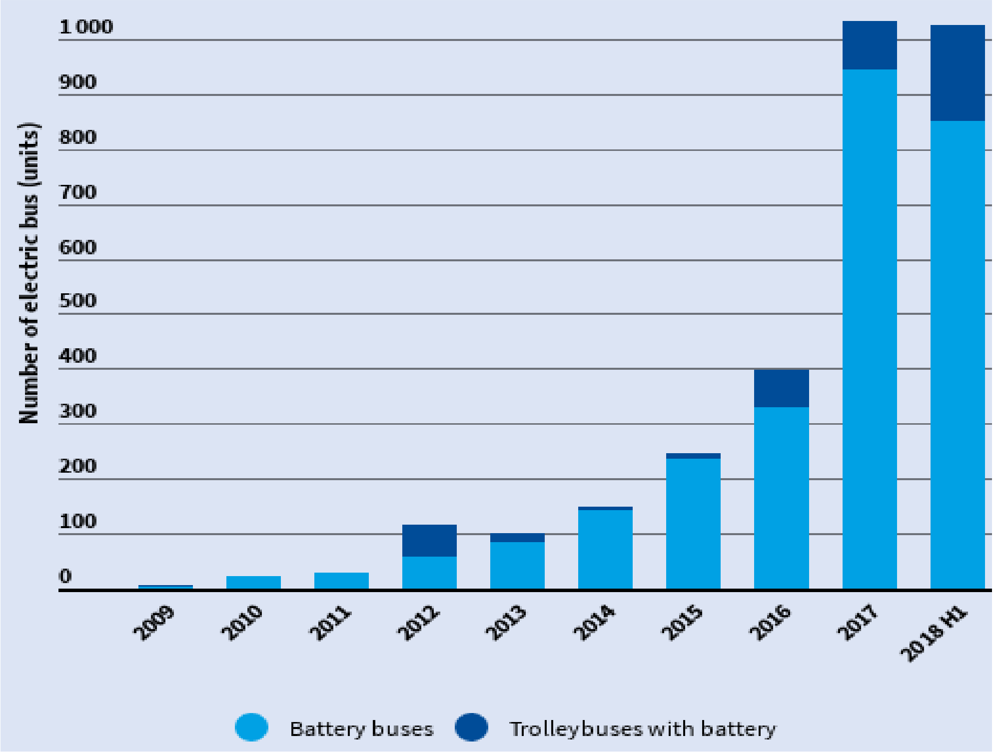
2. Perspectives for fully electric buses in the EU



The European market of electric buses is rapidly increasing.

Some countries are planning to ban diesel vehicles or combustion engines, while many cities are also committing to low/zero emission zones within the cities.

Electric buses are not equally distributed over European countries, with the Netherlands, UK, France, Poland and Germany accounting for more than half the total number of electric buses in Europe.

3. Limitations of using the electric buses

Technological limitations:

- Limited range.
- Grid and charging infrastructure.

Limitations due to the lack of knowledge:

- The operational characteristics, and maintenance necessary;
- Strategies and techniques to optimize the design and implementation of an electric buses project;

Other limitations aspects:

- Difficulties for agencies in changing procurement practices: typically use rigid financial management models, low-risk procurement.
- Traditional procurement practices also do not allocate responsibilities for the new tasks associated with electric buses operations, such as maintaining the batteries and grid infrastructure.

4. Electric buses types to use in urban and interurban transportation

DEPOT CHARGING

OPPORTUNITY CHARGING

COMBINATION

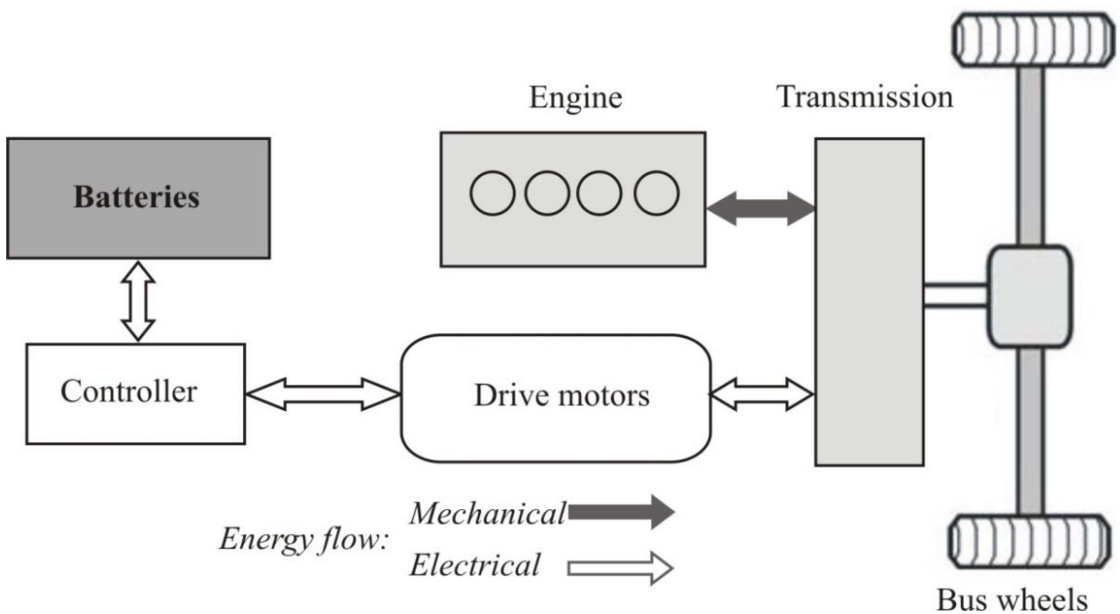
Overnight charging – ONC.

Opportunity charghing - OC.

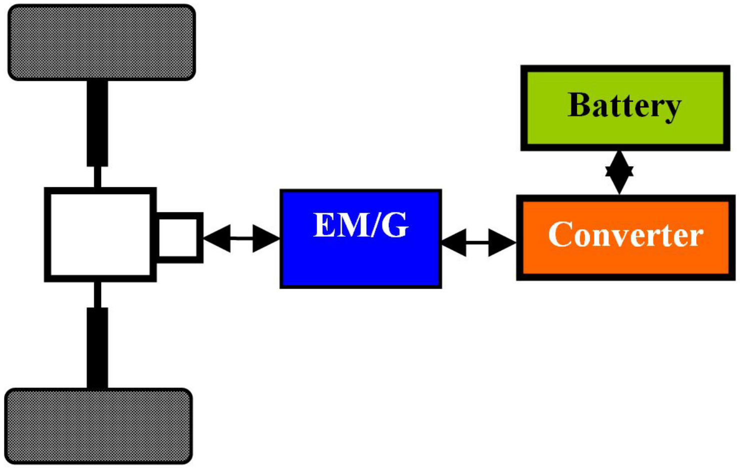
Combining depot charging and opportunity charging.

5. Electric buses technology configurations

- **Hybrid electric buses (HEBs)**
- **Battery electric buses (BEBs)**
- **Fuel cell electric buses (FCEBs)**



Paralel electric drive system for hybrid electric buses.



Battery electric drive system for electric buses

The main electric bus components:

-The drive motors,

-an Auxiliary Power Unit (APU),

-controllers and inverters,

-the energy storage device and

-other auxiliary systems, such as air conditioning and lighting.

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6. The drive system and the optimization of the electric buses operating

The energy for an electric bus is stored in a battery (or ultracapacitor) to be supplied to the electric motor.

Battery Electric Buses (BEB)

Increasing the battery capacity results in an increased range, however this also increases the vehicle cost, increases weight, and decreases passenger capacity.

Overloading of the local electricity grid is another infrastructure challenge that arises through electric buses implementation, especially if large numbers of opportunity BEBs are used in one area.

7. Electric motors used to drive the electric buses

They have frequent starts and stops, they need high acceleration rate for fast starting and capability to work in harsh environments.

Motor drives require high efficiency over a wide speed and torque region, high torque and power densities, fast dynamic response, simple construction, high reliability, regenerative braking capability, good controllability and low noise

- **DC motors**
- **Squirrel cage induction motors (IM motors)**
- **Permanent magnet brushless motors (PM)**
- **Switched reluctance machines (SRM)**

Comparison between electric motors to drive the electric buses.

Characteristic	DC	IM	PM	SRM
Efficiency	2	4	5	4.5
Weight	2	4	4.5	5
Cost	5	4	3	4
Total	9	12	12.5	13.5

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8. The auxiliary equipment used on the electric buses: main equipment, energy consumption and optimization

HVAC: Heating,

Ventilation, and

Air Conditioning.

Other auxiliaries:

- Battery cooling,
- Air compressor,
- Steering,
- Doors drive,
- Lights.

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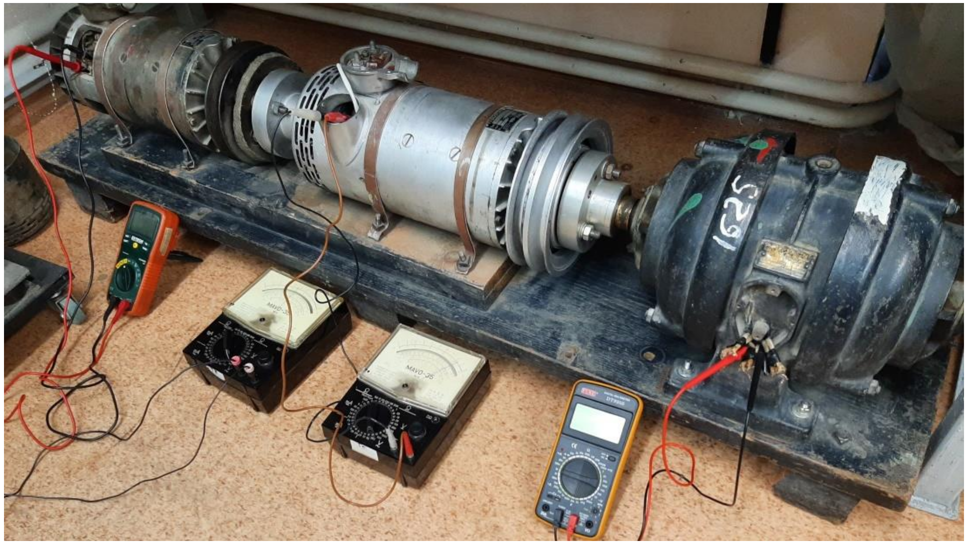
ELECTRIC BUS TEST BENCH

An important aspect is to analyze the electric traction system for the electric bus at variable loads. The principles are studied in the laboratory on a test-bench including an electric motor and generator as variable load.



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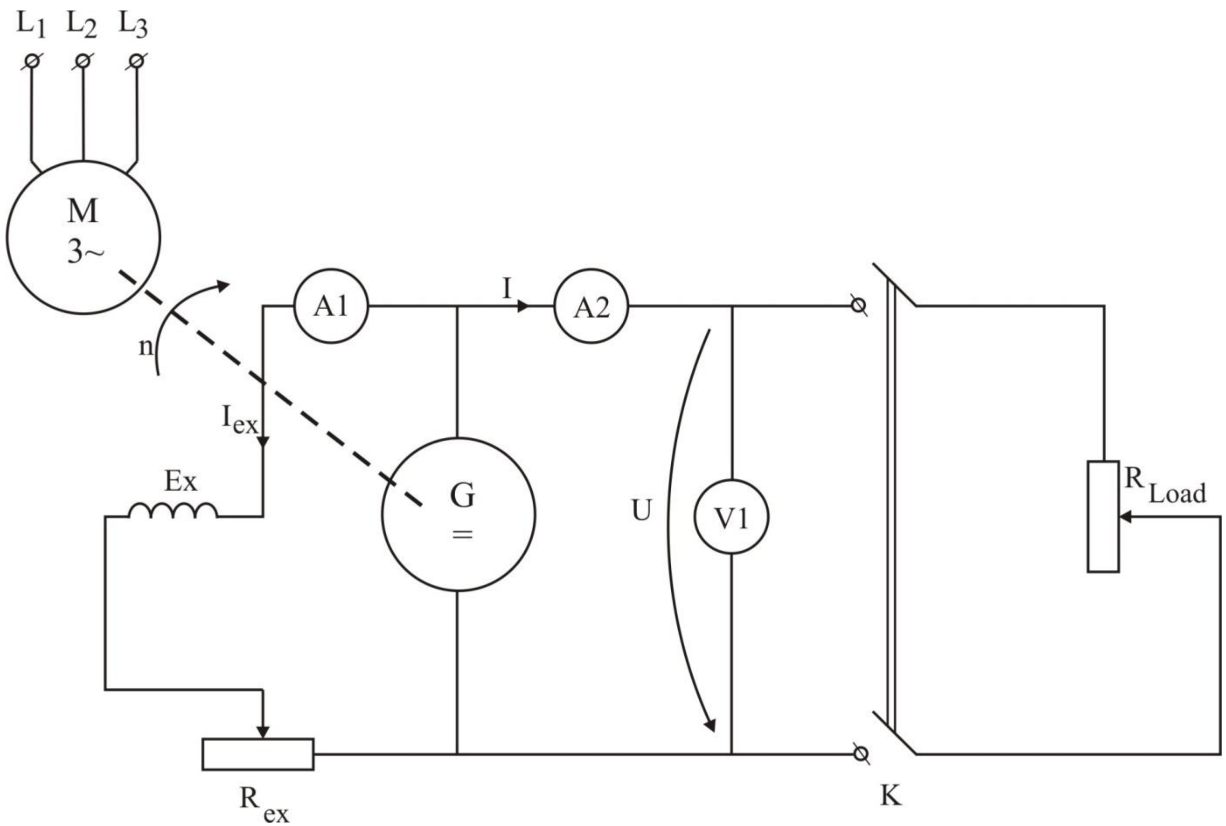

Electric diagram of the traction system drive structure.

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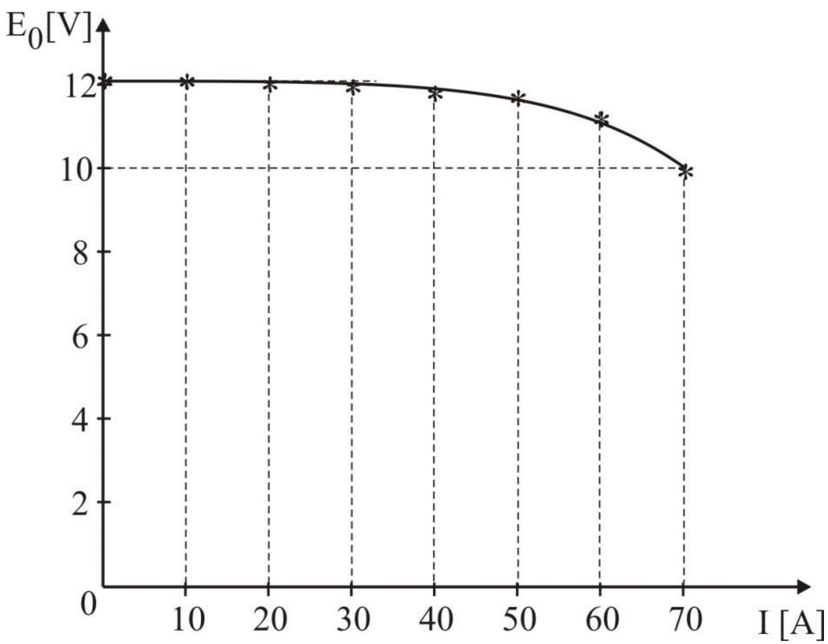
External characteristic of the DC generator



Experimental control characteristic of the DC generator

I – load current (variable load by R variable).

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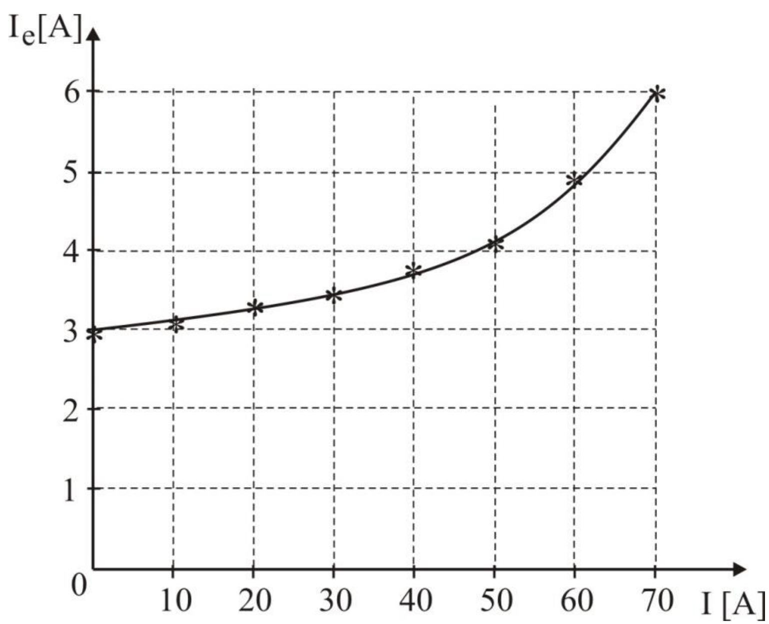
Control characteristic of the DC generator



Experimental control characteristic of the DC generator

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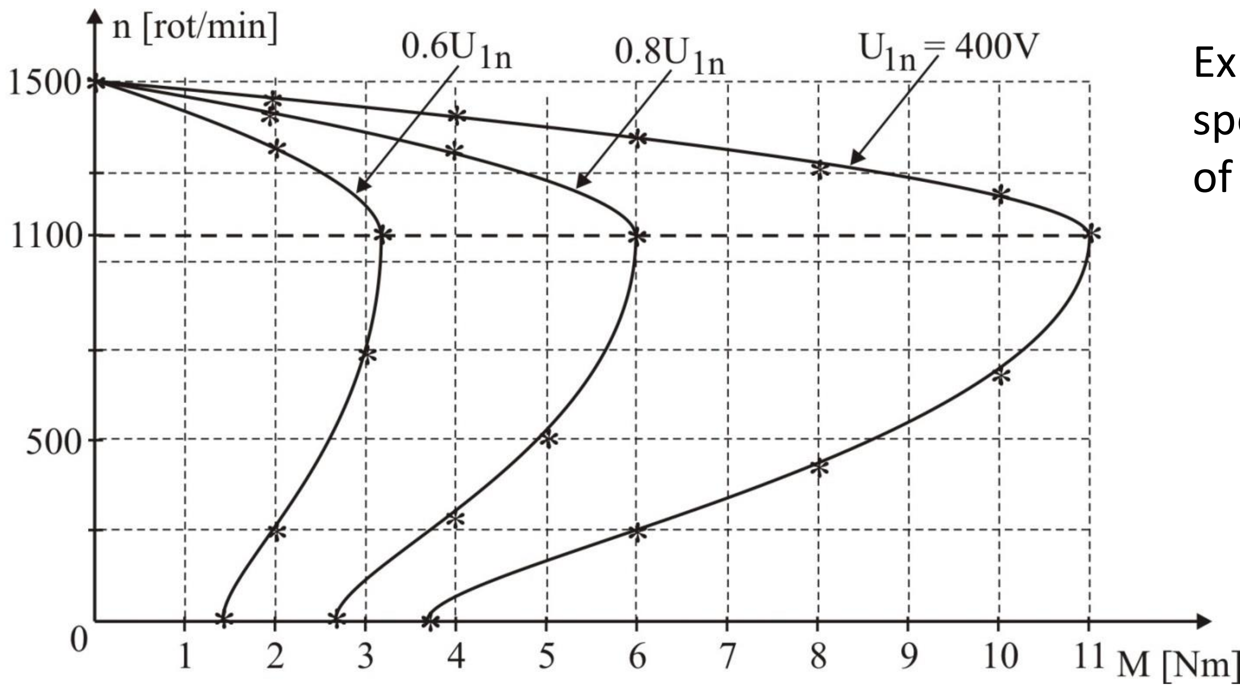
Torque speed characteristics of the three-phased AC motor

The torque speed characteristics are considered for the next supply voltages:
0.6 Un;
0.8 Un;
Un = 400 V.



Experimental torque speed characteristics of the AC motor.

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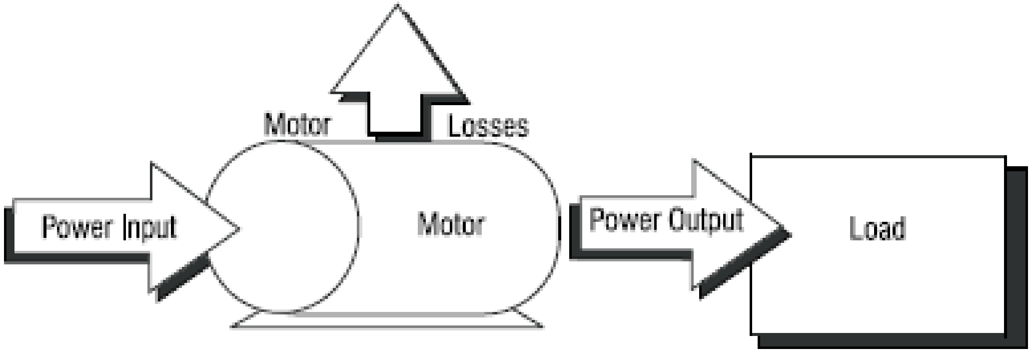
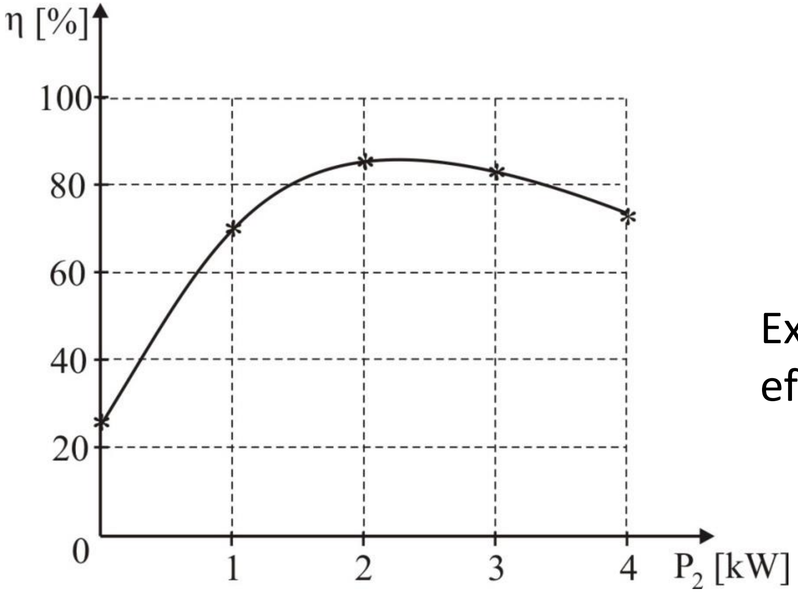
Efficiency of the three-phased asynchronous motor



Power configuration for an electric motor.



Experimental characteristic for the efficiency of the AC motor.

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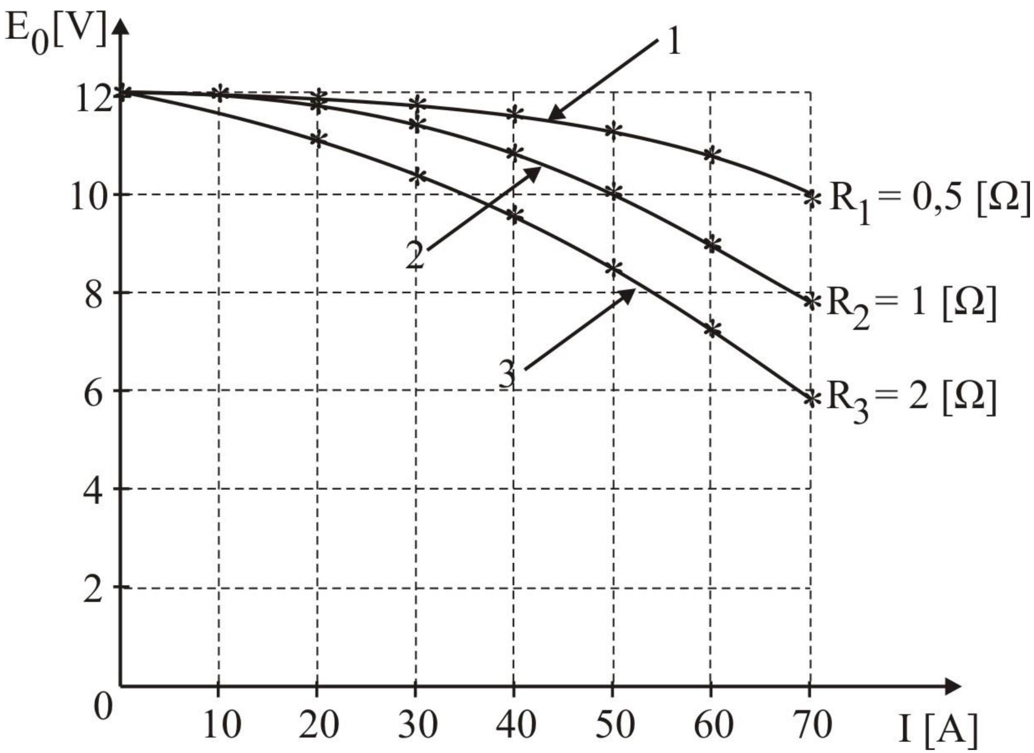
Experimental external characteristics of the DC generator for different resistive loads



Experimental external characteristic of the DC generator for different resistive loads.

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Activity 3.2. ANALYSIS OF THE AUXILIARY LOADS

Description and methodology

A research and analysis regarding the auxiliary loads on the electric bus in order to estimate and to improve their energy efficiency.

Study a heating/cooling system to be used on an electric bus from thermal efficiency point of view.

It will be developed an automation system based on PLC (Programmable Logic Controllers) for an optimal control of the heating/cooling devices.

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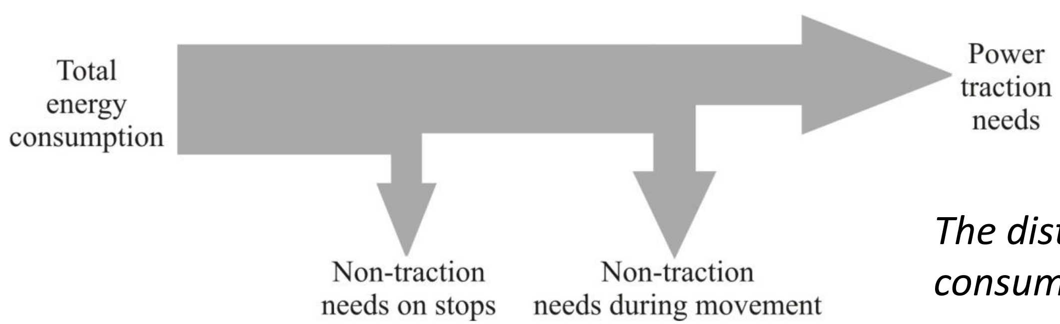
GENERAL ASPECTS ON AUXILIARY LOADS

- The fixed energy consumption auxiliaries, which are used both when the electric bus is standing and when it is running;

- The variable energy consumption auxiliaries, which depend on the fluctuant characteristics (e.g. number of the bus stations, number of traffic lights on the route, number of the curves, weather as sunny/cloudly, day/night, other traffic conditions).



The distribution of electric energy consumed by vehicles.

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The auxiliary systems can be considered also of two categories:

- Auxiliary systems **for safety** (lights, horn, window cleaner, doors opening etc.) and,

- Auxiliary systems **for comfort** (climate control, media etc.).

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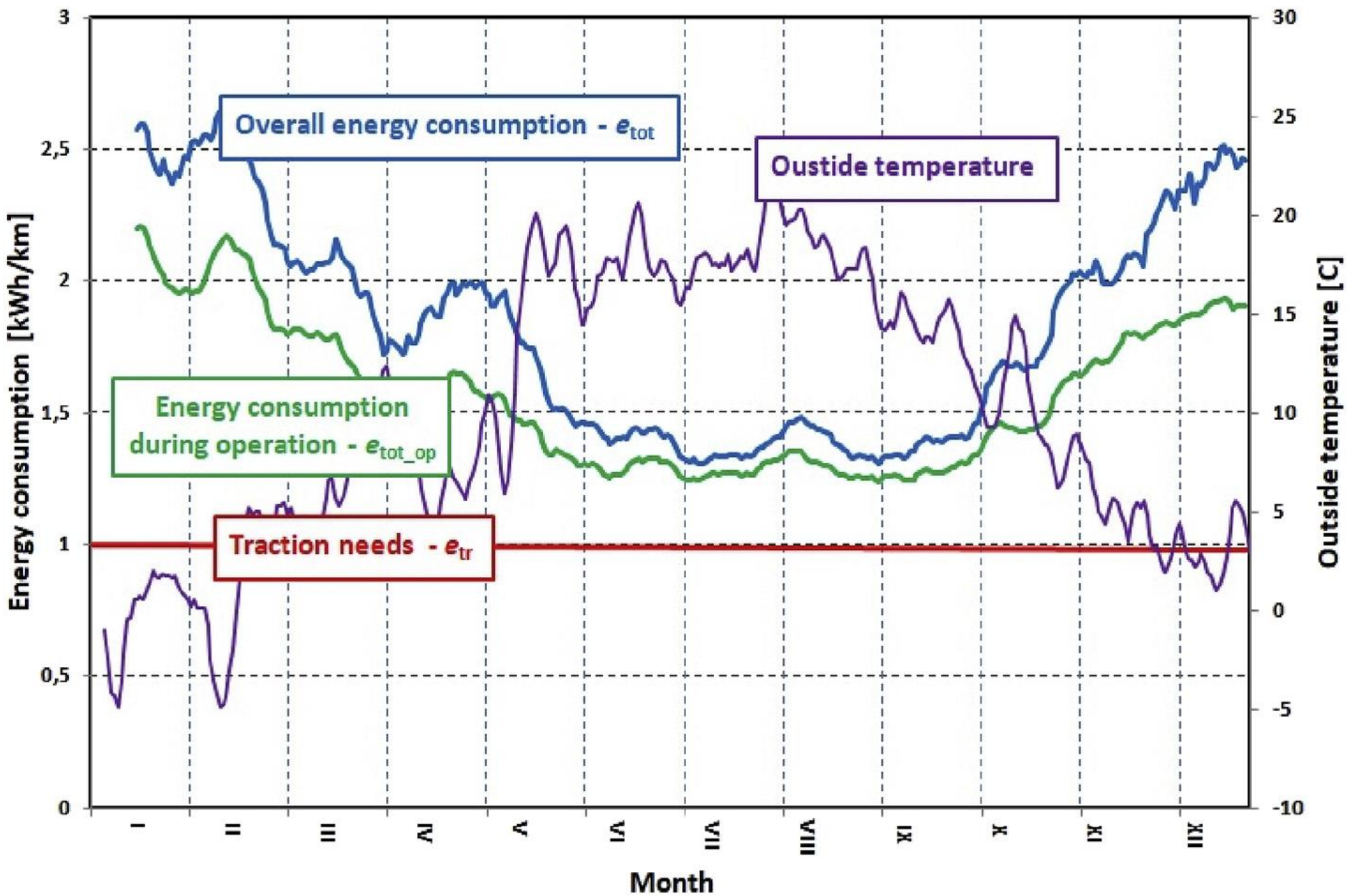

The values of average energy consumption and daily average outside temperature in annual scale, [Bartłomiejczyk, 2018].

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COMFORT OF THE PASSENGERS AND THE AUXILIARY ENERGY DEMAND

What a person perceives as a comfortable temperature depends on many parameters:

1. **Air humidity**: humidity causes the temperature that is perceived by a person to be amplified.

2. **Air velocity**: if there is an air flow around the person, the heat energy transfer between the person and the ambient air increases.

3. **Radiation**: besides the cabin air being heated up by the sun, a person could also feel the direct effect of the radiating sun.

4. **Seasonal effects**: comfort is also closely related to temperature differences. If the outside temperature in the winter is 0°C, an inside temperature of 15°C might already feel warm. Instead, in the summer, this setpoint might be too low.

5. **Metabolism**: differences between persons in metabolism cause differences in the perceived comfort in temperature (body weight, gender and age).

ECO-Comfort

Optimization of the thermal system of electric vehicles is defined as the ECO-comfort functionality. This functionality can be summarized in two topics:

1. Dynamic temperature setpoint: A temperature setpoint can vary over the day to account for ambient temperature changes. Similarly, the same method can be applied between summer and winter conditions.

2. Pre-conditioning: Pre-conditioning means that the cabin climate is already controlled towards the desired temperature while the vehicle is still connected to the charger either in the depot or in route at terminal stops. This way, the initial required energy peak to control the temperature is taken directly from the grid rather than from the battery. This improves also the driving range of the vehicle.

ENERGY MODEL FOR AN ELECTRIC BUS

The traction energy consumption is dependent on the sum of resistance forces *F*res, shown in Equation (1).

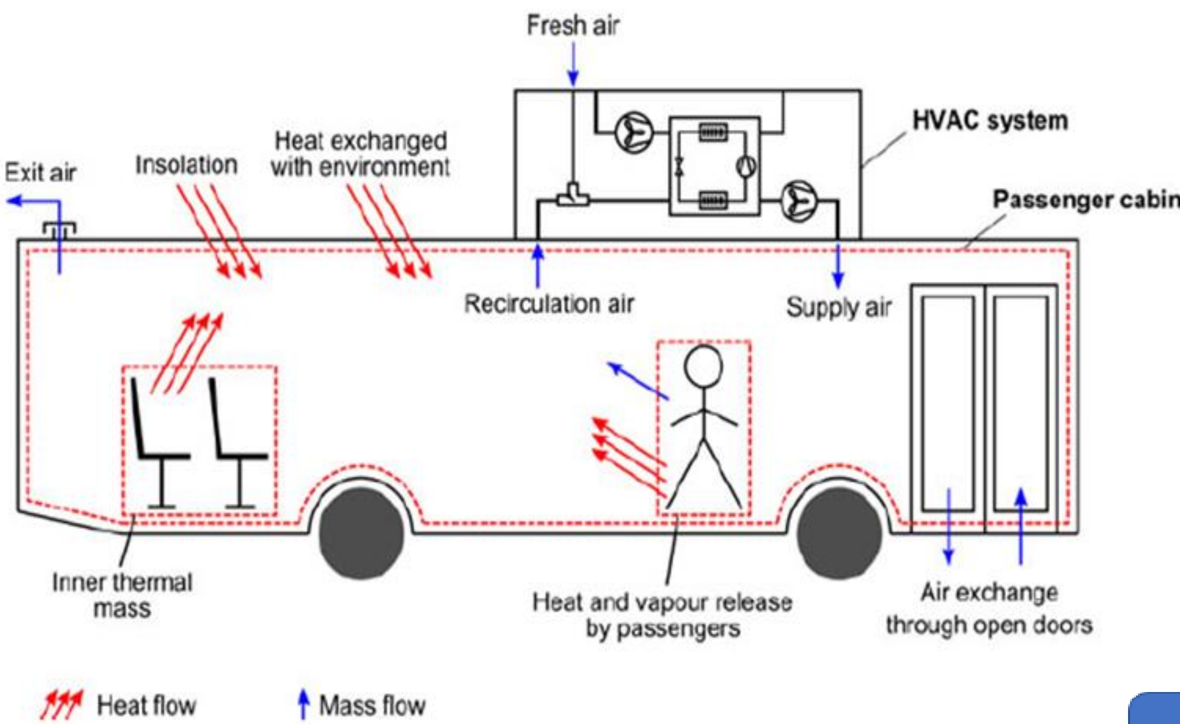
$$F_{\mathrm{res}} = \lambda_m m\dot{v} + mgf_R\cos(\alpha) + {}^{1}\rho_L c_W A v^2 + mg\sin(\alpha). \qquad (1)$$

The total required battery power *P*total:

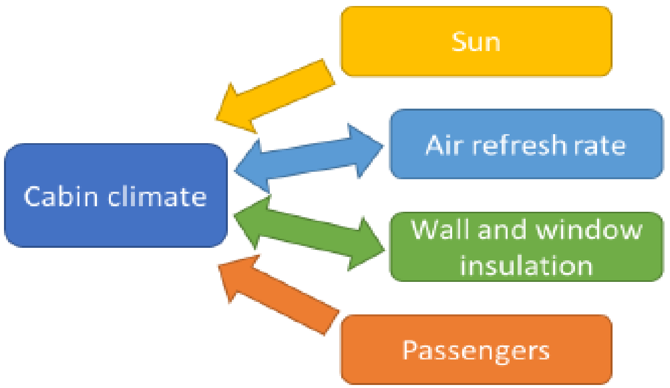
$$P_{total} = \frac{F_{res}\vartheta}{\eta_{drive}} + P_{aux} \qquad (2)$$

Auxiliary power demand is mainly dependent on the electric power of the HVAC system *P*HVAC and to other components *P*others:

$$P_{aux} = P_{HVAC} + P_{others}. \qquad (3)$$



Thermal model and the environment heat exhange for an electric bus.



Influences on the cabin climate.

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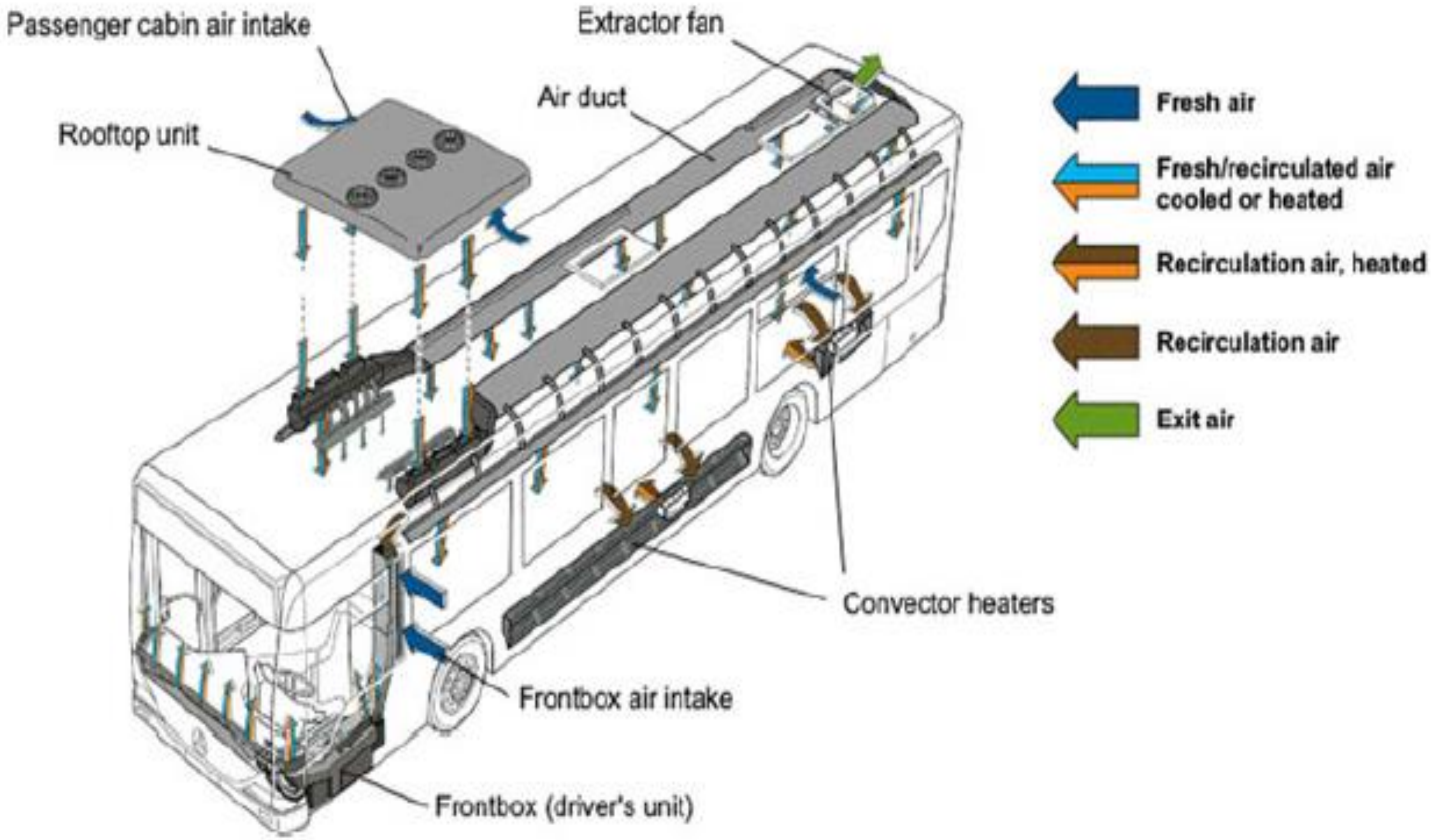
HEATING, VENTILATION AND AIR-CONDITIONING (HVAC) SYSTEMS



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OTHER AUXILIARY LOADS

Lighting (indoor, outdoor)

Windows cleaning system and seat heating.

Audio system.

Opening and closing of door, windows and roof.

Anti-lock Braking System – ABS.

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OVERALL ENERGY CONSUMPTION OF AUXILIARY SYSTEMS

Auxiliary systems	Part of traction battery energy, %
Climate control: – cooling; – heating.	 Up to 30% Up to 35%
Power steering	Up to 5%
Braking system	Up to 5%
Other (lights, media, locks etc.)	Up to 5%

The information presented in Table is more general and does not include all operational conditions of electric vehicles.

The **lightning, passenger information systems, and air compressor are responsible for 20-25%** of total energy consumption.

Under standard operating conditions, **the non-traction energy consumption is up to 1.2 kWh/km.**

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S7-1200 PROGRAMMABLE CONTROLLER

The S7-1200 controller provides the flexibility and power to control a wide variety of devices in support of your automation needs.

The compact design, flexible configuration, and powerful instruction set combine to make the S7-1200 a perfect solution for controlling a wide variety of applications.

The CPU combines a microprocessor, an integrated power supply, input and output circuits, built-in PROFINET, high-speed motion control I/O, and on-board analog inputs in a compact housing to create a powerful controller.

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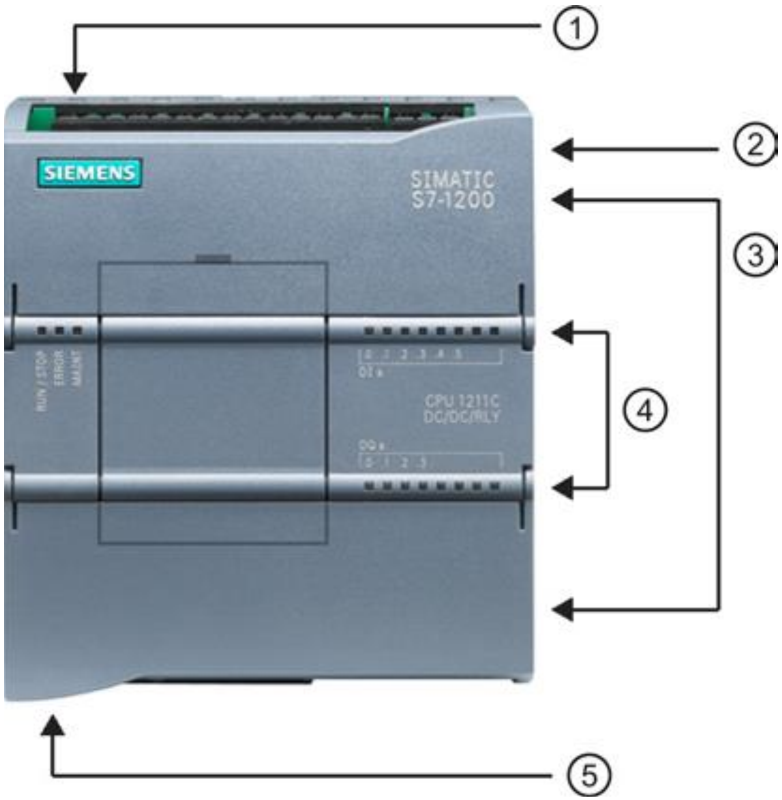

① Power connector.

② Memory card slot under top door.

③ Removable user wiring connectors (behind the doors).

④ Status LEDs for the on- board I/O.

⑤ PROFINET connector (on the bottom of the CPU).

● Organization blocks (OBs) define the structure of the program. Some OBs have predefined behavior and start events, but the user can also create OBs with custom start events.
● Functions (FCs) and function blocks (FBs) contain the program code that corresponds to specific tasks or combinations of parameters. Each FC or FB provides a set of input and output parameters for sharing data with the calling block.
● Data blocks (DBs) store data that can be used by the program blocks.

Operating modes of the CPU:

The CPU has three modes of operation:

STOP mode,

STARTUP mode, and

RUN mode.

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CONCLUSIONS AND OUTPUTS ACHIEVED

The analysis considered for the test bench for the drive system of the electric bus shows that the test bench can be used for the researches and experimental tests in order to study the electric buses drive system and their electrical characteristics and performances.

The analysis considered for the auxiliary loads on the electric bus shows that these supplementary consumers have different weight in the total energy consumption of the vehicle, but even the smaller ones can be important in the energy consumption optimization and the bus performances.
Having a wide view over these auxiliary loads offer possibilities to develop new strategies and solutions to reduce the energy consumption and to increase the overall efficiency of the electric bus.
Programme Outputs and main outputs of the project were achieved based on the activities and researches carried aut on the Activity 3.1 and Activity 3.2.

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Output 3.1. Increasing the energy efficiency of the auxiliary loads

First of all they were identified the auxiliary loads specific for an electric bus, that is: heating, cooling, various electric systems (lighting, doors, windows, windshield wiper, ventilation for the traction motors, battery cooling, air compressor, steering pump).
Activity 3.2 in the project (Analysis of the auxiliary loads) extended the researches and results into the increasing of the energy efficiency of the auxiliary loads.

Output 3.2. Increasing the overall energy efficiency of the electric bus
The increasing of the overall energy efficiency of the electric bus was considered from various perspectives, such as: efficiency of the drive motors, efficiency of the battery charging, and to supply the auxiliary loads.
An automated model controlled with PLC have been started to be developed in order to implement and to control energy strategies on the auxiliary loads, having as final result an overall reduction of consumption by saving electricity to auxiliary consumers.

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Programe output 1. Number of environmentally friendly (carbon-proofed) cross-border transport initiatives developed

In order to achieve the program output, into the TUIASI laboratories it was realized a test bench for studying the electric energy consumption, and the possibilities to increase the energy efficiency of the electric bus.

It was studied power consumption, current consumption, useful power, efficiency of the drive line and other various electric parameters which are important in improving the energy efficiency. Another aspect was to study the possibilities to improve the operating of the auxiliary loads by integrated them within the main power supply system (heating, cooling, doors operating, ventilation).

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This is also achieved on the basis of optimal using of the power supply and include also the renewable resources in order to build an Eco-friendly transportation solution, but also rapidly and safe, over the cross-border area between Romania and Republic of Moldova.

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*** https://www.uitp.org.
*** https://www.rtec.md/256-com-stuceni.html

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THANK YOU FOR YOUR ATTENTION!

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