THE STUDY OF HYBRID AND ELECTRIC VEHICLES WITH HYBRID ENERGY SOURCE IN LABS

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IESRES Erasmus+ Teaching Activity, 8-13 May 2017
Klaipeda, Lithuania

THE OBJECTIVES OF THE R&D

- 1. INTRODUCTION
  - 1.1 Presentation of the driving system
  - 1.2 Presentation of the hybrid energy source
- 2. THE CONCEPTION AND BUILDING THE STAND
- 3. THE HYBRID DRIVING SYSTEM
- 4. HYBRID ELECTRIC POWER SUPPLY
  - 4.1 The selection of the batteries
  - 4.2 The selection of the Fuel Cell
  - 4.3 The selection of the ultracapacitors

THE GOALS

- Increasing the efficiency of the drive process
- Finding a new solution for the drive process
- Finding an efficiency solution for supply electric sources for vehicles
- Obtaining a flexible stand for R-D of the hybrid drive systems
- Obtaining a flexible supply electric sources for vehicles
- Obtaining a laboratory model for the vehicle

1. INTRODUCTION

- The oil crises, which become more and more acute, correlated with the prospect of the depletion of the oil sources, as well as the ecological issues, represent the drive of the research aiming at discovering new solutions for autovehicle propulsion.

- A temporary solution for achieving an ecological car, which will use a different type of fuel, is represented by the hybrid solution. Such a car variant started to be available since the year 1997.

- As part of the ELECTROMET Research Centre expertise area, the question of the hybrid driving systems was addressed, along side with the increasing the efficiency of the hybrid power source.

1.1 Presentation of the driving system

- The solution developed and achieved aimed to build a complex operation stand with applications in automotive, capable of working in the following variants: classical, electric, hybrid-series, hybrid-parallel.

- The stand also models a minicar of 300 kg mass, and the speed of 56 km/h, so as the whole, it represents the model of a car which exhibits a complex operation.

1.2 Presentation of the hybrid power source

- The hybrid power source of the stand consists of two sources:16 x 12V, 24Ah lead-acid batteries and an 8KW fuel cell along side of an ultracapacitor 110F, 48V.
- The two power sources can operate either independently, or in a hybrid manner.

2. THE CONCEPTION AND BUILDING THE STAND

A classic vehicle can be assimilated as the model in Figure 1. Engine **E** develops the angular speed Ω_E , and the **ME** torque. In accordance with the ratio of transmission i_i from the gearbox, the output value of the torque going out of the gearbox is **Mi** , and the angular speed Ω_i . In the differential there will be a final ratio i_f , and the wheel will have the torque **MR** and the angular speed Ω_R.

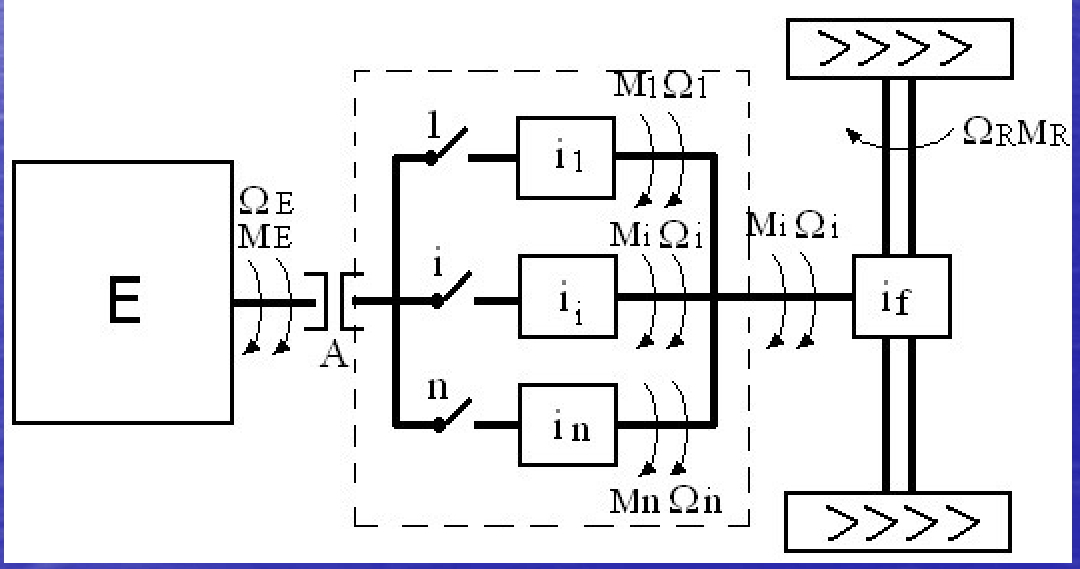


Fig. 1 The structure of the classic car

The mass of the car m_a can be modeled by a flywheel having an inertial moment J_v and so to determine the car's kinetic energy at speed v_a becomes equal to the kinetic energy of the flywheel at the angular speed Ω_V imposed:

$$\frac{1}{2} J_V \Omega_V^2 = \frac{1}{2} m_a v_a^2 \quad (1)$$

From relation (1) results that the inertia moment of flywheel J_v depends on the driving angular speed of Ω_V :

$$J_V = m_a \left(\frac{v_a}{\Omega_V} \right)^2 \quad (2)$$

If we take into account the relation between v_a , the angular speed of wheel Ω_R and the radius of the wheel r_R , we will obtain:

$$J_V = m_a \left(\frac{\Omega_R}{\Omega_V} r_R \right)^2 \quad (3)$$

or

$$J_V = m_a \left(\frac{\Omega_E}{i \cdot \Omega_V} r_R \right)^2 \qquad (4)$$

where:

Ω_E – the angular speed of the engine;
i – the total transmission ratio from the engine to the wheel, in this case $i = i_i \cdot i_f$

To obtain the smallest flywheel possible, it is imperative that Ω_V should be as high as possible, yet is must not exceed the rotation rate of the engine.

Also, it would be taken into consideration that:

$$\frac{\Omega_E}{i_i} = \Omega_V \qquad (5)$$

In other words, we can model the vehicle with a flywheel driven by an angular speed Ω_V within the interval:

$$\Omega_R \leq \Omega_V \leq \Omega_E \qquad (6)$$

For calculating the initial value of the flywheel, we proceeded from $m_a = 300kg$ and $v_a = 15.55 m/s$ imposing the condition that $\Omega_V = 50\pi \ rad/s$.

Under these circumstances, the inertia moment is calculated as $J_V = 2.94 kgm^2$

Once the flywheel is developed, the problem should be raised if we could model another car considering the data below:

$$m_{a1} = k_m \cdot m_a$$
$$v_{a1} = k_v \cdot v_a \qquad (7)$$

where:

km – represents the ratio between mass ma1 of the new car and the mass of the modeled car ma ;

kv – represents the ratio of the speeds of the two cars: va1 , the speed of the new car, va , the speed of the modeled car.

The flywheel will have to be driven with another angular speed Ω_{V1} , for the new car:

$$m_{a1} \cdot v^2{}_{a1} = J_V \cdot \Omega_{V1}^2 \qquad (8)$$

From here it results that:

$$\Omega_{V1} = \Omega_V \cdot k_V \cdot \sqrt{k_m} \qquad (9)$$

Hence, if the engine is capable, another car can be modeled, observing relation (9), with the condition that the flywheel does not exceed the safety values of the angular speed allowed by its materials.

The flywheel also models one of the advance resistances, namely the resistance to acceleration.

Fig. 2.2 The flywheel

To model the behavior of a real car we need to consider: resistances to running, the resistance of the air, and the slope resistance also.

All these are modeled by a generator with separate excitation GE2. Its power should be:

$$P_{GE2} \geq f \cdot m_a \cdot g(\cos\alpha)v_a + 0,5\rho c_x A_f v_a^3 + m_a g(\sin\alpha)v_a \quad (10)$$

where: f – the running resistance coefficient, 0.009;
m_a – the mass of the modeled car;
g – gravitational acceleration, 9.81m/s2;
α – the slope of the road, ;
v_a – the speed of the car, 15.55m/s;
ρ – the density of the air, 1.16kg/m3;
c_x – aerodynamic drag coefficient, 0.335;
A_f – the area of the maximal cross section- front area- 1.8m2.

In this case, we did not take into consideration the resistance to the slope, hence with the first two terms our generator should have the power:

$$P_{GE2} \geq 405.616 + 1{,}315.0324 = 1.72 kW \qquad (11)$$

We chose a 2kW generator which is big enough for this job.

The ratio between the angular speeds of the wheel and that of the flywheel results from relation (3) as:

$$i_{\Omega} = \frac{\Omega_R}{\Omega_V} = \frac{1}{r_R}\sqrt{\frac{J_V}{m_a}} \qquad (12)$$

For example, considering r_R =0.280m, there follows i_{Ω} =0.3535.

For any pair of values (i) given, the angular speed $\Omega_{R(i)}$ and torque, $M_{R(i)}$ of the wheel the following angular speed $\Omega_{V(i)}$ and torque $M_{V(i)}$ of the flywheel results:

$$\Omega_{V(i)} = i_{\Omega}^{-1} \cdot \Omega_{R(i)}$$

$$M_{V(i)} = i_{\Omega} \cdot M_{R(i)} \qquad (13)$$

Values $\Omega_{R(i)}$, $M_{R(i)}$ can be obtained for various cycles through simulation with ADVISOR, Tab.1.

Cycle	V_a (m/s)	$\Omega_{R(i)}$ (rad/sec)	$M_{R(i)}$ (Nm)	$\Omega_{V(i)}$ (rad/sec)	$M_{V(i)}$ (Nm)
UPIT20	8.94	31.7694	19.3298	89.87	6.833
UPIT25	11.17	39.7376	24.4263	112.4118	8.63
UPIT26	11.62	41.3332	25.5815	116.9256	9.04
UPIT27	12.069	42.9296	26.782	121.441	9.46
UPIT29	12.96	46.1245	29.3189	130.479	10.36

Table 1

On the stand

Taking into account that we have mounted, on the shaft of the flywheel, a torque transducer, and the adjustment of the power for the shaft of the flywheel, $P_{V(i)}$, is done by regulating the excitation current of generator GE_2, the excitation current will be regulated in such a way that the intended torque is obtained at the shaft of the flywheel.

The model of the car is shown in Figure 3, where:

TM - Torque transducer, and M is the corresponding display device;

V - The flywheel;

GE2 - The generator, whose excitation is programmable, as its goal is to model the vehicle's advance resistances;

Fr- The electric brake.

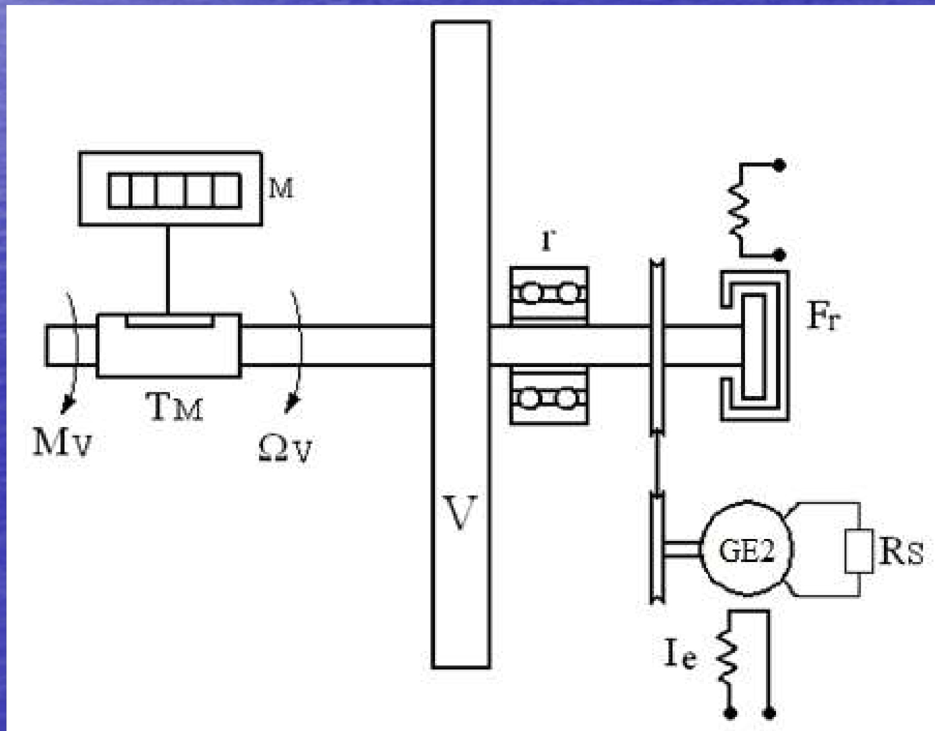


Fig. 3 The model of the car

3. THE HYBRID DRIVING SYSTEM

The driving system is made up of two power sources: an electric motor (M), and an engine (E), with the possibility for each of the sources to operate separately, or together, in accordance with the principle presented in Figure 4.

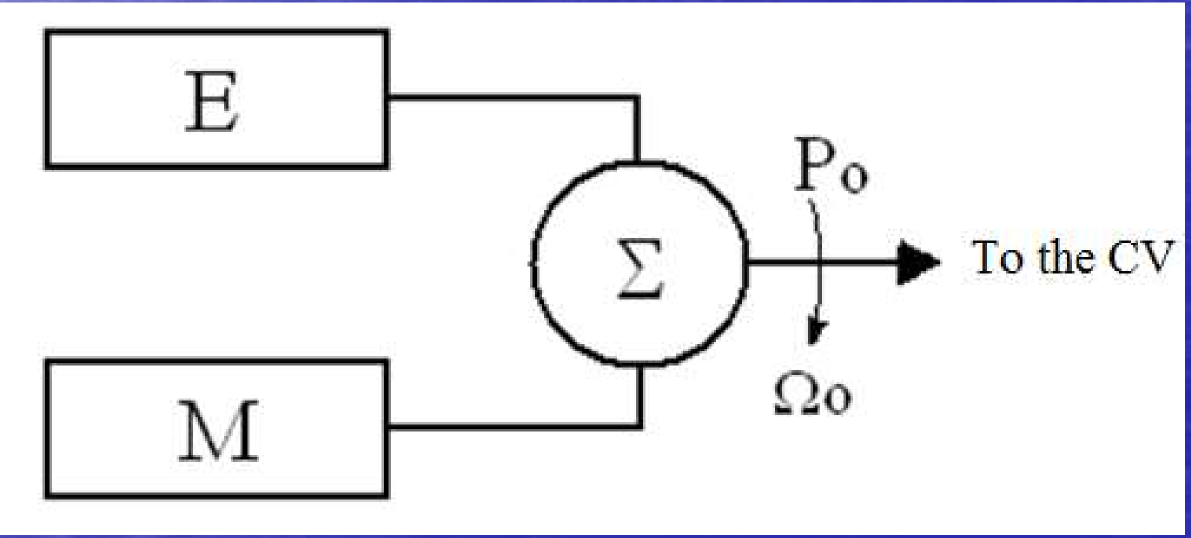


Figure 4

The output power P_0 is given by relation:

$$P_0 = \frac{P_E + P_M}{2} \qquad (14)$$

where:

P_E – is the power produced by the engine;
P_M – is the power developed by the electric motor.

The angular speed at the output of the driving system is:

$$\Omega_0 = \frac{\Omega_E + \Omega_M}{2} \qquad (15)$$

The principle scheme of the stand is presented in Figure 5.

E- The engine; M- The electric motor;
Ae1,2 – Electric clutches;
F1, 2 - Electromagnetic brakes;
GE1- Generator witch can be driven by the thermic engine, in the particular case of the operation in the hybrid-series variant;
Σ - The differential device
A- Clutch;
CV- The gearbox.

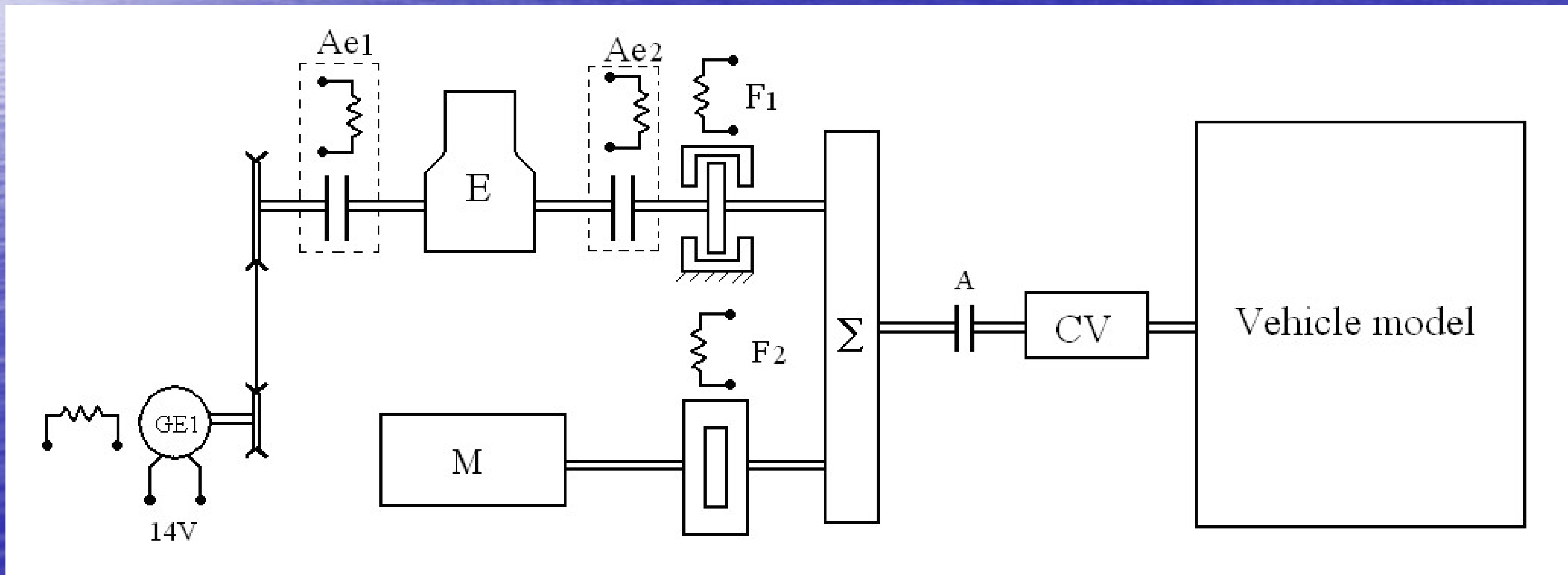


Fig. 5 The principle schema of the stand

The engine **E** has access to both ends of the exit shaft. A **GE1** generator is coupled, at one of its ends, by means of an electromagnetic clutch. The other end of the heat engine is coupled to the differential device **Σ**, through clutch **Ae2** and the electromagnetic brake **F1**.

The electrical motor **M** is connected to the second entry of the differential mechanism **Σ**.

A mechanic clutch **A** allows uncoupling the drive system from the flywheel.

The system of electromagnetic clutches **Ae1**, **Ae2**, and the electromagnetic brakes **F1**, **F2** allow doing the necessary combinations for the construction of the large-series hybrid variant, respectively the parallel hybrid, operating only with the engine, operating only with the electric motor.

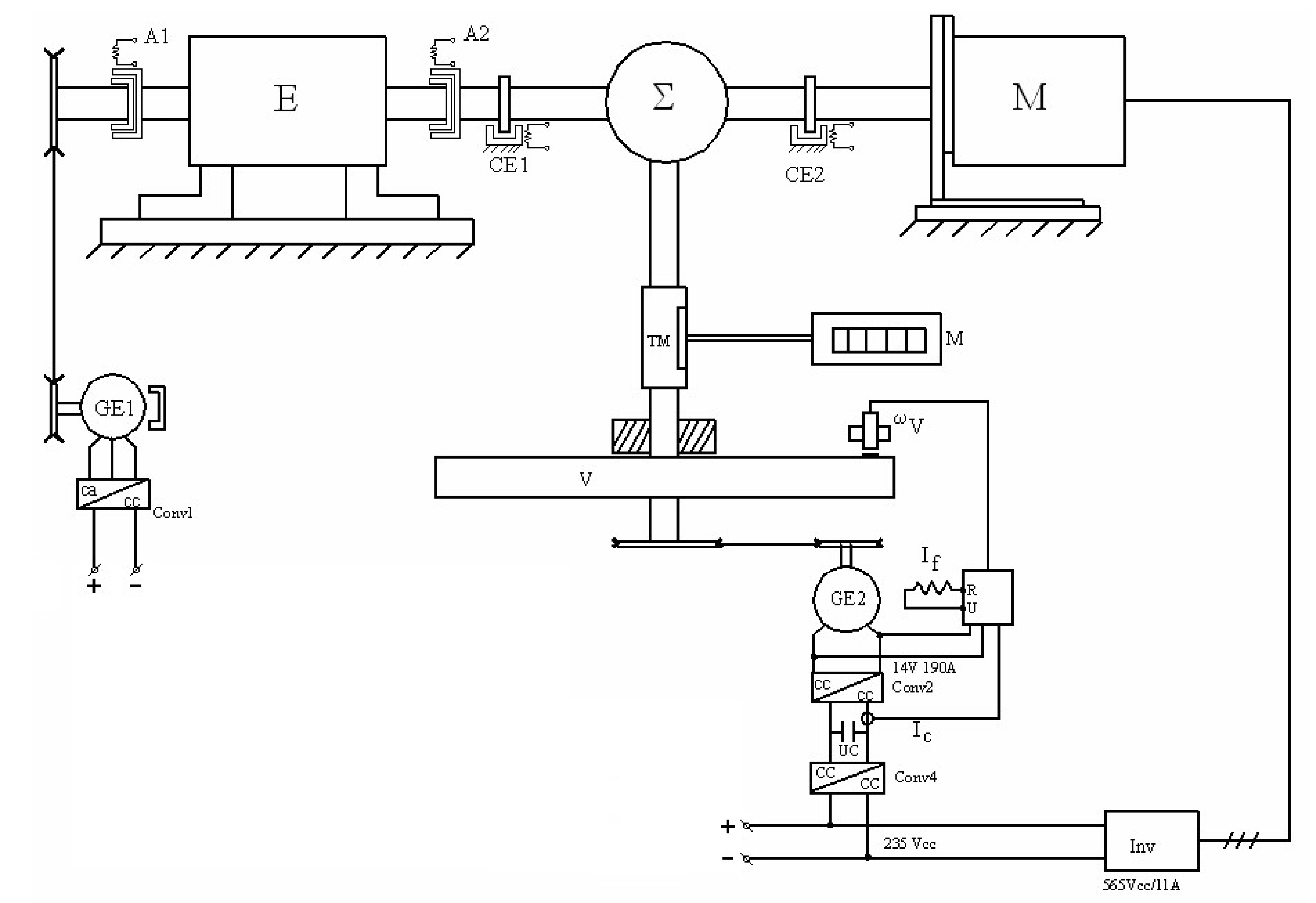


Fig. 6 Chart of the hybrid stand – the excitation current of GE2 will be regulated in such a way that the intended torque is obtained at the shaft of the flywheel

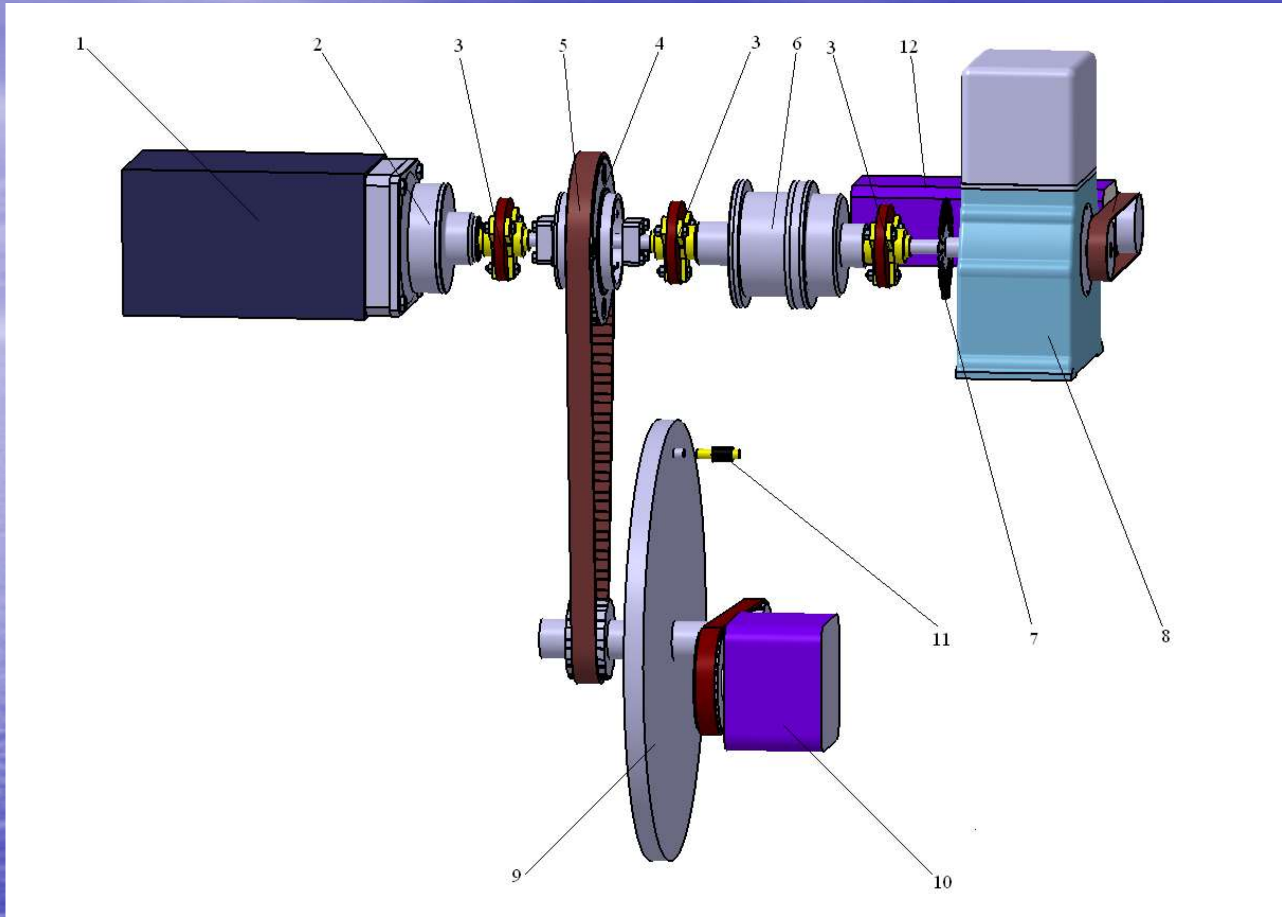


Fig. 7 Hybrid operation stand

1-electric motor M; 2-blocking system; 3-coupling; 4-planetary mechanism; 5 transmission belt; 6-separation and blocking system; 7-rotation transducer; 8-thermic engine E; 9-flywheel;10-electric generator GE2; 11- position transducer; 12-electric generator GE1.

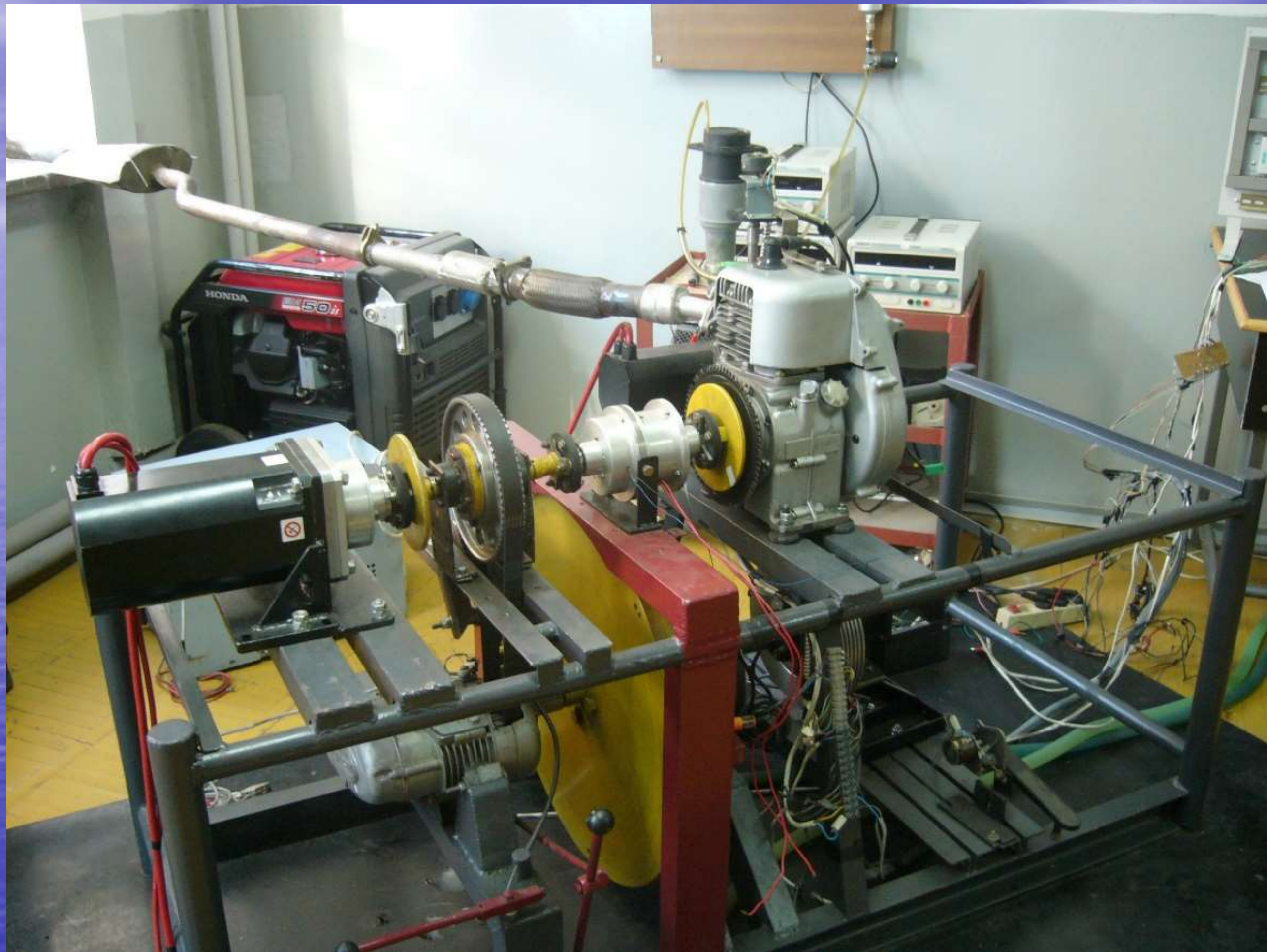


Fig.8 Hybrid stand

4. HYBRID ELECTRIC POWER SUPPLY

There are two basic sources: a pack of batteries of secondary cells, B (16 batteries x 12V, 24Ah) made of lead-acid and a Fuel Cell, FC of 8 kW, with a voltage ranging between the limits 47-76V, having the work current within the limits 0-170A.

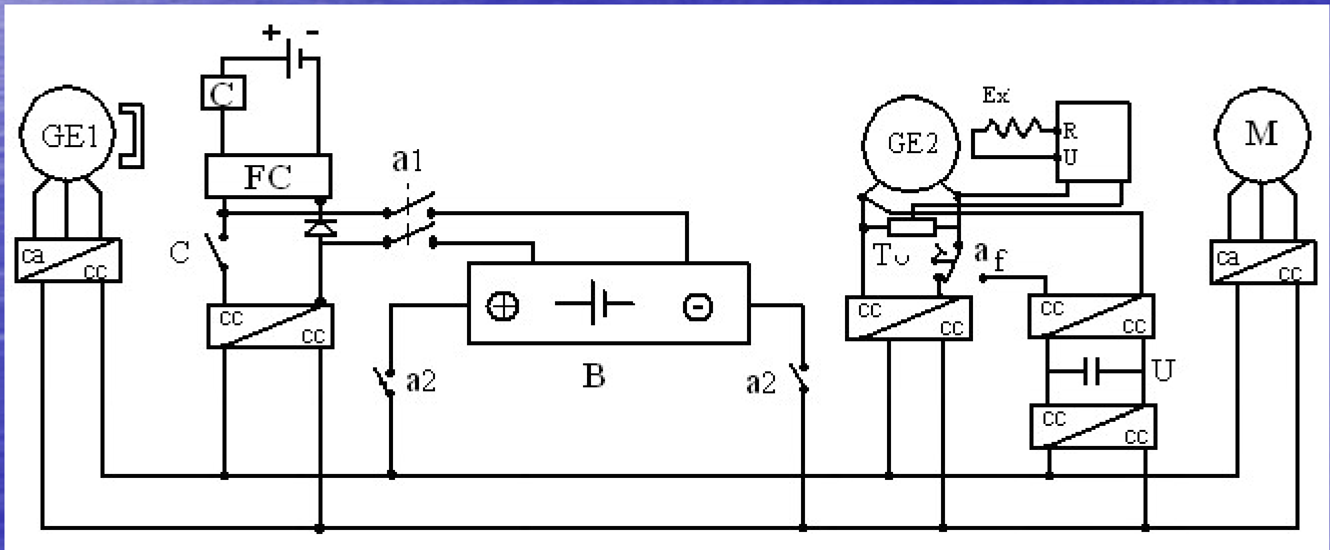


Fig. 9 The schema of electric power supply

Through switch **a1**, the set of the batteries **B** can be coupled in parallel to **FC**, and through **a2**, to the main voltage terminals. The two switches, **a1** and **a2**, must not be connected simultaneously. The main load of these sources is represented by the electrical motor of stand **M**.

In the electrical schema another two electric generators appear: **GE1 and GE2**.

GE1 can operate when the engine works, either in the situation of simulating a series hybrid, or in the situation when it does not work in the economic points, and its coupling is necessary, as well.

GE2, which is driven by the same shaft on which the flywheel is mounted, accomplishes two parts – that of a brake intended to model the advance resistance of the car, and that of a generator intended to recover energy on braking. A switch **af**, actuated at the same time as the brake pedal, introduces the recovering circuit, which uses an ultracapacitor **UC (110F, 48V)**.

4.1 The selection of the batteries

When selecting traction batteries, consideration should be given to energy aspects, weight and gauge, cost price and charging time.

The energy aspects aim at:

- battery capability to provide the peak power required by the electric motor;
- ensuring the vehicle's desired autonomy - the battery has stored energy for a given route.

The power of the battery, PB, must be higher than the power of the electric motor, PM:

$$P_B \geq \frac{P_M}{\eta_M \cdot \eta_B} \qquad (16)$$

P_B - Power of the battery
P_M - Power of the electric motor
η_M - efficiency of the electric motor
η_B - efficiency of the batteries

The total energy required:

$$W_{et} \leq W_B = 0.8 \Delta U \cdot C \qquad (17)$$

W_B - The energy of battery;
C - The capacity of battery;
$\Delta U = Umax - Umin$

Determination of the mass and volume of the battery can be done in two ways.

a). starting from the power P_B:

(18)

$$m_B = \frac{P_B}{p_{sbm}}$$

$$Vol_B = \frac{P_B}{p_{sbv}}$$

where: p_{sbm} – The specific power of battery [W/kg];

P_{sbv} – Power density [W/l];

b) starting from the energy W_B;

(19)

$$m_B = \frac{W_B}{w_{SBm}}$$

$$Vol_B = \frac{W_B}{w_{SBV}}$$

where: w_{SBM} – The specific energy of battery [Wh/kg];

w_{SBV} – The energy density [Wh/l];

Initial data:

P_B **= 5 kW ,** W_B **= 0.312 kWh**

For lead-acid battery

- The specific power p = 250 W/kg
- Specific energy WB = 30 Wh/kg
- Energy density WB(1) = 75 Wh/L

$m_{TB} = 10 \cdot 13 = 130$ kg
$Vol_{TB} \approx 3.16 \cdot 13 = 54$ l

We chose:
16 buc x 12V x 24 Ah, 8.5 kg
$m_{TB} = 136$ kg
$Vol_{TB} = 60$ l

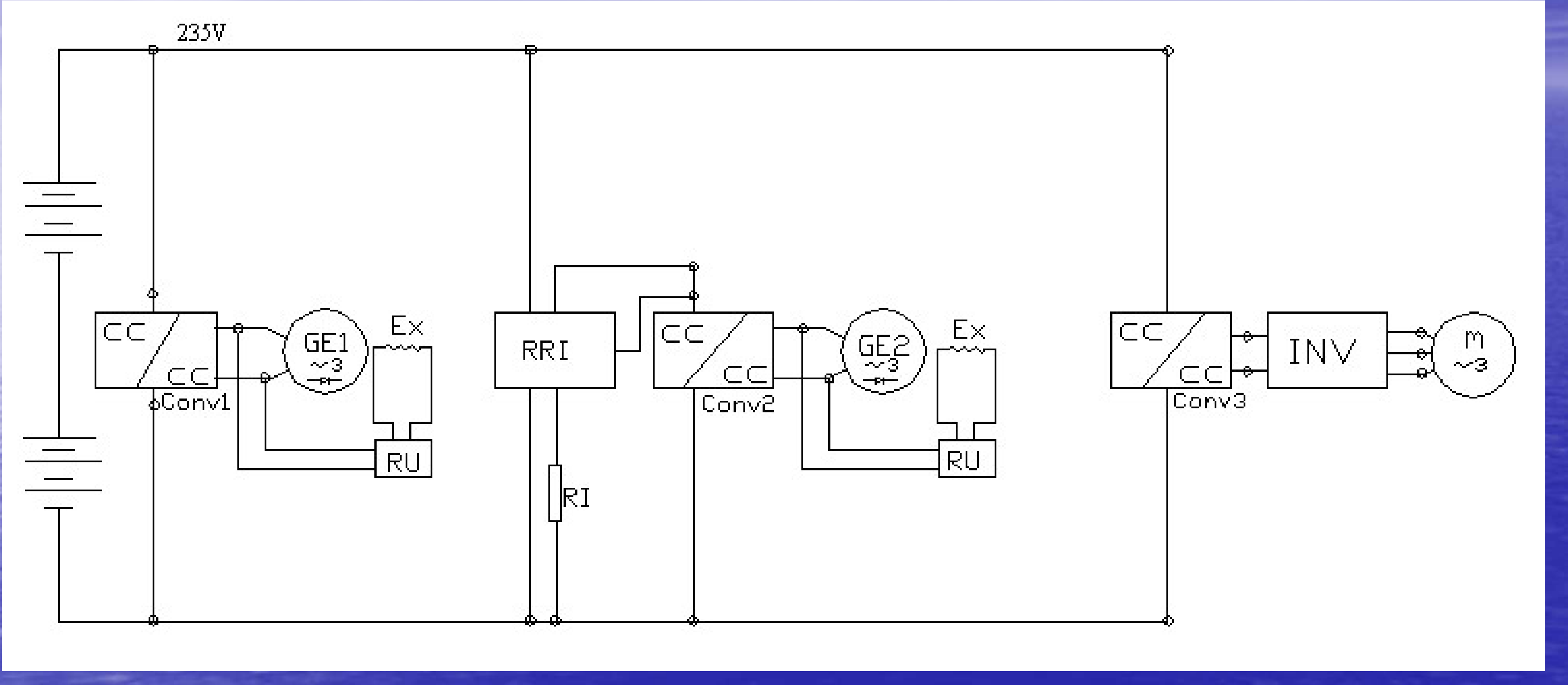


Fig.10 The complete system for electrical energy supply with batteries

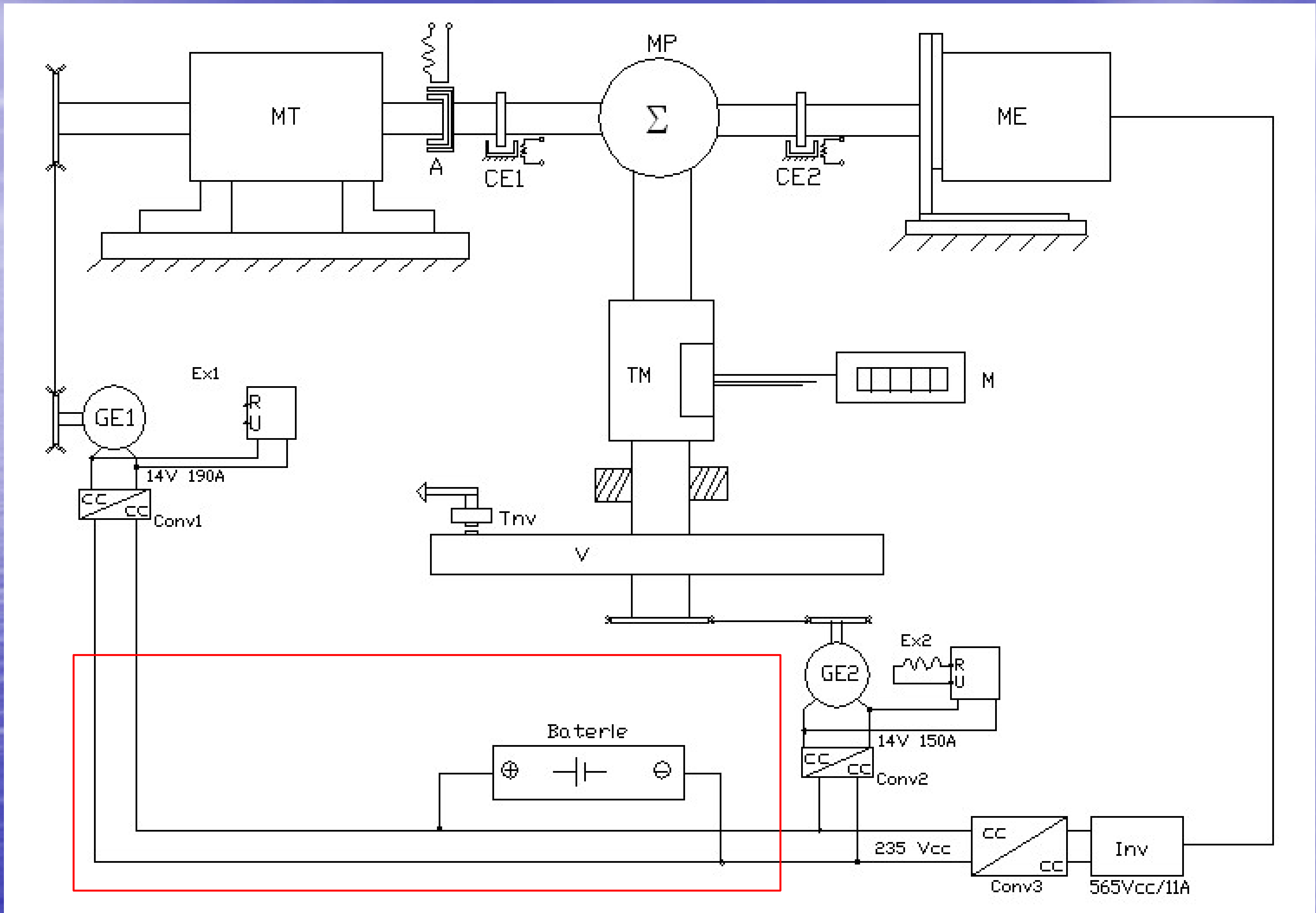


Fig. 11 Chart of the hybrid stand

4.2 The selection of the Fuel Cell

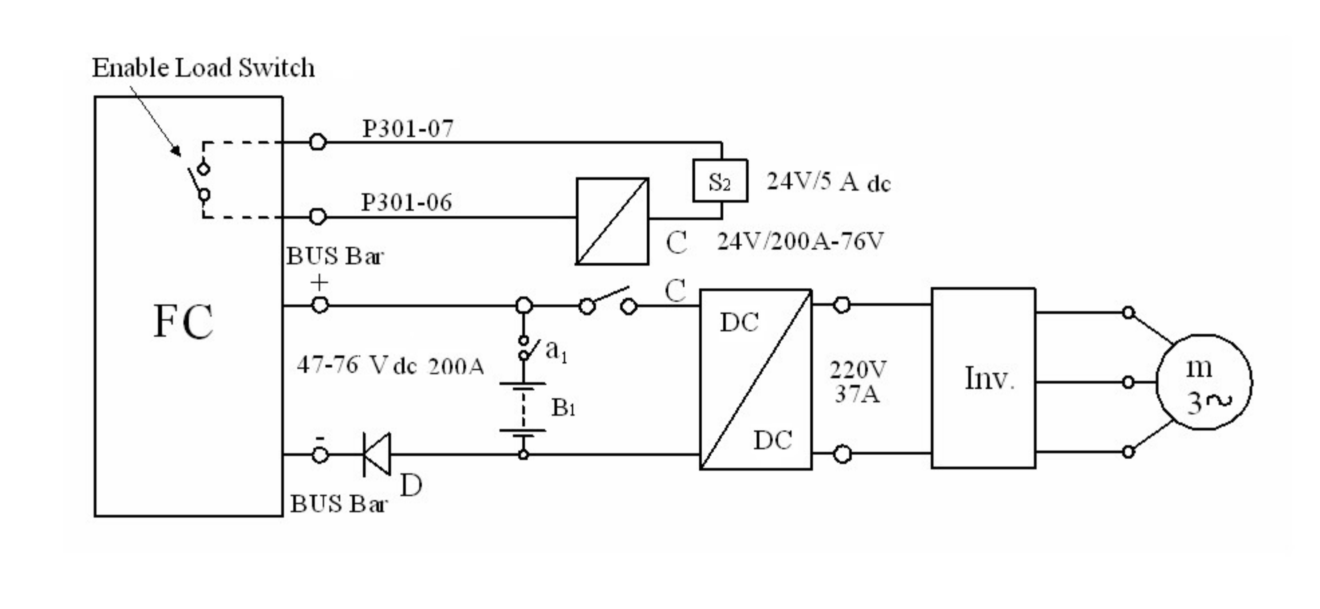


Fig.12 The power electric schema

The power electric schema of the operation system includes the following:

- a load contactor C with a normal contact mounted in series to the positive bar of the FC;
- an external power source of 24V for supplying the coil of the contactor;
- a diode D connected to the negative terminal of the FC;
- a set of 6 batteries, B1, having the possibility of being connected to/ disconnected from the force terminals of the FC, with a switch a1;
- a converter 47-76 V, 200 A dc/ 220 Vdc, 37A, DC/DC;
- an inverter Inv. for the drive motor m;
- the drive motor m.

After starting the fuel cell FC and validating the connection of the load, the internal contact is closed, supplying the coil C of the load contactor. Contact C, normally open, allows supplying power to converter DC/DC and inverter Inv. The drive motor will be supplied.

Auxiliary systems for the fuel cell

In order to be able to work, the FC needs a series of auxiliary systems:

- for hydrogen supply;
- for cooling;
- for evacuation and drainage, which have been designed and made.

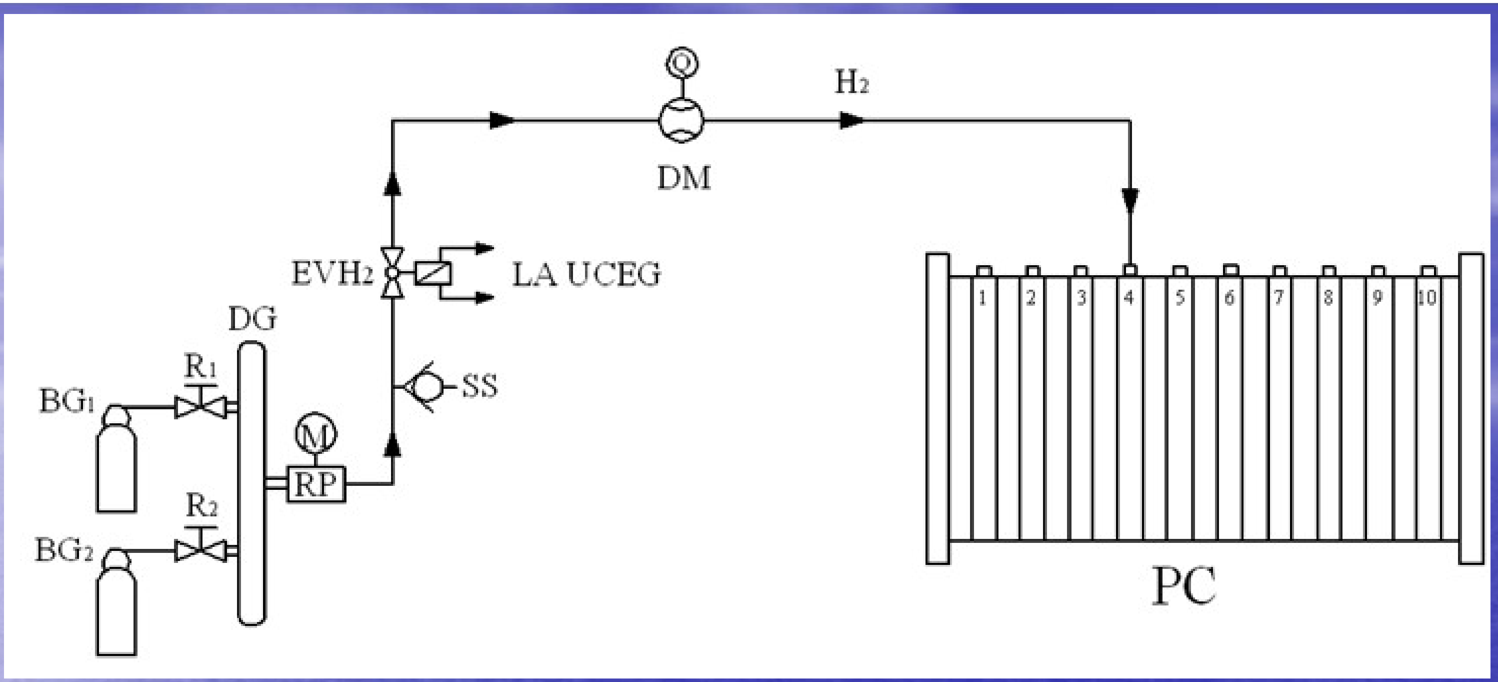
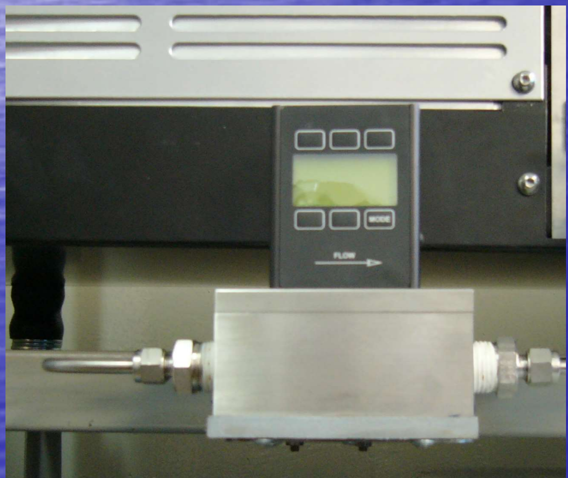


Fig. 13 Hydrogen supply

BG1, BG2 – bottles of hydrogen supply; DG – hydrogen distributor; RP – pressure regulator; M – manometer; SS – safety valve; EVH2 – hydrogen safety electro valve; DM – hydrogen flow meter; Q – indicator device.

- The distributor is designed to work with two bottles, having two inlets and an outlet.
- The pressure regulator reduces the hydrogen pressure to 600-700kPa.
- The safety valve does not allow exceeding the pressure of the hydrogen in the system above 950kPa.
- The electro valve with the normally closed contact allows controlled access of hydrogen to the FC.
- Measuring the hydrogen consumption is done with a device which is one with the body of the flow transducer.



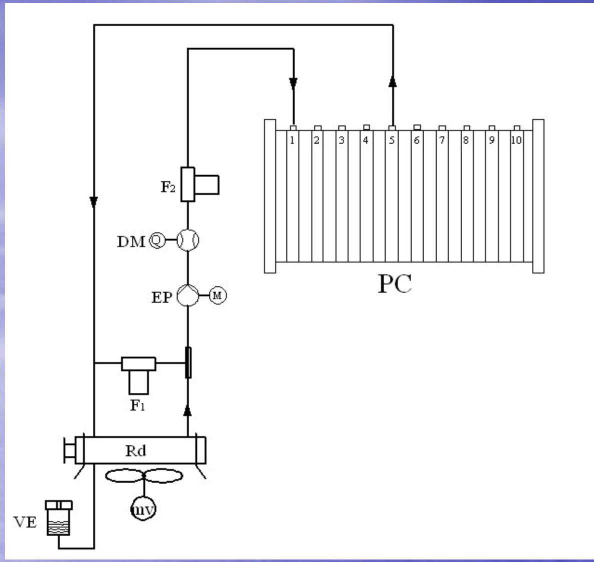
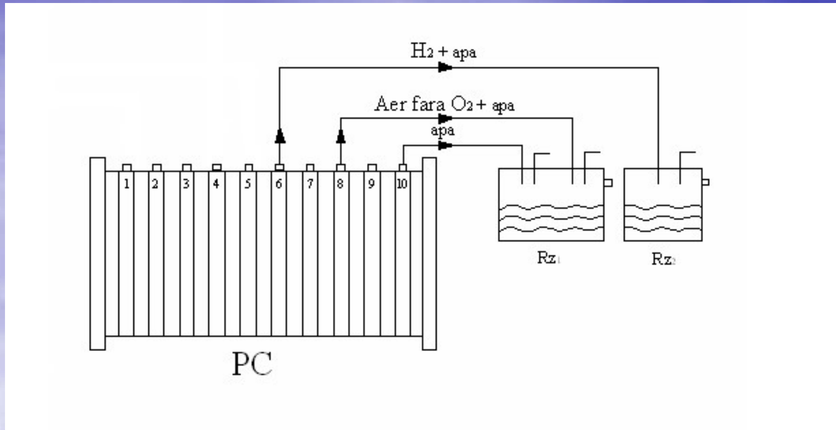



Fig. 14 The cooling system

- The amount of heat that the cooling system must dissipate is smaller than 10kW. We have used a system intended to cool a small car, endowed with a ventilator motor group.
- Instead of the all or-none heat transducer mounted on the radiator, we have provided a thermocouple, a component part of a regulating loop that also includes a regulator with an indicator device.
- Besides the element F1 mounted in parallel to the radiator were also mounted: a process filter (F2) with a filtering element, a water-meter, and a differential manometer.



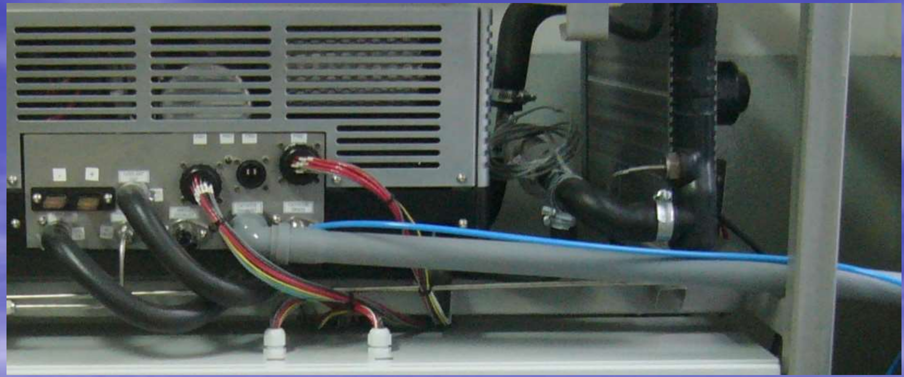


Fig. 15 The evacuation and drainage system

- The **cathode evacuation** products consist of:
  - warm air, depleted oxygen;
  - water.

- Another part supplied is a **drainage** port meant to drive away the excess water in the cathode elimination system.

Anode evacuation assumes:

- Combustible hydrogen-and-water concentrations.

Roughly, all the gases having to be expelled towards the outside, evacuation was done outside the room housing the FC.

- Care was paid not to allow water to accumulate along the evacuation lines, or flow back into the cathode or anode ports. As the reverse pressures on the cathode and anode evacuations are increased as the evacuation circuit increases, it was designed that the pressure decrease should not exceed 4kPa.

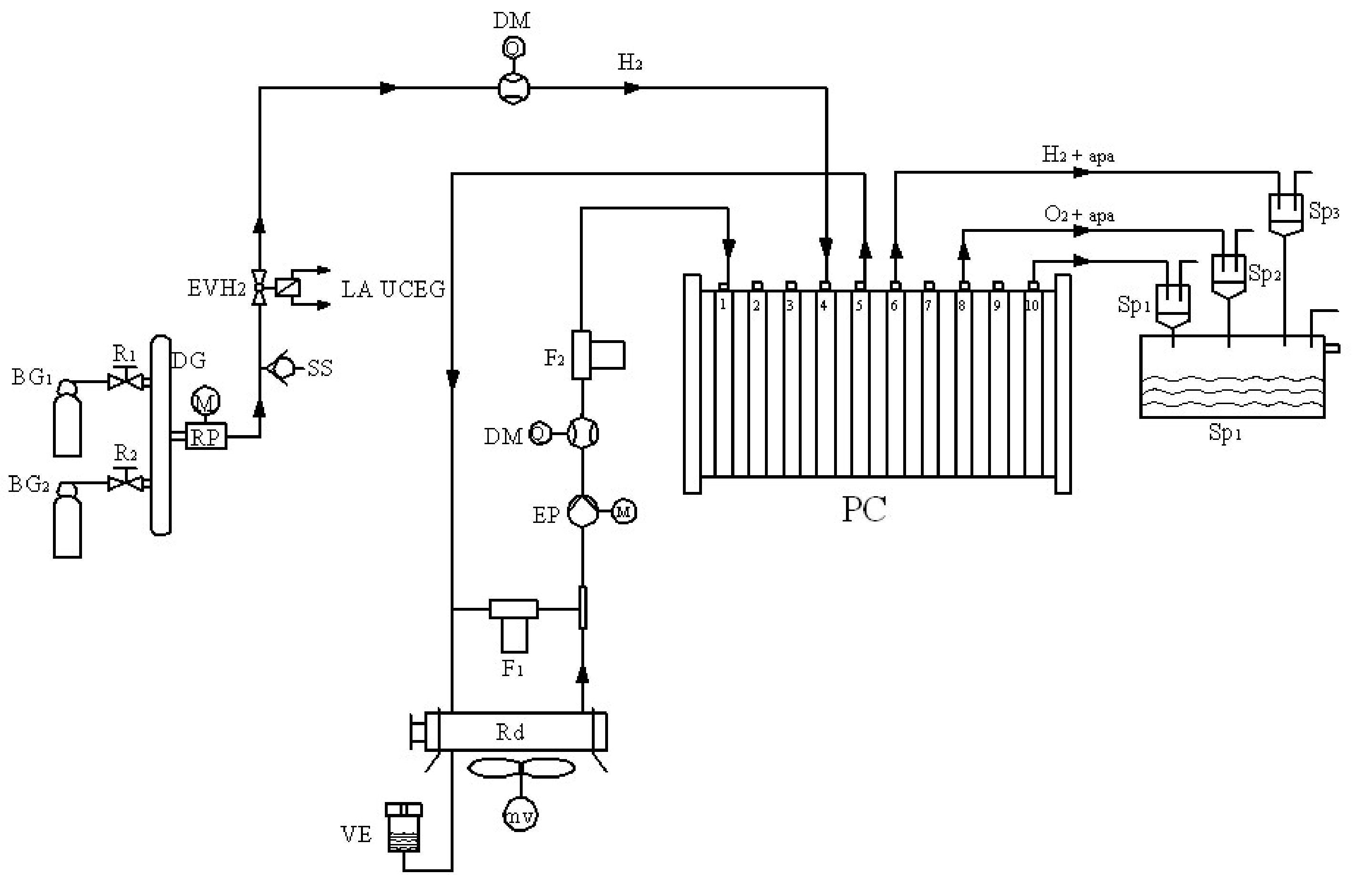


Fig.16. The schema of the auxiliary circuits for the PC

FC – fuel cell; EP – agent recycling electro pump; m – pump motor; F1,F2 – filters; Rd – radiator; mv– motor ventilator; VE – expansion vase.

1 – cooling agent inlet; 2, 3 – electric terminals; 4 – hydrogen inlet; 5 – agent outlet; 6 – anode evacuation; 7 – interface connector; 8 – air outlet; 9 – spare connector; 10 – cathode water evacuation

4.3 The selection of the ultracapacitor

Recovering energy on car braking is a source of saving fuel, and determines reconsidering the present braking system.

The new braking system presupposes:

- the existence of a generator;
- correctly choosing the ultracapacitors, UC, its system of loading and delivering energy;

The control of the energy flow, of the minimal and maximal values of the currents, and of the UC voltage are fundamental aspects.

Determining the parameters of loading the UC on braking

The kinetic energy of the flywheel W_V models the kinetic energy of the car:

$$W_V = \frac{1}{2} J_V \omega_V{}^2 \qquad (20)$$

where:

$J_V[kgm^2]$ – the inertia moment of the flywheel;
$\omega_V[rad/s]$ - the angle speed of the flywheel.

The recover energy of the flywheel is that obtained for an angle speed superior tot the value of 10π rad/sec (≈ 10km/h).

For the various angles speed values of the flywheel, the total energy W_v, as well as the recover kinetic energy values, ΔW_V are calculated.

ω_V rad/sec	10 π	42,06	20 π	89,656
W_v [J]	1478,94	2653,564	5915,76	12057,297
ΔW_v [J]	0	1174,62	4436,82	10578,357

ω_V rad/sec	30 π	112,17	40 π	**50 π**
W_v [J]	13310,46	18873,162	23663,04	**36973,5**
ΔW_v [J]	11831,52	17394,22	22184,1	**35494,56**

ω_V rad/sec	60 π	70 π	80 π	90 π	100 π
W_v [J]	53241,84	72463,06	94625,16	119794,14	147894
ΔW_v [J]	51762,9	70989,12	93173,22	118315,2	146415,06

Table 2 The total and recoverable energy

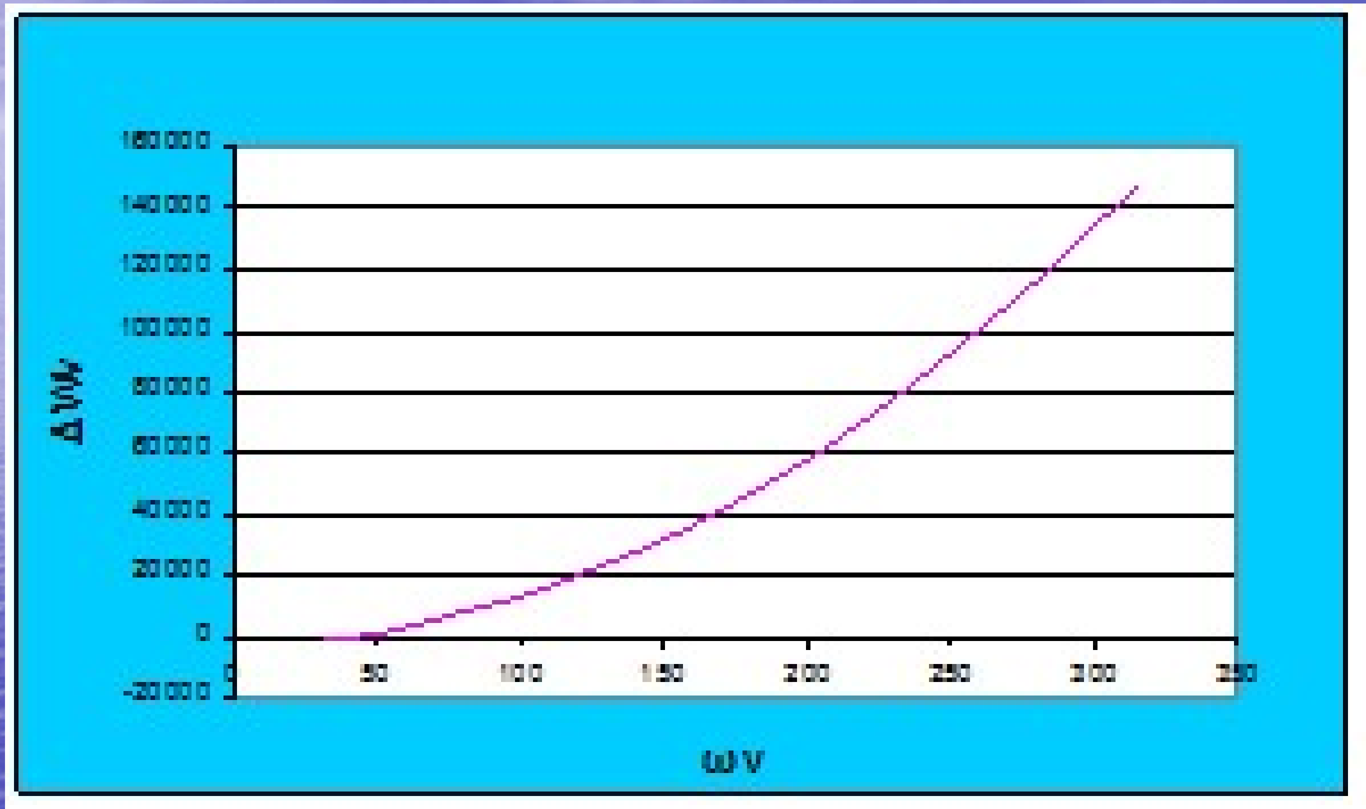


Fig. 17 Variation of recoverable kinetic energy of the flywheel with angular speed

Recovering the energy is done in a UC that can store the maximal energy:

$$W_{UC\max} = \frac{1}{2} C U^2{}_{\max} = 126,720\ J$$

where:

C – capacity of UC, 110 F;

Umax - the maximal voltage of UC.

Considering an acceptable variation of the voltage across the terminals of the UC as 20% of Umax, the minimal value of the voltage across its terminals will be 38.4V and for this the energy is 81,100.8 J. Consequently**, the maximum energy which will flow to, and from the UC will be 45,619.2 J.**

Comparing that energy with the recoverable maximum energies calculated, we find that this UC can retrieve the energies entirely up to ω_V **= 50**π rad/sec**,** the corresponding value of which is **Δ** W_v **= 35,494.56 J < 45,619.2 J.**

- **The recover energy** upon braking: the generator GE2 flows on to a set of ultracapacitors, with a capacity of 110F/48V.

- The braking is purely electric: in the first phase, a generator GE 2, works, as a brake and, under a certain threshold of the flywheel rotation, a powder brake intervenes, until complete stoppage is realized.

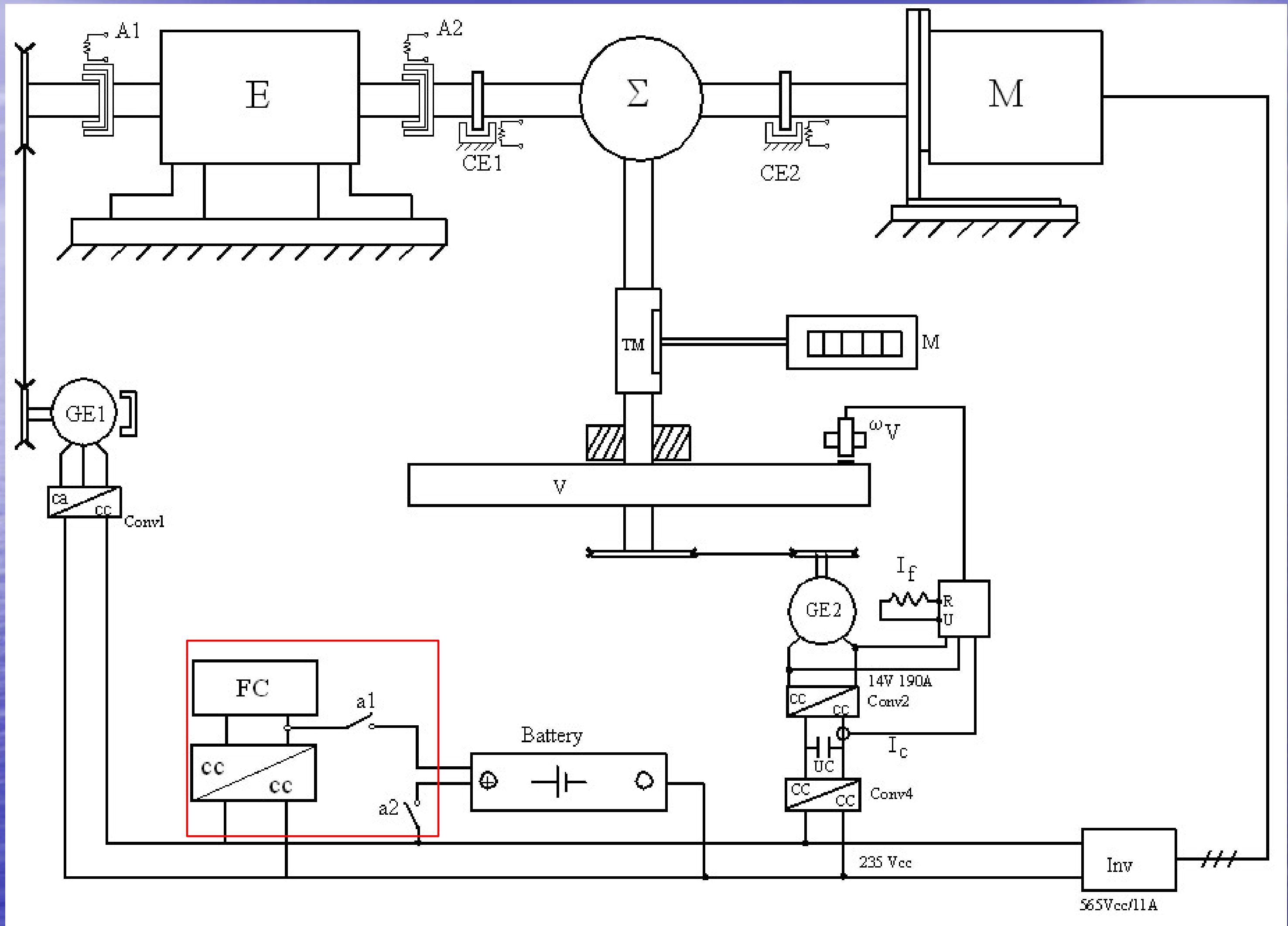
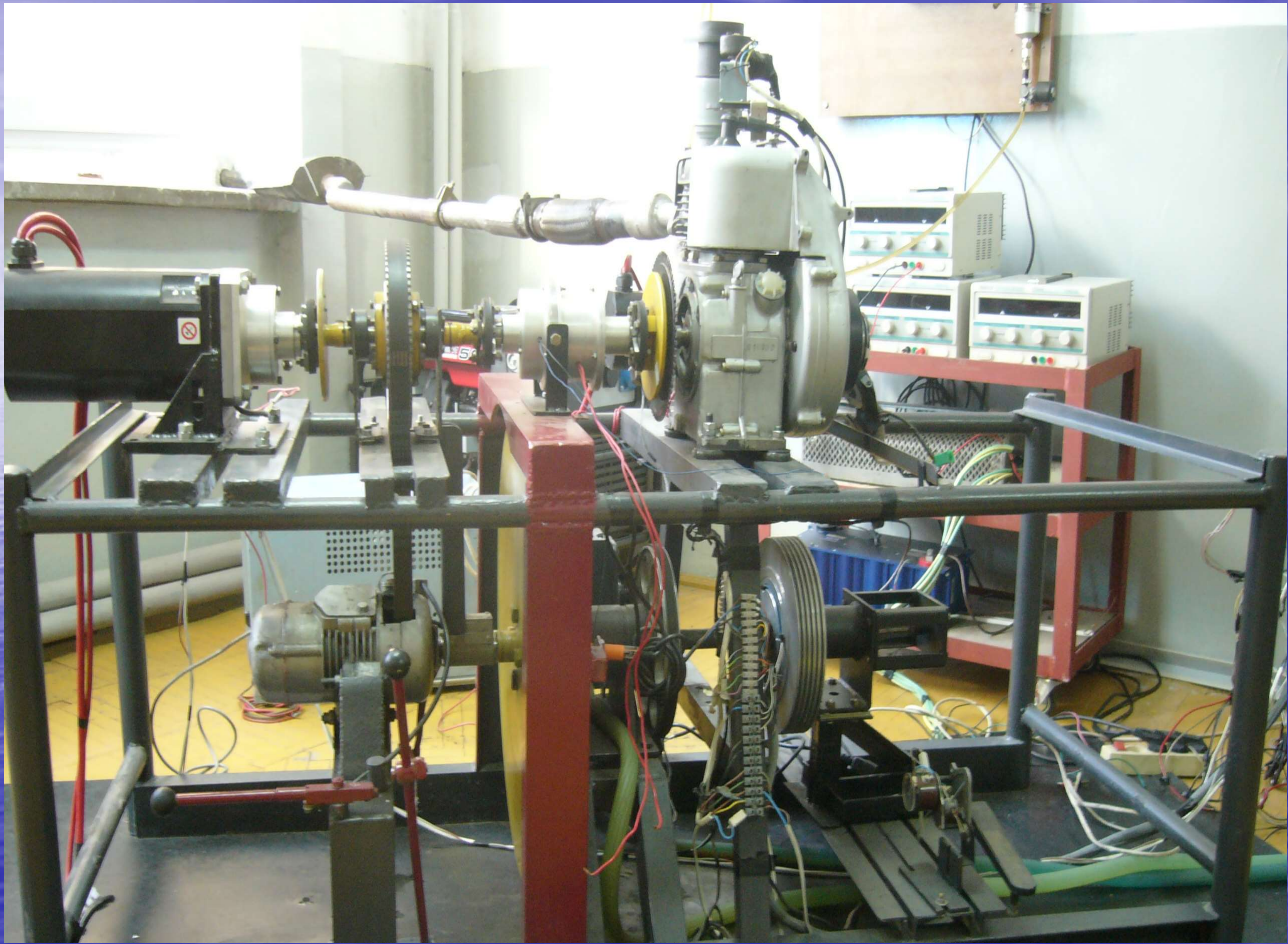


Fig. 18 Chart of the hybrid stand with hybrid energy source




METROM
Motor Nr.
Turaţie 3000
Tip AL75
CP 6
BRAŞOV-ROMANIA

CONCLUSIONS

- The stand of the hybrid drive system with a hybrid power supply system built at the University of Pitesti is a complex stand which allows the study of both the hybrid drive systems, and the electric ones.
- Powering the stand can be realized by using, as well, an electric hybrid system made up of electric batteries and fuel cells.
- The recover of the brake energy is possible by means of an ultracapacitor.

Thank you for your attention!

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