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HUNGARIAN ELECTRIC VEHICLES AND A NEW HYBRID CONCEPT

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Abstract

The first 34 pieces of electric lorries were built and used between 1924 – 1945 by the Hungarian Royal Post for the transportation of parcels and packages with mechanically parallel-series switched lead-acid batteries. Following the 'semiconductor age' the Research Institute of the Electrical-Industry (VKI) constructed 10 pieces of chopper controlled EV-s with a payload of half a ton for the Post again. Following researches on hybrid buses and a duo-bus, in 1989 the factory PULI started to produce 300 two-seaters and other smaller cars a year mostly for excursion purposes, or coffin- transporters in cemeteries. Our endeavour was to construct a continuously changeable transmission with high efficiency driven by an internal combustion engine (IC), and because the mass of batteries are generally very heavy we reduced them to the necessary minimum value. The same batteries are able to start the engine through a permanent magnet generator, operating now as a starter. The expected life-time of such a starter has to be 30 times higher than a conventional DC one. This makes it possible to stop the engine at crossings and in jams more often and this reduces the pollution. A new proposed hybrid EV drive with power-branching has electric and (IC) drive for 2 or 4 axles using a planetary gear which makes possible a drive on highways with combustion engines, at down-towns with electric power, and on hills with both in parallel operation. At the actual presentation we introduce our slides or photographs about the construction, manufacturing and production of our electric cars. 2

Keywords: HÉV, chopper, control system, dc-ac, dc-dc, inverter, induction motor, synchronous generator, hybrid strategy.

1. Constructions before World War II

It can easily be calculated that an average, medium sized car needs about 100 m^3 air for the consumption of 8 litre petrol on a 100 km highway trip, and what is even worse it makes a NO_x, CO, HC, SO_2 and other gas pollution because of insufficient burning. And this is only a single car. Multiply it with the number of vehicles and we get easily the result why we deal in our times always more and more with alternative solutions for our traffic problems.

But quite other reasons created our first electric vehicles in the 1920-ies. There were only few pump stations, but there were electric networks in bigger cities and the series excited DC motor with its constant power characteristic seemed to be an ideal drive for cars on roads and even on hills. And what is more, as I recently read a report in the monthly paper of the Hungarian Royal Post from 1933, [1] they decided to buy and use electric lorries for the transportation of packages and other goods in our Capital Budapest, because even an electric motor driven DC battery charger generator was a cheaper solution in those years, than the creation of pump stations for Internal Combustion chamber engines (IC). And even those electric lorries with their 8 m^3 useful room and 2.5 tons payload for the packages operated till 1944, some of them overcame the days of the siege of the city in World War II. Their maximum speed of 30 km/h was sufficient to drive from each house to the other slowly, and to wait for the postman to deliver the packages. The maximum quantity of these lorries were 34 pieces.

2. Constructions after the Semiconductor Age

Our first experience was made in the nineteen-sixties on a small electric truck, at the Department of Transport Automation of the Technical University of Budapest. With the original battery and DC series motor of the truck, we built a thyristor chopper into the same area, from which the mechanical controller was taken away. Into an accelerator pedal we took a potentiometer, which was the only 'moving part' of the equipment. On this truck we could measure the electrical behaviour of the chopper, and could test some safety requirements [2] for the automatic stop of the vehicle in the case of any failure in the control system.

For medical purposes, our Department and the Research Institute of the Electrical Industry (VKI), produced 2 small ambulance cars independently from each other, for the transport of 3 sitting patients, or for a stretcher and another patient. Electro-motorboat and motorcycle experiments were followed in the seventies made by VKI.

And then again the Post gave financial support for a greater investment, ordering 10 small lorries of 2.7 tons total weight, and 0.5 tons payload, with a max. speed of 55 km/h, within a range of 50 – 80 km, with a 192 V, 23 kWh lead-acid battery related to a 5 hours discharge. The series excited DC motor had an average/maximum power of 17/40 kW, at the revolution of $n_{\max} = 5000$ rpm.

Compared to the pre-war construction, these lorries were smaller, but faster and had a current limiter unit in the thyristor control. The chopper ran with a constant frequency and had a PWM voltage control with a space factor between a range of 8 – 92%. The series inductance and the flywheel diode smoothing unit ensured a continuous current flow under any conditions. The car had a built-in charger and an independent 12 V automobile-electric system, fed by a DC/DC converter, from the 192 V main battery, applying current for the lamps of the vehicle. The acceleration got his input signal from a pedal driven potentiometer. The brake consisted of 3 independent systems: an electrical one for resistance braking operated at the 'higher' positions of the accelerator pedal, a hydraulic one operated by the brake pedal, and a handy one for fixing the vehicle at stop. There was a built-in voltmeter on the board, signalling the charges in a way, at the driver's disposal.

For gaining a lighter battery, there was constructed a special polypropylene housing, with some thinner electrode plates, compared to those in starters. So they got an energy density of nearly 32 kWh/kg. These small lorries served the Post in Budapest for about 5 years.

The next two experiments have been made also at the VKI on the field of urban mass transport. Their aim was to reduce air pollution in urban traffic, although in those years there were significantly less private cars on our streets than in our days. At first a city autobus was reconstructed to a hybrid Diesel-electro one. Because Internal Combustion chamber engines (IC) have an optimal revolution, where the emissions of gases have a relative minimum value, a Diesel engine has driven with this constant r.p.m. a synchronous generator. This drive had a mechanically operated revolution control. The electrical values were controlled by its excitation to produce constant voltage and a limited max. current on the terminals of its 3 phase silicon rectifier output. This drive was charging continuously a battery system, which fed two external excited DC traction motors, also through chopper control, to make possible a regenerative braking.

The tests made on this vehicle proved, that the total air pollution even under optimal conditions was not significantly better, because of the worse efficiency of the whole system, than that of the direct Diesel drive [3].

The other mass-transport experiment was made on a trolley bus reconstructed to a so called duo-bus. Here we had a 72 V external excited DC motor, and the vehicle was fed partly from a 600 V DC urban trolley bus overhead network, and partly from a built-in battery system. The vehicle could be separated from the overhead wires, to join some near districts into its route. Concerning these abilities there existed 4 different operating conditions:

- Overhead wire drive
- Battery drive with regenerative braking
- Battery charging from the 600 V overhead network
- Overhead wire drive, with battery charging

Both vehicles had regenerative braking and for safety requirements, resistance and mechanical brakes, too. The simplified electrical scheme can be seen on *Fig. 1*. Meanwhile we have seen a similar construction in Germany/Esslingen, where they have solved even the automatic disconnection and reconnection of the trolleys with much skill.

The results of both very expensive experiments were the following:

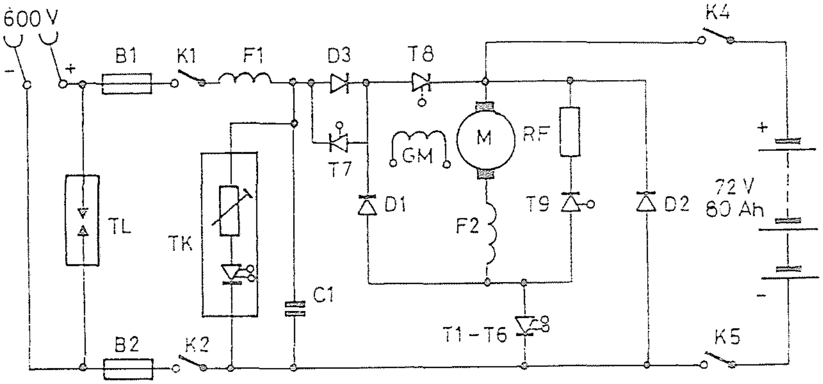


Fig. 1. Schematic connection of the Duo-bus experiment. B1 – fuse; K1 – main switch; Ft – inductance; D – diode; T – thyristor; TL – surge arrester; TK – chopper; RF – brake resistance; C – condenser; GM – excitation coil

- Industrial electronics reached such a high level, that practically all of our earlier 'dreams' could be fulfilled by it.
- Automatic control makes it possible to limit overload currents, as well as overvoltages, to protect our electrical equipments against human and environmental harms.
- We are able to replace DC series excited traction motors by external excited ones to realize feedback braking on one hand, and field weakening for reaching higher speed in modern city traffic, on the other.
- Some years later we could prove that, using DC/AC inverters even the DC motors can be replaced by induction, or synchronous ones with permanent magnetic excitation, to reach simpler, smaller and safer motor constructions.
- The electric vehicles have proved their indisputable advantages in downtown traffic by their zero pollution, noiseless operation, no consumption at red traffic lights and with their starting torque even at zero revolution.
- We have in all our experiments a single problem – but it is a tremendous one – to store electrical energy in nearly such a small mass as conventional fuel does it.

3. Hungarian Realities of the Present

It is said, if combustion engines would have been developed so rapidly as the electronic technology did, even a matchbox sized motor could drive a car, and air pollution would be negligible. But let us come back to realities! Year by year we hear good news about experiments from all around the world, finding new solutions to store more energy in smaller batteries and flywheel masses.

Following the described experiments, a Hungarian company, named PULI, reached the conclusion as many other foreign manufacturers did, to produce cheap two-seater electrocars for urban and sporting use. They remained at the realities: used ten units of 6 V, 240 Ah lead-acid batteries for the traction motor drive and a cabin heating for the winter, and a 12 V, 44 Ah one for the supply of the automobile electrical equipments. The motor was a 60 V, – 3.8/7.2 peak kW, 3250/6000 peak r.p.m. series DC construction with a starting current of 145 A. Max. speed of the vehicle was between 62 – 65 km/h, with an action range in urban traffic of 70 km, and on highways of 100 km. Its min. turn radius was 3.45 m, had a front wheel differential drive with sun-and-planet gear. The number of guaranteed charge-discharge cycles of the battery was about 300, with a built-in controlled charging unit. The accelerator pedal construction consisted of a 5 kΩ potentiometer, which controlled a 350 Hz frequency MOS transistor chopper with PWM and had an automatic current limiter. At reverse drive switching, the control circuit watched first the revolution of the motor, gave an automatic order for braking if necessary, and started the car with a limited current value only after its total stop. The basic construction had no feedback brake, but the power transistor chopper had a built-in diagnostic unit, so any maintenance could be done easily. The epicyclic gear had a constant ratio of 1:7.8 and the steering was solved with a linear gear. The total weight of the two-seater was 950 kg, with a payload of 170 kg weight. A mini-lorry construction, had 1400 kg total and 400 kg useful weight. The total efficiency of the construction was at 80%.

In 1993 Hungary had the honour to invite guests from all over the world to the International Solar World Conference and Exhibition. The scientists of the world are firmly convinced that our present energy policy has to be changed sooner or later. One of the critical points is the energy of urban transport. One of the exhibitors was the firm PULI, with his above mentioned electrocar. This company together with the engineers of the former VKI showed their photovoltaic charger to offer an alternative and renewable energy source for urban transport. Our scientists do their best to find a way-out from the present situation. In rich countries from the western world as the USA, Germany, France and Japan the costs for the construction and experiment of EV-s is financed mainly by those firms, who build IC engine driven cars. The PULI factory had no financial background so in 1995 they had to stop their production, because foreign firms covered the international EV market and they had no chance any longer. The firm turned over to produce more perspective products. After more than 70 years there is no EV production in Hungary ...

4. Hybrid EV Drive Concept with Power-branching

Our proposed new power drive is primarily convenient for small sized cars and vans and is extremely convenient in urban traffic for its economic, comfortable and environmental friendly behaviour. This solution offers a front axle drive or an ideal 4 wheel drive on icy roads; it is not only like a locked differential gear drive, but the ratio of front/rear axle torque can be continuously controlled even during operation under loaded conditions. Under 'normal' summer highway conditions it operates as an only front drive vehicle. The proposed drive affords quite new surprising services as zero emission operation in urban jams, although the action radius of this drive is not more than 10 kms and the acceleration and final speed are not higher than 1 m/s^2 – and 30 km/hour, but requirements in traffic jams are not higher than that. In case of a longer urban trip the built-in Internal Combustion engine (IC) can be started at any time.

4.1. The Theoretical Construction

The proposed drive does not need any clutches. Its schematic structure can be seen in *Fig. 2,* which can be considered as an overview of the car, too. The (IC) is driving the internal toothed gear of the three-shaft planetary gearbox (P) by shaft No. 1. Shaft No. 2, which is in connection with the crown of (P), drives through the differential gear (D) the front wheels of the car. The shaft No. 3, which is in connection with the sun-gear of (P), drives a permanent magnet excited 3 phase generator (PG). (P) is in reality an asymmetric drive, which operates so, that if shaft No. 2 is not rotating, the revolution of (PG) has to be about four times higher than the revolution of the (IC).

Under no load conditions (PG) is rotating, but the load current is zero, so there is no torque on shaft No. 3. According to the fundamental construction of (P), the torque on shaft No. 2 must be also zero, that means that there is no driving force on the wheels.

At the maximum speed of the car, (PG) is electrically short-circuited by a transistor (T) on *Fig. 3.* In this case (PG) is rotating very slowly and the short circuit current of it is as much as necessary. The torque of (PG) should be in balance with the torque on shaft No. 2, i.e. with the necessary driving requirements. Generally, this slow revolution of (PG) can be considered as the slip-loss of the drive. According to the high gear ratio of shaft No. 3 on one hand, and the permanent excitation on the other hand, this loss is not higher than 1% of the whole power of the (IC). This does not characterise only the maximum speed case, but all the other partial-load cases, too, when the (IC) is able to drive the car alone.

In case if the driving force has to be increased, (PG) supplies electric

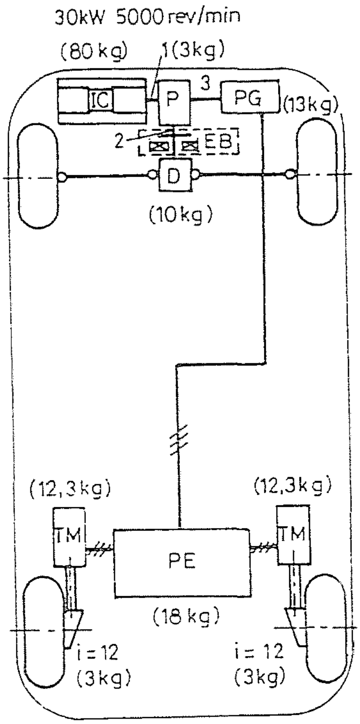


Fig. 2. Schematic structure of the proposed hybrid drive. IC – internal combustion engine; P – three-shaft planetary gearbox; D – differential gear; PG – permanent-magnet generator; TM – traction induction motor; 1, 2, 3 – shafts of P; PE – power electronic unit (detailed on *Fig. 3*); EB – electromagnetic brake (optional)

power to the two induction motors (TM) driving the rear axles through a power-electronic device (PE) while the front axle is driven by the (IC). Needed a higher speed, the accelerator of (IC) has to be pushed deeper, and at the same time the frequency of the boost-chopper can be continuously changed. The draft of the power-electronic device (PE) can be seen on *Fig. 3.* The alternative current of (PG) is rectified by a bridge connection (RE), boosted to a higher voltage level by the chopper (CH), smoothed by condenser (C) and inverted by a transistor-diode bridge to any wanted frequency and 3 phase current, to supply the (TM) motors. This can be made continuously according to the position of the accelerator. The operation of the boost-chopper makes it possible to reduce the electric power continuously even till zero, at a fixed torque ratio of (P).

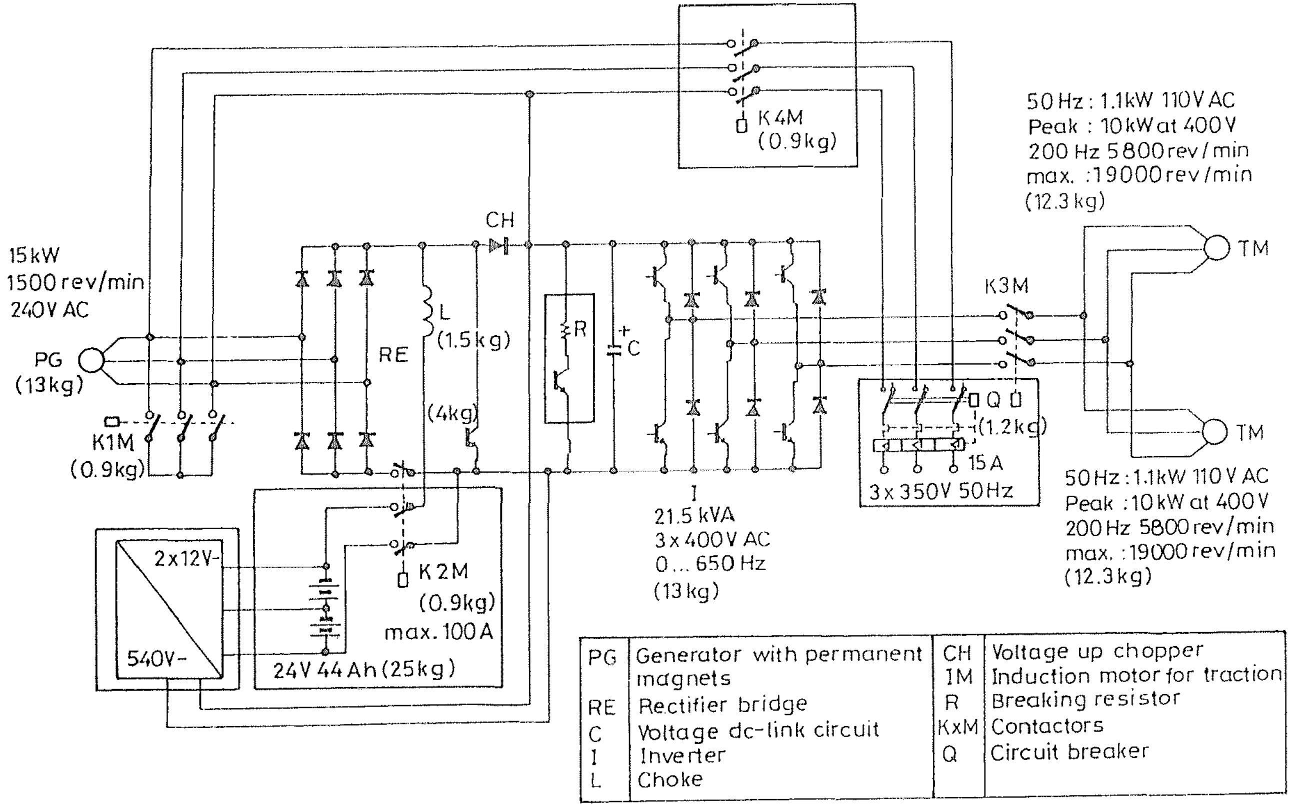
Industrial realisability of the proposed drive seems to be competitive for industrial purposes, too. To prove it, we have given in *Fig. 2* the mass of the inverter, an induction motor available in commerce (in round brackets), and the estimated masses of other parts [in square brackets]. The sum of these makes 74.6 kg. For comparison the mass of a commercial 4 wheel driven car has at least about a 100 kg overweight. This does not mean that the avaible parts could be used without modifications for the proposed drive, but these alterations do not need significant requirements.

4.2. Main Advantages

- The power of the (IC) can be used in a wide range, because the power transmission ratio is continuously changeable.
- The operation is absolutely free of skipping.
- In urban traffic the energy saving takes approximately 20% due to regenerative braking.
- On highways the induction motors run mostly under unexcited, no-load conditions, their iron and copper losses are practically zero.
- Even the efficiency of power transmission in acceleration is higher than those in hydrodynamic or hydrostatic continuous drives.
- On icy roads there is a possibility to control the drive so that the adhesive coefficient should be equal on all the 4 wheels.
- The dimensional size of the electric drive at the car is significantly less, owing to the direct mechanical drive components compared to a totally electric driven car.
- In overcrowded down-town regions the vehicle is able to operate as a zeroemission car.

4.3. Disadvantages

- Power electronic devices are expensive.
- In backward direction only the electric drive is available, but this reversion is easily realisable.



PG	Generator with permanent magnets	CH	Voltage up chopper
RE	Rectifier bridge	IM	Induction motor for traction
C	Voltage dc-link circuit	R	Breaking resistor
I	Inverter	KxM	Contactors
L	Choke	Q	Circuit breaker

Fig. 3. Hybrid car electronic control circuit

4.4. Options

- Electric resistance and feedback braking is possible, but for emergency and park braking a mechanical brake is necessary, too.
- Zero pollution operations in urban traffic is realized by two 12 V series connected normal starter batteries, which supply the energy through the (CH) boost-chopper with a voltage of 540 V. The (L) inductance is indispensably necessary for the (CH) chopper (*Fig. 3*).
- Starting the engine from the battery whose voltage is boosted also by (CH), by (I) and by the dashed line feedback to the (PG), the generator will work now as a starter motor with a twice higher efficiency than a conventional series excited DC one.
- There is no need for an extra battery-charging generator, and the 540 V/2×12 V static inverter is estimated not to be heavier than 1 kg. Under the conditions of a normal highway speed traffic the (K1M) contactor short circuits the (PG) and so (CH) do not operate. In such cases (I) controls the (TM) in a slightly braking operation to keep the 540 V constant. This assures the battery charging till the vehicle is rolling.
- The vehicle is able to operate also as a small power station at weekend-houses, where the electric network is not available. In this case the circuit breaker (Q) separates the induction motors from the inverter, so the electromagnetic brake (EB) stops immediately the car, turns the inverter (I) to a constant 3×230 V, 50 Hz output and controls the (IC) according to any demanded power even in case of asymmetric load for any housekeeping purposes.

5. Remarks

Owing to shortage in our capital investments we are looking for firms who see and find advantage in our conception, and are ready to cooperate with the more than 60 years old traditions of Hungarian EV industry. We hope to find the best way for such a partnership.

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