hybrid electric vehicle

Dainius JANULEVIČIUS*, Algimantas VALINEVIČIUS, Darius ANDRIUKAITIS
Department of Electronics Engineering, Faculty of Electrical and Electronics Engineering,
Kaunas University of Technology
Studentų g. 50-438, LT-51368 Kaunas, Lithuania
*Corresponding author. E-mail: dainius.janulevicius@elinta.lt

INTELLIGENT PLUG-IN HYBRID ELECTRIC VEHICLE

Summary. City pollution is a very important issue which effects our daily life and our health. Commercial trucks which run diesel engines are responsible for most of the pollution in our cities. With new intelligent plug-in hybrid technology fuel consumption can be reduced by more than a half. By reducing fuel consumption internal combustion engine emissions decrease. The IPHEV also has an integrated GPS system which can track the vehicle and work with the onboard computer system to automatically turn off the diesel engine and switch to pure electric mode when the vehicle enters the city center or a designated green zone. The electric motor uses a $LiFePO_4$ battery which has a range of 35 to 65 km. The additional hybrid control unit makes IPHEV system universal and attractive to commercial vehicles manufacturers.

INTELIGENTNY HYBRYDOWY POJAZD ELEKTRYCZNY

Streszczenie. Problem zanieczyszczeń w miastach jest bardzo ważnym zagadnieniem, który wpływa na nasze codzienne życie i zdrowie. Za większość zanieczyszczeń w miastach odpowiedzialne są samochody ciężarowe z silnikami Diesla. Dzięki nowej inteligentnej technologii hybryda plug-in zużycie paliwa można zmniejszyć o ponad połowę. Poprzez zmniejszenie zużycia paliwa uzyskuje się również zmniejszenie emisji spalin. System IPHEV jest zintegrowany z systemem GPS, który może śledzić pojazd i współpracować z systemem komputera pokładowego pojazdu i automatycznie wyłączyć silnik wysokoprężny i przełączyć się na tryb elektryczny, gdy samochód wjeżdża do centrum miasta lub do wyznaczonej strefy zielonej. Silnik elektryczny pracuje na baterii LiFePO4, który zapewnia zasięg 35 do 65 km. Dodatkowa jednostka sterująca systemem hybrydowy IPHEV sprawia, że jest to uniwersalne i atrakcyjne rozwiązanie dla producentów pojazdów użytkowych.

1. INTRODUCTION

Emissions from vehicles used in commercial transportation is part of the human impact on global warming and the greenhouse effect. One method of cutting the greenhouse gases from the vehicles is by decreasing the fuel consumption. The majority of commercial vehicles use diesel engines which are significant sources of emission and pollution producing particulate matter (PM), carbon dioxide (CO_2) and nitrogen oxides (N_2O). These greenhouse gases directly and substantially affect global warming [1]. By utilizing a hybrid system commercial vehicle fuel consumption can be reduced which reduces emissions and decrease urban pollution and commercial transportation's impact on the environment in general. The hybrid conversion kit enables the vehicle to be powered by the conventional diesel engine

or by electric motor alone or by both motors at the same time in hybrid mode. The hybrid mode uses the diesel and electric motors in combination reducing the fuel consumption and emissions. The pure electric mode enables the truck to be driving using only electricity from the batteries consuming no petroleum and producing zero emissions.

The additional systems for commercial vehicles includes a GPS, a hybrid control unit, an electric alternative current induction motor, a battery pack, a power electronics module and an additional cooling system. The installed electric motor produces 55 kW (90 peak) 450 Nm of torque (850 peak). The power generated by the electric motor can be an auxiliary power unit for the diesel engine or be the primary source of propulsion depending on the zone where the vehicle is driven. Such a system has been developed to reduce overall fuel consumption and provide the capability of using the vehicle in pure electric mode in the low pollution zones.

2. SYSTEM DEFINITION

The intelligent plug-in hybrid electric vehicle (IPHEV) functions as a pure electric vehicle for short distances greatly reduces fuel consumption when the electric motor is working in conjunction with the internal combustion engine (ICE) improving fuel efficiency up to 25 %.

IPHEV main features:

- EV mode switch by GPS green zones
- 30 km to 60 km of pure electric range
- Up to 5.5 t vehicles
- 850 Nm torque

The intelligent plug-in hybrid electric vehicle technology is the future of urban and suburban transportation. This technology will create commercial vehicles which have all the advantages of zero emissions vehicles while having unlimited range with combustion engine outside the city green zones. For short distances this vehicle works as a pure electric vehicle and when utilizing the combustion engine for long distances the vehicle will be a hybrid combustion/electric motor powered vehicle improving fuel efficiency and reducing overall emissions. Fuel consumption test results are shown in Table 1 [2]. Testing was conducted with a 126 HP 2.3 l F1A engine.

Tab. 1

Fuel consumption in real life test results

	50 km cycle	**100 km cycle**	**150 km cycle**
11 kWh battery pack	2.7 l/100 km 72 g/km CO_2	4.76 l/100 km 119 g/km CO_2	5.44 l/100 km 144 g/km CO_2
22 kWh battery pack	0.68 l/100 km 18 g/km CO_2	2.72 /100 km 72 g/km CO_2	4.08 l/100 km 106 g/km CO_2

Depending on battery capacity, the average fuel consumption can be up to 35 % - 80 % less than a conventional commercial vehicle. According to these test results it is obvious that a commercial vehicle with IPHEV system is ideal for short distances. IPHEV fuel consumption with 22 kWh and 11 kWh battery packs displayed in Fig. 1.

The IPHEV also has an integrated fleet management system which allows the creation of a geographical zone, in this case a green zone, for example, a densely populated area like a city center or an airport where the vehicle will operate in pure electric mode only. When entering into such a zone, the vehicle warns the driver and automatically switches from the diesel motor to the electric engine if battery capacity is more than 10 %. The fleet manager can create the green zones in the cloud based software and then the zones will be distributed to each of IPHEV vehicles in fleet. The onboard GPS system communicates with the truck's onboard computer system to determine when the commercial vehicle has entered a zone. The system is accurate within 15 to 50 meters. The structure of fleet management system is shown in Fig. 2.

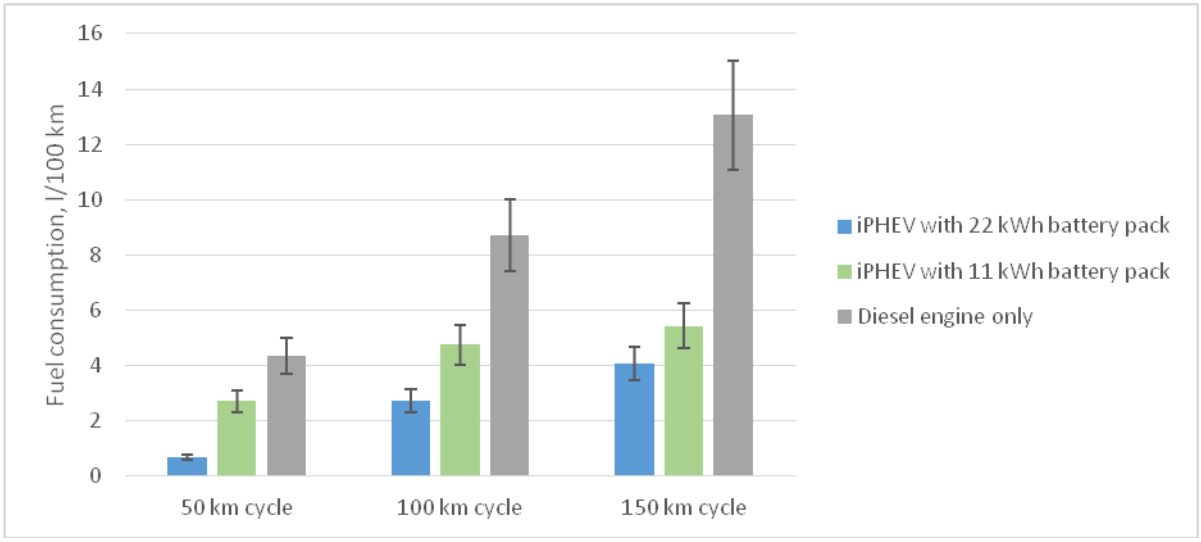

Fig. 1. Fuel consumption with 22 kWh and 11 kWh battery packs

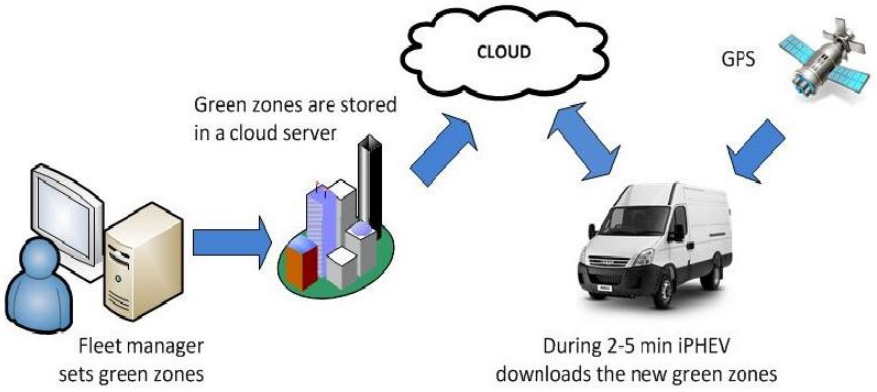

Fig. 2. Structure of fleet management system

The IPHEV also sends additional information to fleet management system: speed, location, driving mode, green zones violation. The system can provide the fleet manager with instantaneous or regularly scheduled reports. The fleet management system provides vehicle tracking, operation reports, service alerts among other functions.

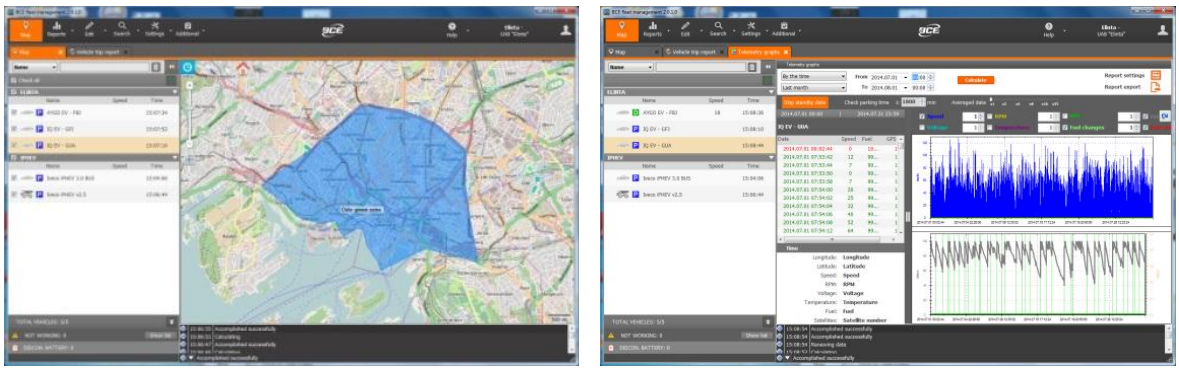

Fig. 3. Fleet management application

3. IPHEV STRUCTURE

The IPHEV is a single-axis series system. The ICE output is directly connected to the electric motor rotor shaft and then to the rear drive wheels through the differential. IPHEV designed for the trucks includes the hybrid control unit with GPS system, power electronics module, electric alternative current induction motor, battery pack, charging system and the additional cooling system [3]. The whole additional system weighs approximately 295 kg. The generic system model is shown in Fig. 4 [4].

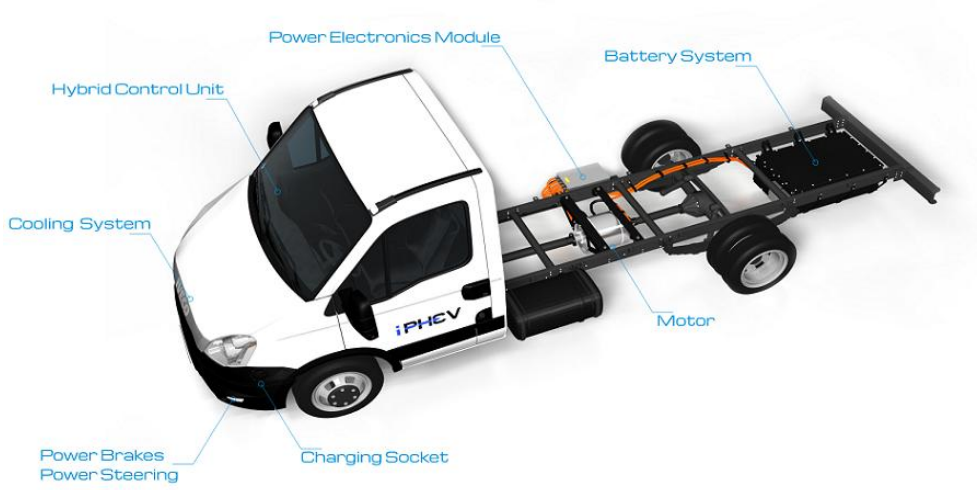

Fig. 4. IPHEV structure

Unlike most plug-in hybrid electric vehicles on the market today where the vehicle automatically selects the mode of traction, the intelligent plug-in hybrid electric vehicle system allows the driver or the fleet manager to select the mode of traction where needed. Regular PHEV would deplete the battery capacity travelling at low speed in traffic congestion on the highway heading for the city center, requiring the petrol engine to kick in reaching the city center. IPHEV will travel in combined mode, regardless of speed and switch to pure EV mode when reaching the city center, allowing zero-emission distribution for a total distance of 35 to 65 km.

A simple DIN mount user interface allows driver to see the hybrid system status and select modes manually.

IPHEV has the following modes (see Fig. 5):

- EV MODE - Pure electric traction
- HEV MODE - Depletes battery while driving
- SAVE MODE - Maintains battery capacity
- CHG MODE - Charges battery while driving [5]

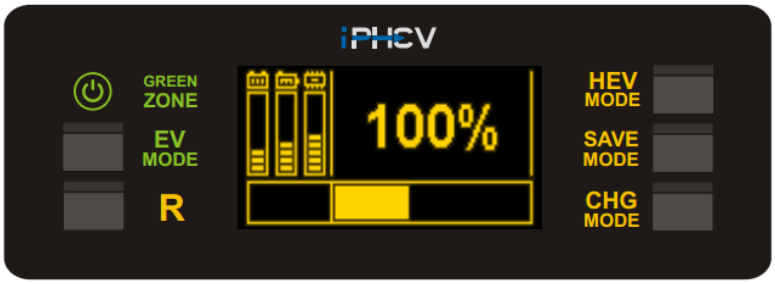

Fig. 5. IPHEV control screen

3.1. $LiFePO_4$ BATTERY

The IPHEV system has a battery box with lithium iron phosphate battery cells. $LiFePO_4$ batteries are being used in the electric mobility applications because of their superior thermal and chemical stability. Better battery safety characteristics are being achieved compared to the other types of cathode materials for battery. This battery type can survive temperatures up to 40°C without decreasing the lifecycle of the battery. The battery life span is dependent upon the operating environment. It is very important to use a cooling system for batteries because higher operating temperatures decrease the battery life span. Comparison of capacity fading at different temperatures are shown in Fig. 6 [6].

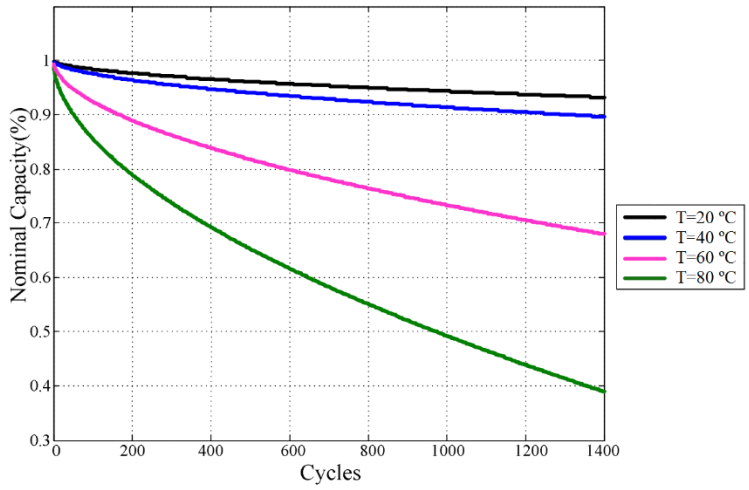

Fig. 6. Battery capacity at different operating temperatures

$LiFePO_4$ battery performance peaks at 3000 cycles. After the 3000 cycles the capacity decreases to 80 % which is still a decent amount of energy to be stored. $LiFePO_4$ has high energy density – 121 Wh/Kg [7]. Such a battery fits very well to the vehicle because most of them have low safety awareness. This type of battery has no hazardous or noxious substance and it is an environmentally friendly. For the more it is maintenance free and the longer durations having a low state of charge does not affect the battery [8]. IPHEV 22 kWh and 11 kWh batteries shown in Fig. 8. Battery box specifications presented in Table 2.

Tab. 2

Battery box characteristics

Battery type	$LiFePO_4$
Number of cells	44
Battery voltage	150 V
Energy	11 kWh / 22 kWh
Life cycles	3000 (> 12 years lifetime)
Integrated AC-DC Charger	3.6 kW / 7.2 kW
Integrated DC-DC Converter	1.2 kW
Integrated battery management system	Distributed
Integrated battery heating	170 W
Cooling system	Liquid
Operation	-30 ... 45 °C
Weight	185 kg

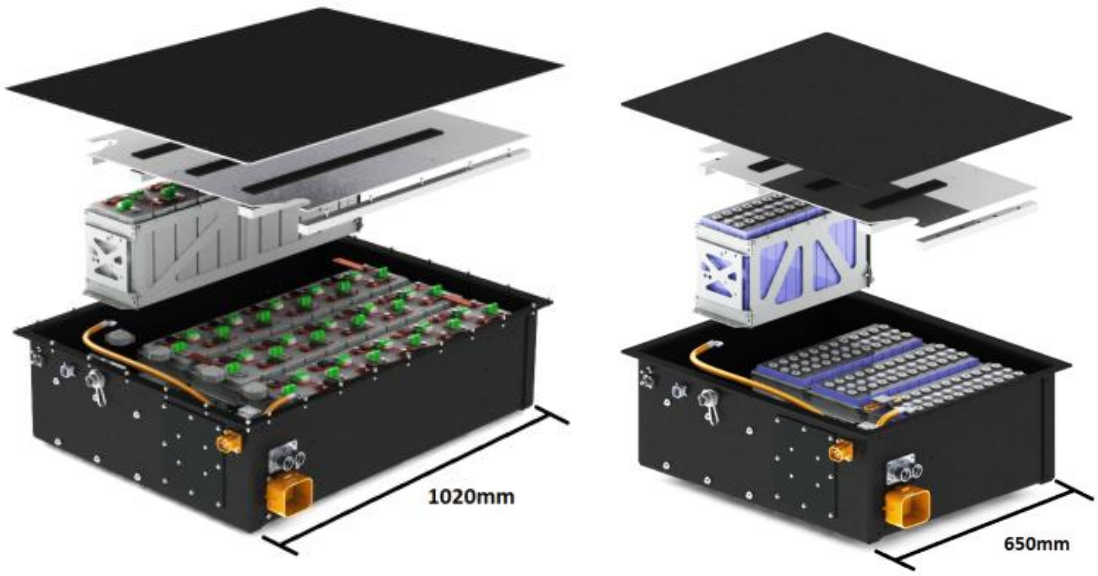

Fig. 7. 22 kWh and 11 kWh battery packs

The battery's ability to hold a charge, like all batteries, decreases with battery age and usage which results in decreased vehicle range. This is normal and expected and is not indication a malfunction of the vehicle or battery. The battery's ability to hold a charge is affected by how you drive the vehicle, store the vehicle, how you charge the battery and the battery temperature during vehicle operation and charging.

To save battery life it is recommended to:

- Avoid storing a vehicle in temperatures below -25°C for over 7 days.
- Allow the battery charge to be below at least 80 % before charging.
- Do not leave the vehicle discharged with less than 30 % state of charge over 14 days.
- If the vehicle is not to be used for an extended period of time (1 moth or more), charge the lithium battery fully, disconnect service plug and 12V battery.

3.2. CHARGING

A plug in hybrid electric vehicle with 11 kWh battery pack is equipped with a Mode 3 Type 2 charging cable. A full charge at a charging station requires about 4 hours at 3.6 kW power. The IPHEV with 22 kWh battery pack uses 32 A single phase charging. A full charge takes around 3.5 hours at 7.2 kW power. Mode 2 charging is also an option and at 2.2 kW charging takes 7 hours to 13 hours depending on battery capacity.

3.3. LIQUID COOLED INDUCTION MOTOR

The induction motor traction system is developed to last. The liquid cooled motor and controller are able to produce over 850 Nm of torque instantly which enables the system to be used for 3.5 t to 5.5 t commercial vehicles or small buses. The electric engine is a six pole liquid cooled induction motor designed for high power applications in pure electric and hybrid vehicles. There are two versions of the motor. The LCM-160-6-100 version is designed for low speed inline shaft hybrid operation and LCM-160-6-250 is designed for pure EV high power applications. The liquid cooled induction motor shown in Fig. 8. The specifications are presented in Table 3.

Fig. 8. Liquid cooled induction motor

Tab. 3

Induction motor characteristics

	LCM-160-6-100	**LCM-160-6-250**
Motor type	AC induction	AC induction
Battery voltage	150 VDC	350 VDC
Efficiency	90 %	93 %
Continious power	55 kW	110 kW
Peak power	90 kW	250 kW
Continious phase current	350 A	450 A
Continious torque	450 Nm	300 Nm
Peak torque	850 Nm	600 Nm
Top speed	4000 RPM	8000 RPM
Cooling	Liquid	Liquid
Weight	91 kg	91 kg

LCM-160-6-100 electric motor produces 55 kW continuos, 90 kW peak power and 450 Nm of torque (850 Nm peak). LCM-160-6-250 electric motor produces 110 kW power and 300 Nm of torque (see Fig. 9).

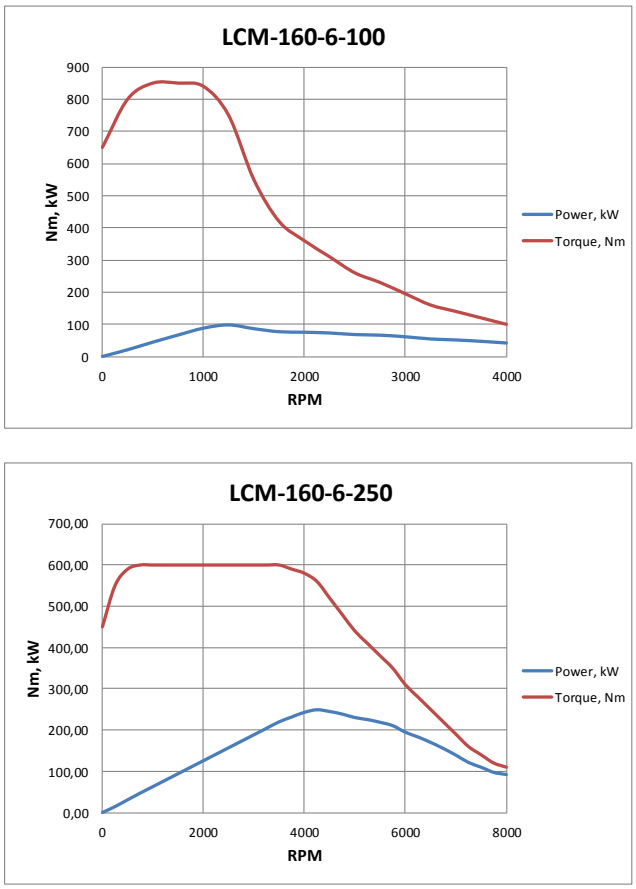

Fig. 9. Electric motors power and torque characteristics

3.4. INDUCTION MOTOR CONTROLLER

IPHEV's powerful and efficient motor controller works using MOSFET transistors. With only 150 V/DC voltage supply it is capable of producing up to 90 kW peak power. It can be used in hybrid or pure EV vehicles, boats or other battery driven machinery (see Fig. 10). The specifications are presented in Table 4.

The IPHEV induction motor controller main features:

- High efficiency;
- CAN v2.0 BUS;
- Built-in contactor;
- Liquid cooling;
- Robust IP67 case;
- Simple user software;

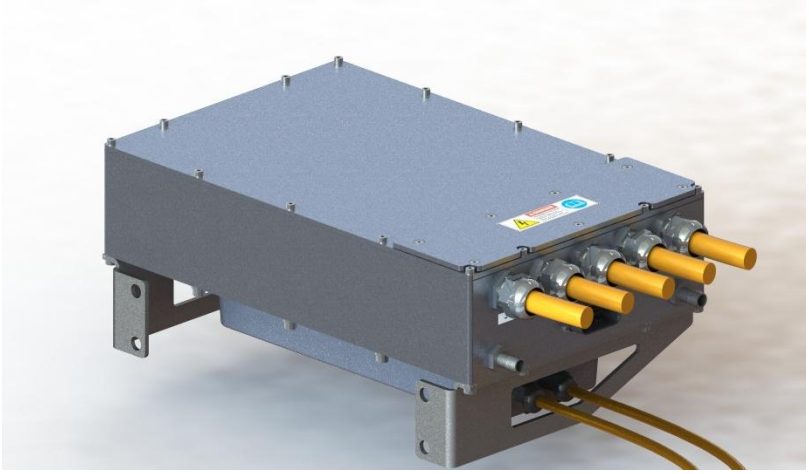

Fig. 10. Induction motor controller

Tab. 4

Induction motor controller characteristics

Controller type	MOSFET
Efficiency	98 %
Battery voltage	150 VDC
Continuous power	55 kW
Peak power	90 kW
Boost phase current 2s	900 A
Continuous phase current	500 A
Max DC battery input current	630 A
Operational temperatures	-40...+65°C
Protection class	IP67
Cooling	Liquid
Size	260 x 405 x 93 (mm)
Weight	11 kg

3.5. HYBRID CONTROL UNIT

Like all Plug-In Hybrid vehicles IPHEV is designed for short distances. The average fuel consumption depends on a driving cycle length, vehicle weight and battery capacity. The hybrid control unit coordinates the electric motor with the diesel engine. In combined mode the electric motor assists the diesel engine during acceleration and reduces fuel consumption. The regenerative system charges the battery while braking. With 85 Hp, 850 Nm electric motor vehicle is smooth and comfortable to drive within the green zones.

Universal hybrid control unit (HCU) fit to most of the internal combustion engine driven vehicles. HCU connects with existing vehicle engine control unit (ECU) and body computer signals. HCU does not interfere with ECU, it just measures the signals, and uses body computer provided input and output signals like engine start, engine stop, brakes output signals, etc. Other signals like accelerator, ignition, clutch position are measured using high impedance inputs. The EV mode algorithm shown in Figure 11 and HEV mode algorithm is shown in Fig. 12.

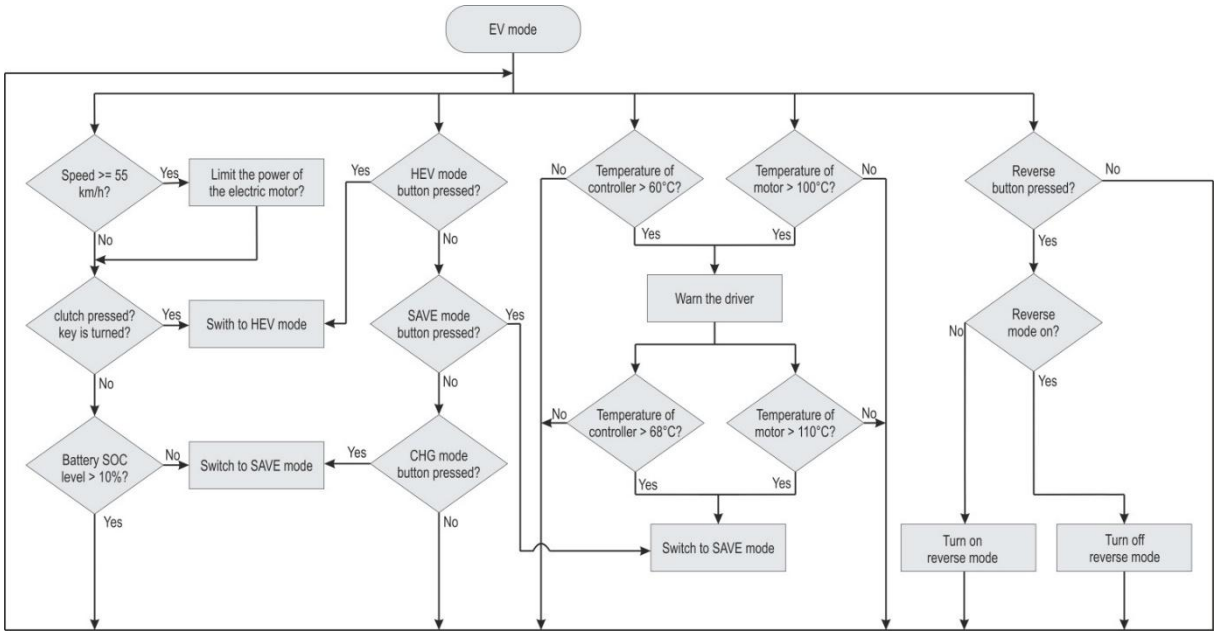

Fig. 11. EV mode algorithm

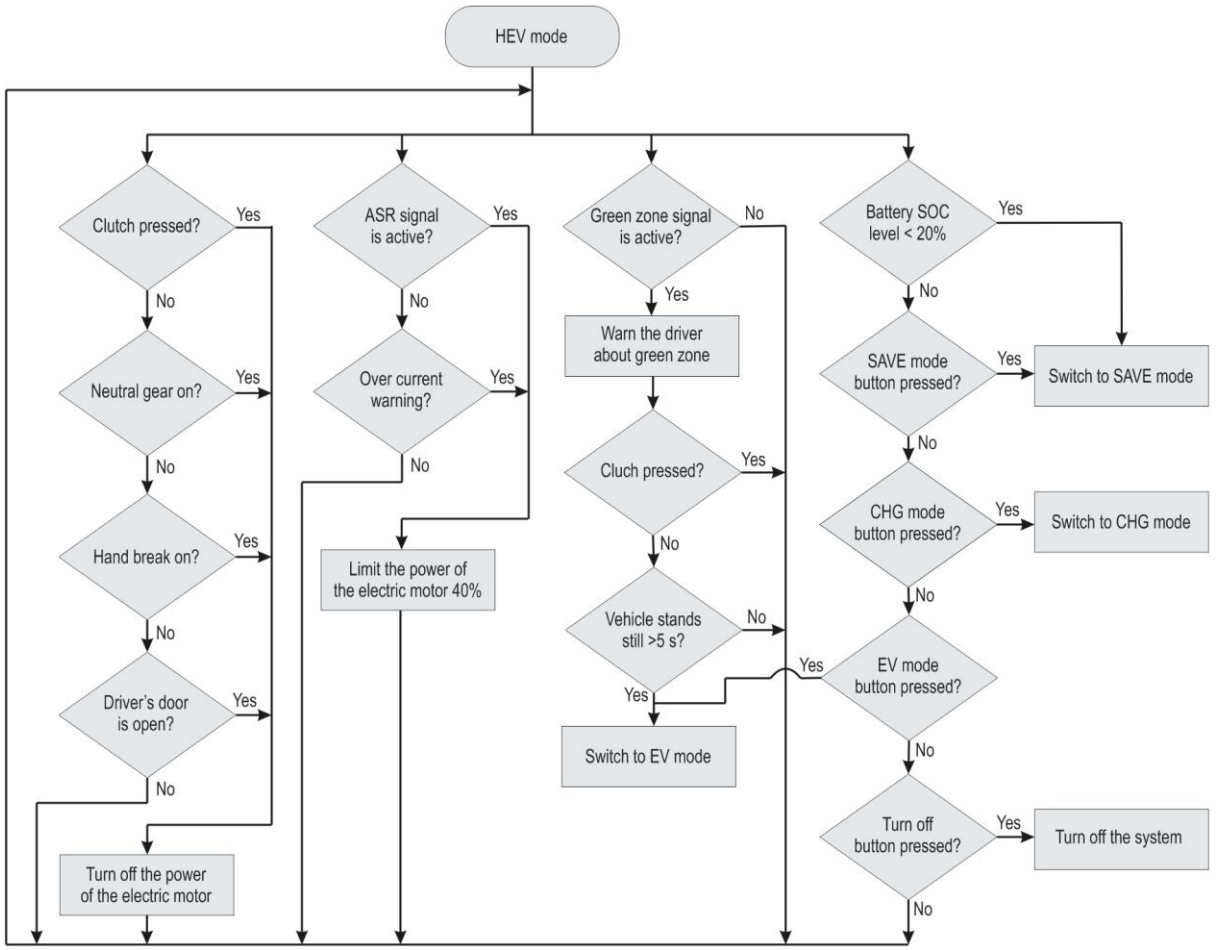

Fig. 12. HEV mode algorithm

The HCU can be controlled remotely by GSM and GPS on the green zones, or modes can be switched manually using a single input mode button. The HCU switches between EV and HEV mode, stopping or starting the internal combustion engine. The HEV mode is designed to save fuel while driving with the combustion engine running [9]. Depending on speed, acceleration and engine load HCU controls the power of electric drive increasing power, acceleration and fuel efficiency.

Depending on a road conditions 25-30 % less fuel is consumed when the driving speed is less than 70 km/h. The HEV mode does not deplete the battery. This mode is similar to KERS (Kinetic energy recovery system) using only 5 % of battery capacity, leaving the battery full for pure EV mode operation [10]. When driving on the highway at constant speeds HCU switches to charge mode, charging the battery with extra energy at rate of 20 % per 100 km [11]. The HCU has an integrated diagnostics system, which sends information using the GSM network to fleet manager or it can be accessed with provided CAN-USB tool.

Prototype of IPHEV tests were carried out in Norway. The test distance was 5000 km in 2 months. The IPHEV was presented at the opening of Mode 3 charging park in Oslo. During the event Norway minister of transport Ketil Solvik-Olsen tested the IPHEV Iveco Daily. According to him IPHEV system can solve a lot of transport problems and reduce city pollution.

4. CONCLUSION

This paper has attempted to define the intelligent plug-in hybrid electric vehicle system, show the system structure and principles of operation. The fuel and the energy urban consumption tests were performed on the commercial vehicle that has the additional IPHEV system installed. IPHEV system gives additional 55 kW of power and 450 Nm of torque. Depending on battery capacity, driving cycle average fuel consumption can be reduced by 35 % to 80 %.

Integrated fleet management system provides vehicle tracking, operation reports, service warnings and other functions. Using GPS system IPHEV indicates green zones where the vehicle operates in pure electric mode only. IPHEV also provides additional information to the fleet management system: speed, location, driving mode, green zone violation, monthly or weekly reports.

The IPHEV system has a 11 kWh or 22 kWh $LiFePO_4$ battery which allows zero-emission operation for a range of 35 to 65 km. The system also consists of 6 pole liquid cooled induction motor and 90 kW peak power motor controller. The whole additional system weights approximately 295 kg.

The hybrid control unit coordinates the electric motor with the diesel engine and fits most of the internal combustion engine driven vehicles. The IPHEV features will radically change commercial vehicle market.

REFERENCES

1. Demir, E. & Bektas, T. & Laporte, G. A review of recent research on green road freight transportation. *European Journal of Operational Research.* 2014. Vol. 237. No. 3. P. 775-793.
2. Lintern, M.A. & Chen, R. & Carroll, S. & Walsh, C. Simulation study on the measured difference in fuel consumption between real-world driving and ECE-15 of a hybrid electric vehicle. In: *Proceedings of Hybrid and Electric Vehicles Conference.* 2013. Available at: http://ieeexplore.ieee.org/ stamp/stamp.jsp?tp=&arnumber=6728838
3. Wang, X. & He, H. & Sun, F. & Sun, X. & Tang, H. Comparative Study on Different Energy Management Strategies for Plug-In Hybrid Electric Vehicles. *Energies*. 2013. Vol. 6, P. 5656-5675.
4. *Elinta Motors. Electric vehicles manufacturer*. Available at: http://www.elintamotors.com/ Electric-vehicles/iphev
5. Ma, C. & Song, M. & Ji, J. & Park, J. & Ko, S. & Kim, H. Comparative study on power characteristics and control strategies for plug-in HEV. *Vehicle Power and Propulsion Conference.* 2011. Available at: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6043156

6. Shen, J. & Dusmez, S. & Khaligh, A. *An Advanced Electro-Thermal Cycle-Lifetime Estimation Model for LiFePO$_4$ Batteries*. 2013. Available at: http://ieeexplore.ieee.org/stamp/stamp.jsp ?tp=&arnumber=6574494
7. *Calb Europe. LiFePO$_4$ battery manufacturer.* Available at: http://en.calb.cn/product/show /?id-630
8. Wang, X. & Adelmann, P.& Reindl, T. Use of LiFePO$_4$ Batteries in Stand-Alone Solar System. *Energy Procedia*, Vol. 25. 2012. P. 135-140.
9. Karbowski, D. & Smis-Michel, V. & Vermeulen, V. Using trip information for PHEV fuel consumption minimization. In: *Proceedings of Electric Vehicle Symposium and Exhibition (EVS27)*. 2013. Available at: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber =6914710
10. Hu, C. & Huang, A.Q. & Gao, Y. Comprehensive lost minimization strategy for parallel plug-in hybrid electric vehicles. In: *Proceedings of Transportation Electrification Conference and Expo (ITEC).* 2013. Available at: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6573501
11. Ma, X. & Ming, W. Energy-saving Driving Mode for PHEV Drivers based on Energy Cycle Model. In: *Proceedings of Hybrid and Electric Vehicles Conference.* 2013. Available at: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6728837