Sectional hybrid drive

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Traineeship report

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2 Introduction of the problem

Air pollution and global warming are big issues nowadays. A large part of emissions are accounted for by transportation, so the need for cleaner vehicles is obvious. One of the possibilities of reducing emissions of vehicles is the use of hybrid drives. There are different kinds of hybrid configurations. The sectional drive is one of them and has specific advantages over the currently used configuration.

In this report a small city car, with a sectional drive is considered.

Goal is to make an energetic study on a small city car equipped with a sectional hybrid drive.

The conditions are: cheap and simple. For cheap small city vehicles it is important to have cheap components and manufacturing processes. In general it means that simpler solutions, mean less parts en lower costs.

A sectional hybrid drive for small city car is investigated, to see if it is a suitable solution for this kind of vehicles. The reason to use a hybrid solution is, that the trend is cleaner, more economical and silent. An alternative for now and the near future is a hybrid. The sectional drive is a new kind of hybrid so few research on this topic is done. It is probably a cheaper solution, so it is useful for a small car.

Small city cars have to have low emissions, because it is important for old cities to stay clean. Partly they consist of pedestrian area's, where no cars are allowed. But for cars with low noise and zero emission, exceptions are made. This makes small city cars very good items for implementing hybrid drives.

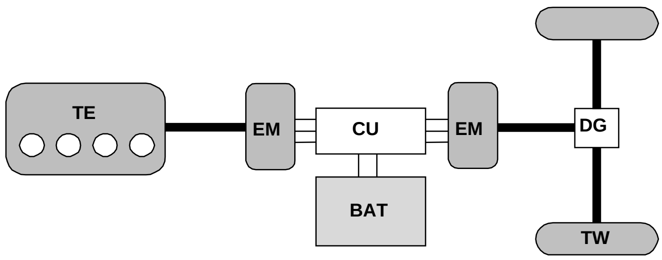
3 Theory of hybrid drives

3.1 Hybrid drives

In general there are two different kinds of hybrid drives, parallel and series. The parallel hybrid drives that are used today can roughly be characterized by the 'Prius' hybrid and the 'Insight' hybrid. The theory of both series and parallel are discussed in the following paragraphs.

3.1.1 Series hybrid

The series hybrid is characterized by the fact that there is no physical connection between the primary energy source, usually an internal combustion engine, and the wheels. Mechanical energy generated by the ICE is never used to drive the wheels but is always converted into electrical energy by a generator. The engine is operated in its highest efficiency point and has a more or less constant output. The electrical energy coming from the generator is consequently constant. This energy is used to drive the electric motor connected to the wheels. The load of the vehicle is far from constant, as well as the essential power. To fulfill this demand, a battery can deliver extra power when the generator power is too low. In case of energy surplus, the same battery can store this energy. If there is a low demand of power for a longer time, the engine can shut down. In this way, intermittent use of the engine can be effected.
The advantage of this type of system is that the ICE can operate at its maximum efficiency at all times, which is not possible in parallel hybrids. However, losses in energy conversion (2x) and storage cancel for a large extent the higher efficiency of the engine.



TE: thermal engine,
EM: motor/generator
BAT: battery, CU: control unit
DG: main differential
TW: traction wheels

Figure 3.2 Layout series hybrid drive

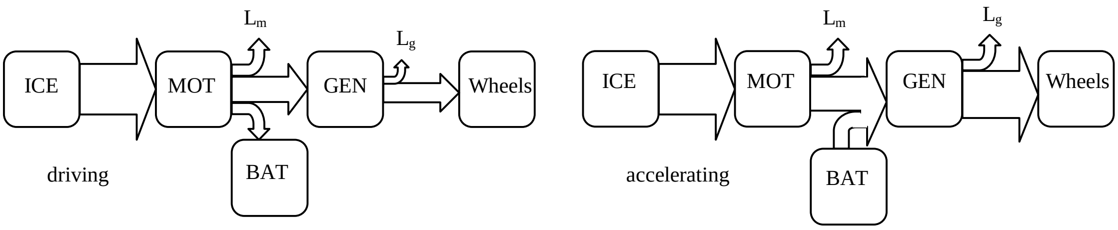
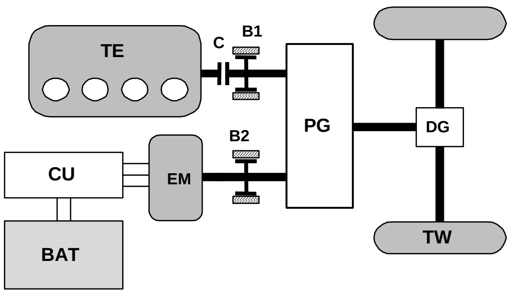


Figure 3.1 Energy flow in series hybrid

3.1.2 Parallel hybrid

Parallel hybrid drives differ from series hybrid mainly on the issue of the energy flow. In parallel hybrids, the main power source can be connected directly with the wheels. This creates a high efficiency for the energy transmission. The electric motor also has the possibility of a direct connection with the wheels. The engine and motor can drive the vehicle together or the motor can be used as a generator while the ICE drives the vehicle. A very common and powerful way of connecting the two power sources to the wheels is via a planetary gear as in Figure 3.3. It is also possible to mount engine and motor on the same shaft as is done in the Honda Insight. The use of a planetary gear gives more possibilities and the controllability of angular velocities and torques is better.



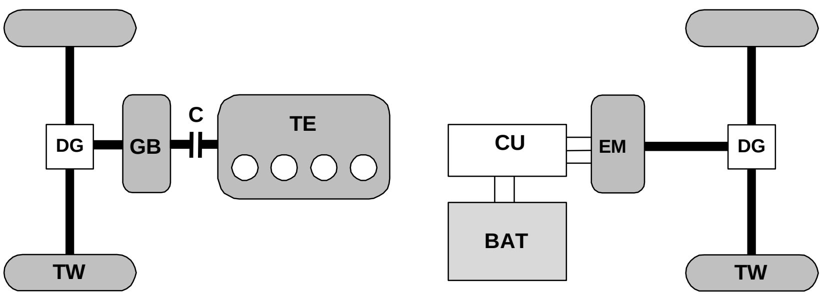
TE: thermal engine
PG: two degrees of freedom planetary gear
EM: motor/generator, BAT: battery, C: clutch
B1, B2: shaft brakes, DG: main differential
TW: traction wheels, CU: control unit

Figure 3.3 Layout of a parallel hybrid drive

3.2 Sectional drive

The suggested new configuration [

Figure 3.4] in the small city vehicle differs from the mentioned ones. The ICE is connected directly to the wheels, so from that point of view it could be called a parallel hybrid. The energy transfer from the ICE to the electric motor is however not via a mechanical connection such a planetary gear. Energy flows via the wheels and the road to the electric motor. In the small city car the ICE drives the front wheels in a conventional way and the rear wheels are driven by an electric motor.



TE: thermal engine
EM: motor/generator
BAT: battery, C: clutch
GB: gearbox
DG: main differential
TW: traction wheels
CU: control unit

Figure 3.4 Layout of a sectional hybrid drive

Energy from the engine still can be accumulated in an indirect way. While the engine drives the vehicle, the motor can be used as a generator to brake the rear wheels. In order not to decelerate, the engine has to provide more power than necessary under normal conditions. In this way the engine can be operated in higher load regions, in which usually the engine is more efficient.

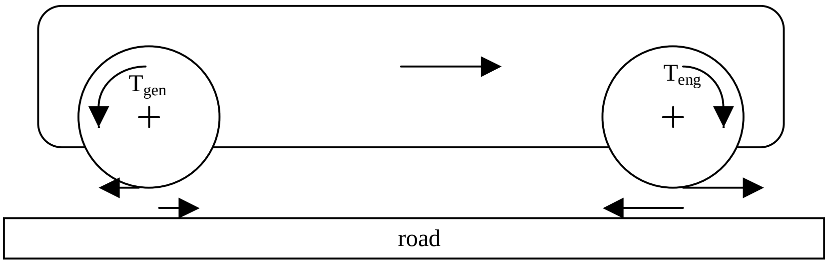


Figure 3.5 Forces in sectional hybrid drive

As can be seen in fFigure 3.5 Forces in sectional hybrid drive, the engine connected to the front wheels delivers torque T_{eng}. This torque is converted to a force on the rigid road. This force is used to overcome losses and to accelerate the vehicle. In this case the surplus of force can be taken by the rear wheels. The electric motor in generator mode can adsorb a part of the force to charge the batteries. If the engine cannot produce enough torque, the electric motor can also produce torque to assist the engine.

Transferring force from a rotating wheel to the road causes wheel slip. This means that the wheel actually has a higher rotational speed than expected from radius of the wheel and the relative speed between road and vehicle. The following equations give the wheel slip of a driven and braked vehicle respectively.

$$\kappa_d = \frac{\omega_w r_{dyn} - v}{\omega_w r_{dyn}}, \ \kappa_b = \frac{v - \omega_w r_{dyn}}{v}$$

With κ_d the slip of the driven vehicle and κ_b the slip of the braked vehicle. ω_w is the angular velocity of the wheel, r_{dyn} is the dynamic wheel radius and v is the velocity of the vehicle.

The force that can be transmitted to the road is a function of wheel slip and the force, which the wheel is pushed to the road. The latter force is composed of two effects. First the mass causes a force on the axels with the following relationship:

$$F_{g,axel} = m \cdot g \cdot \frac{l - x_{COG}}{l}$$

With m the mass of the vehicle, g the gravity constant, x_{COG} the horizontal distance between the considered axel and the center of gravity and l the distance between the front and rear axel.

This holds for a vehicle in standstill. When the vehicle accelerates the pressure on the rear axel will become bigger and the pressure on the front axel will decrease. The opposite happens when the vehicle decelerates. For the rear axel:

$$F_{acc,r} = m \cdot a \cdot \frac{y_{COG}}{l}$$

For the front axel:

$$F_{acc,f} = -m \cdot a \cdot \frac{y_{COG}}{l}$$

With a the acceleration of the vehicle and y_{COG} the vertical distance between the center of gravity and the road surface.

Also the aerodynamic drag can contribute to the vertical wheel force, as is utilized extensively in racecars, but is not considered in this report.

So the total force on an axel is the sum of both effects:

$$F_{z,axel} = F_{g,axel} + F_{acc,axel}$$

The longitudinal force, F_x that is transferred to the road is the force that is needed to give the vehicle the required acceleration. In Figure 3.6 the longitudinal slip can be found with knowing F_x and F_z.

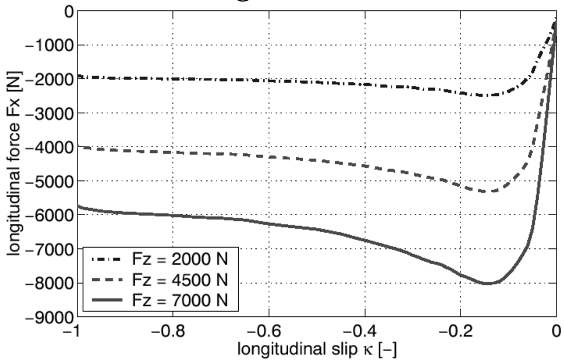


Figure 3.6 Longitudinal force versus longitudinal slip

In Figure 3.6 negative values of F_x and κ are shown. This means that the vehicle is breaking. This figure can be mirrored around the x and y axis to get the same but positive values for accelerating. Simulations show that longitudinal slip stays small of the entire driving cycle, both for accelerating and braking. In the following figures slip values of one of the simulations are shown.

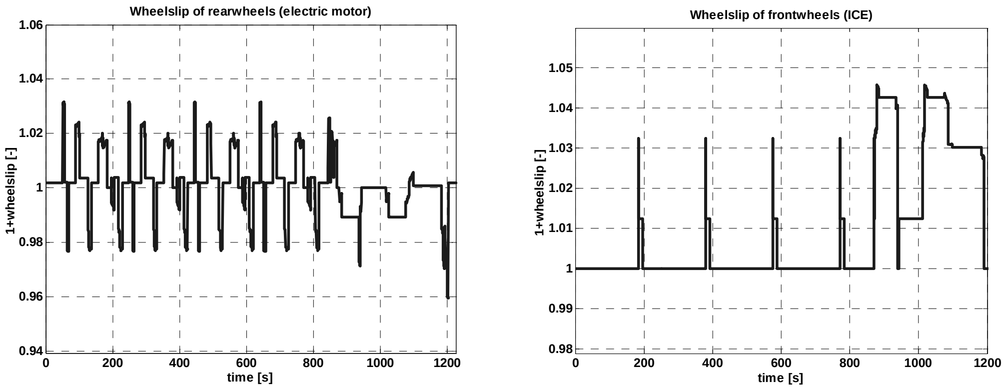


Figure 3.7 Slip values of front and rear wheels

4 Description of the vehicle

The vehicle treated in this report is a small vehicle for use in a city. In this chapter the requirements will be discussed as well as the essential parts.

4.1 Necessary power

A small city car has a mass of approximately 300 kg [1]. Batteries, passengers and luggage/payload not included. About 300 kg can be accounted for that, so the total mass is approximately 600 kg. To drive a constant velocity of 30, 50 and 80 km/h the needed power is listed below as well as the essential power for acceleration.

Stationary velocity [km/h]	30	50	80
Airdrag [N]	33.3	92.6	237
Rolling resistance [N]	60	60	60
Total stationairy [N]	93.3	152.6	297
Needed power [W]	777.5	2119	6600
Accelerating 1 m/s^2	720	720	720
Accelerating power [W]	6000	10000	16000
Total power [kW]	6.8	12.1	22.6

Figure 4.1 Table of power needed at given conditions

For calculating the necessary power these values are used: Mass m=600 [kg], frontal area A = 2.0 [m^2], C_w=0.4, ρ_{air}=1.2 [kg/m^3], rolling resistance F_r=0.01

4.2 Engine

This power has to be delivered by an internal combustion engine and/or an electric motor. Several engines are tried, but for the final design a 2-cylinder Lombardini 505 cc 15 kW petrol engine is used [appendix 9.1.2]. This engine is also suitable for lpg, which makes it easier to adapt it for natural gas. Natural gas can reduce both emissions of CO_2 and poisonous gasses.

A compression ignition engine is also considered. Apart from the environmental disadvantages, such as particle emission and higher NO_x emission, the Otto cycle is, in theory, more efficient than the diesel cycle. In practice however the diesel engine is more efficient. This is mainly caused by the better partial load efficiency. A hybrid architecture can cancel this advantage by using the ICE only at full load. Simulations have shown that the diesel engine in the same architecture is still more efficient.

4.3 Electric motor

For electric traction several types of motors can be used. Asynchronous, PM, or DC motors all need a different electrical system and demand specific electronics. In general DC-motors in combination with the controllers are the easiest and cheapest solution. Efficiency however is not optimal. A 16 kW DC motor is chosen, because of the high torque demands at low motor speed. With this motor it is possible to use only the electric drive over the whole driving cycle. For regenerative braking a sufficiently large motor is needed in order not to overload the motor too much. For a short time it is possible to overload the motor, but not more than twice the maximal rated power.

4.4 Transmission

The electric motor does not need a gearbox. The range of rotational speed is from 0 to 3000 rpm, and the range of vehicle velocity is 0 to 90 km/h. The torque demand at any time in the driving cycle is met, so a fixed ratio is sufficient. To avoid high currents at lower velocities, the motor speed can be increased by a simple gearbox or a cvt. However this makes the vehicle more complicated and more expensive and is not necessary.
The internal combustion engine needs definitely a gearbox in order to cover the whole range of vehicle speeds. For efficiency reasons, the distances between the gears should not be too big. To fill the gap between lowest engine speed and low vehicle speeds a clutch is needed. A standard 4-speed gearbox with dry plate clutch is taken.

4.5 Braking

Braking in an electric or hybrid vehicle in general can be done in two ways. The first one is regenerative braking. The electric traction motors are used as generators to decelerate the vehicle and thus recovering kinetic energy. This energy can be used for the next acceleration(s). The second option is to use conventional disk or drum brakes. These brakes dissipate the kinetic energy, so on first sight regenerative braking is preferable. As no additional equipment has to be installed, this is a very useful means of reducing the use of energy and thereby the fuel consumption.
Regenerative braking does not only come with advantages. In normal driving, decelerations are generally higher in magnitude than accelerations. This causes higher torques for braking than for accelerating and current is approximately proportional to torque. High currents cause high losses so low currents are to be preferred. The internal resistance of the batteries results in too high voltages for braking and too low voltages for driving in case of a high current.
The following equations hold for discharging and charging respectively.

$$V = U(k) - I \cdot R(k) \quad \text{(driving)}$$

$$V = U(k) + I \cdot R(k) \quad \text{(braking)}$$

For the V is the battery voltage, U the electromotive force, R the internal resistance, k the state of charge and the current I>0.
Too high charging voltages cause unfavorable electrolyte gassing in the battery. The problem can be solved to use an electric dissipater such as a heater to get rid of the excess electric braking power. In theory, mechanical brakes are not necessary anymore. For emergency braking and in case of failure of the electric system, it is necessary to have conventional brakes.

4.6 Batteries

To provide the vehicle of electrical power and to have an energy accumulator, batteries are used. There are several types of batteries of which the most common ones are Li-ion, NiMh and lead acid. In general the first two are superior to lead acid from a technical point of view, but are much more expensive [4]
The costs have to be kept low for being an economical alternative to conventional vehicles. Lead acid batteries are mass produced and used intensively, therefore they are very robust and reliable. The lead acid batteries can be divided into two kinds, with liquid sulphuric acid or with a gel. The latter one has some deviate

characteristics. One of them is that they are maintenance free, no liquid has to be added, often referred to as ‘dry-fit’ batteries. The lack of liquid makes them safe to use. That is why lead acid gel batteries are chosen for this design.
To create the needed voltage for the motor, the battery-pack has to have a voltage that is high enough to propel the motor at all speeds. Placing a lot of batteries in series seems the solution, but the mass of the battery pack becomes very large and the resulting capacity is too big. In the design 6 or 12 Volt batteries are used to create 72 volts.
Motorcycle batteries tend to be small, but still can deliver a voltage of 6 or 12 Volt. The low mass, and thereby low capacity makes them very useful for hybrid use. Unfortunately maximum currents are proportionally lower and to handle the high currents the capacity has to have a minimum value of about 50 Ah. Therefore a 12 Volts, 50 Ah battery is taken from Sonnenschein [appendix 9.1.3]. This is a heavy-duty type of battery that is especially suitable for traction purposes. To obtain 72 Volts, 6 batteries are put in series.

4.7 Architecture

In order to use one or both power sources an architecture is chosen. Familiar ones are parallel and series hybrids. This architecture is, as far as I know, new. It has in common with the parallel hybrid that the vehicle can be driven by both engines. In the suggested architecture, the power sources have no physical connection and is thereby modular. It can have advantages for certain applications. The internal combustion engine propels the front wheels and the electric motor/generator the rear axel. Existing electric vehicle have already a rear wheel mounted motor and can easily equipped with a ice on the front axel. Excess power from the ice can be transmitted via the wheels and the road to the rear axel. The motor can work as a generator, as it also does for regenerative braking. The coupling is less efficient than a parallel one, wheel slip will occur at the front wheels and with opposite sign at the rear wheels. So efficiency is reduced double by wheel slip. According to simulations, wheel slip does not exceed extremes of 7 percent per wheel. Increased tire wear can be significant but is not considered in this report.
Existing front wheel drives including gearbox and couplings to the steered wheels can be used without or with less adaptation. When one of both power sources fails, the vehicle is still able to drive in this configuration. In the simulation performed, advantages and disadvantages will be shown.

4.8 Engineering

4.8.1 Electric motor

The electric motor might have difficulties, when the vehicle starts uphill. Motor speed is zero and the torque demand is high. Because of direct coupling of the motor with the shaft the gear ratio is determined by the maximum engine speed. This causes high torques at low speeds. A dc-motor can deliver high torque at low speeds but at hill climbing, torques can get too high.
There are several solutions. Most common would be a gearbox. One reduction would be enough to reduce torque. Normal driving can be done in second gear whereas accelerating uphill requires the first gear. Operating can be done manually as this situation will be rare, especially in a flat country like Poland.
The second option would be a cvt. The gear ratio can be changed continuously, so not only the starting behavior can be improved, but also the motor can be operated in the

highest efficiency region. The efficiency of small cvt transmissions, around 85 %, is too low to compensate for these advantages.
The use of a coupling is another option. Friction couplings, like an ordinary clutch can be used to start with an already spinning motor. Automated clutches like centrifugal clutches can be used for the same purpose, but do not require manual operation.
The fourth option is a hydrodynamic clutch. It has the same principle as the other clutches but has a smoother characteristic. A torque converter would be a very good solution for is the only clutch that can increase the incoming torque. Electric motors usually have a flat characteristic at low speed and increasing of speed does not increase the torque. For efficiency reasons a lock-up is necessary. This lock-up could be closed at normal operation but opened at high torque demands.

4.8.2 Internal combustion engine

The engine has to be connected with the shaft. This can be done in several ways. A belt is flexible and can adsorb vibrations from the engine. The distance between the engine output shaft and the other shaft can be variable. This means that the design can easily be used for slightly different models of cars. Also position alterations due to deflection of suspension, torsion or other reasons can easily be compensated for by the pre-tensioned belt.
A standard gearbox from a OEM can be used. The differential is then integrated in the gearbox and the shafts to the wheels, brakes etc can also be taken from existing manufacturers. The clutch is then the difficult part. One part is connected to the engine's flywheel and the other is part of the gearbox. Normally this is compatible but in this case the engine and gearbox are from different manufacturers. To simplify the connection a rubber belt can be used.

5 Simulink modelling

To simulate the vehicle, a model is made in Matlab Simulink. Driving cycles can be given as input, output can be any signal of which SOC level and fuel consumption are the most important parameters.

5.1 Model description

In general the model comprises the road load conditions, the drive trains, controlling and monitoring possibilities, a tire slip model and a battery model. These models are connected together to become the final model. [appendix 9.2] This is done in an opposite way than it physically would be. In a real vehicle the consequence comes after the cause. For example, the throttle and the total resistance of the vehicle, cause the acceleration. The acceleration causes then the velocity of the vehicle.
In the model this works the other way around. The vehicle has to perform according to the given driving cycle, so the velocity and as a result the acceleration are fixed. The torque that is needed to perform as asked is again a result of the latter. This way of reasoning finally gives the battery State Of Charge and the fuel consumption.

5.2 Driving cycle

A driving cycle gives the velocity that the tested vehicle has to have at a certain time. Generally such a cycle consists of several parts. A typical part starts with an acceleration, then a constant speed and end with a deceleration, resulting zero velocity.
There are lots of different driving cycles. For small city vehicles like the one

considered here, the Urban Driving Cycle is often used. This cycle has a maximum velocity of 50 km/h. To simulate behavior on main roads just outside the city center, an Extended Urban Driving Cycle can be used. The maximum speed is 90 km/h and it is used for the simulations. The duration is 1200 minutes and the traveled distance is about 10 km.

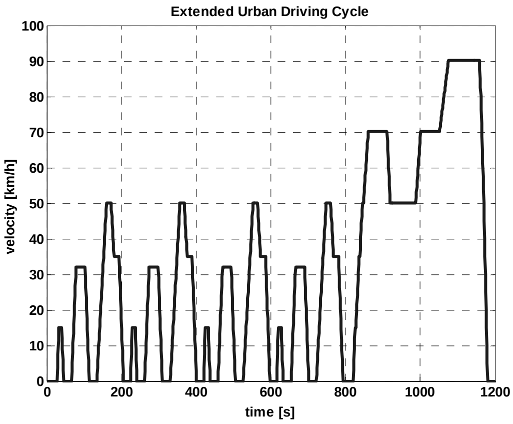


Figure 5.1 Driving cylce used in simulations

5.3 Road load

The vehicle is subject to resistance that consists of three parts. First one is air drag, second is rolling resistance and last is the acceleration resistance. Load by road gradient is not considered.

5.3.1 Air drag

When the vehicle has a relative velocity to the air, a force is working on the vehicle. In this report the absolute wind speed is neglected, so that the following equation can be used:

$$F_d = \frac{1}{2}\rho_a c_w A v^2$$

With F_d is the drag force [N], density of air ρ_a [kg/m^3], drag factor c_w [-],frontal area A [m^2] and the vehicle velocity v [m/s].

5.3.2 Rolling resistance

The resistance caused by the rolling wheels can be described by:

$$F_r = f_r mg \cdot \cos\alpha$$

With rolling resistance F_r [N], rolling resistance factor f_r [-], gravity constant g [m/s^2] and α [^{o}] the angle of the slope. For small angles however, the last term can be neglected [2], hence the next formula is used.

$$F_r = f_r mg$$

5.3.3 Acceleration resistance

To accelerate an item such as a vehicle, a force is needed. The vehicle has mass that has to be accelerated and all rotating parts have inertia. The equation that gives the acceleration resistance F_a is:

$$F_a = \left(m + \frac{\sum J_{red,i}}{r_{dyn}^2} \right) a$$

With the vehicle mass m [kg], the reduced moment of inertia $J_{red,i}$, the dynamic wheel radius r_{dyn} and the acceleration of the vehicle a [m/s^2]
The reduced moment of inertia consists of several rotating parts and their moments of inertia are calculated as if they were at the wheel. So the sum of them is the moment of inertia that the vehicle experiences at the wheels. It means that the gear ratios between the parts and the wheel are very important. F_a is thereby dependent of the gear the vehicle is driving in. The lower the gear, the higher sum of $J_{red,i}$ and the higher the resistance F_a.
Hence the total resistance is:

$$F_{tot} = F_d + F_r + F_a$$

5.4 Internal combustion engine

The internal combustion engine that is chosen for the simulation is a Lombardini petrol engine with a maximum power of 15 kW. From the information supplied by the manufacturer [Appendix 9.1.2] and from another engine, an engine map is created [Appendix 9.1.4]. From the used engine, only the specific consumption at full load is known. A full engine map is taken from a 2.0 liter Otto engine [2] and scaled to the used engine. This map is used to look up the values of specific fuel consumption at a certain load and angular velocity.
The transmission is a standard four speed gear box. For simulation purposes only this gearbox is automated. At a given maximum angular velocity, the gearbox shifts up and at a minimum speed it shifts down. When the highest gear is reached, the gearbox does not shift up anymore and if in first gear the vehicle reaches the speed, which causes the engine to run under the minimum angular velocity, the clutch is opened. The engine then operates at stationary speed and the maximum toque is the maximum torque at that speed found in the torque graph. So even at very low vehicle speeds the clutch transmits torque to the wheels.
For simplicity reasons, the engine is always on and rotating in the model, even when it is off in real situations. Because the power that is needed from the engine is zero, fuel consumption is also zero. This can be seen as stopping the fuel injection at zero load.

5.5 DC motor

The electric motor works via this equation:

$$U_m(t) = R_m I_m(t) + L_m \frac{dI_m(t)}{dt} + E_m(t),$$

$$M_m(t) = \phi \cdot I_m(t),$$

$$E_m(t) = \phi \cdot \omega(t)$$

With U_m the voltage, R_m the internal resistance of the motor, I_m the current, L_m the inductance, T_m the torque, ω_m the angular velocity of the motor, E_m the electromotive force and φ the flux.
For motor and generator mode this equation is the same, however the current changes sign.
So the torque and angular velocity are input and the current and voltage are output. There is a direct connection between the motor and the wheels. So the motor always rotates when the vehicle moves. To be in generator, motor or neutral mode, it is decided by the controller.

5.6 Battery

The battery pack is modeled as subscribed in [3]. The State of charge of the battery changes in the following way:
For discharging:

$$k' = k - Q_{m}^{-1} \int_{t_i}^{t_{i+m}} \eta_A(i_a, \tau)^{-1} i_a(t) dt,$$

$$\eta_A(i_a, \tau) = \left(\frac{i_a(t)}{I_n} \right)^{-\beta(\tau)}$$

With k the State of Charge, k' the State of Charge after discharging, Q_n the nominal capacity, η_A the stored energy usefulness efficiency, i_a the current, I_n the nominal current, τ the temperature and β Peukert's constant.
For charging holds:

$$k'' = k' + Q_{m}^{-1} \int_{t_i}^{t_{i+m}} i_a(t) dt$$

With k'' the State of Charge after charging for a period m.
The SOC is a complex function of temperature. In this report the temperature of the batteries is regarded constant.
To drive the vehicle a certain torque is needed, and hence a current. When generating this current a voltage is the result. From paragraph 4.6 it is seen that the internal resistance R and the electromotive force E or EMF, together with the current determine this voltage. R and EMF however are strongly related to the State Of Charge k, as is shown in fFigure 5.2. The lower the SOC, the higher the R and the lower the EMF. The output voltage of the battery at low SOC levels will be very low. This bad performance is a sign that the battery is 'empty'. At very high SOC the internal resistance is higher than at mediocre SOC levels. To avoid high losses it is advisable not to operate the battery at extreme SOC levels. In the simulations an initial SOC of 0.75 is used, if not mentioned otherwise.

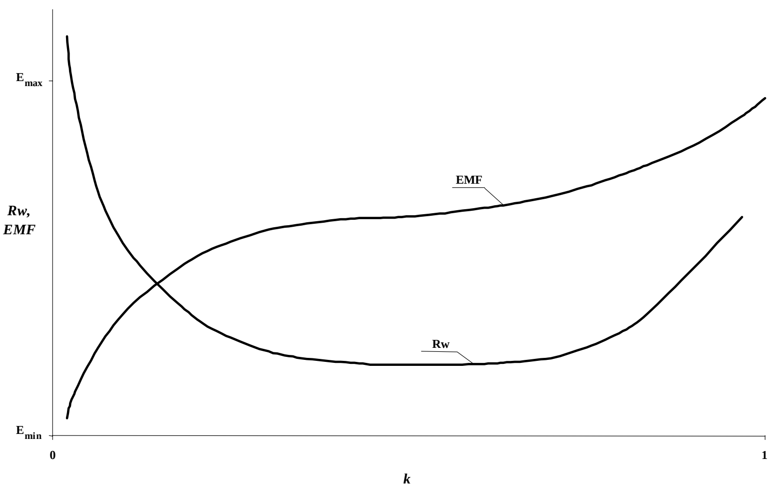


Figure 5.2 Electromotive Force (EMF) and Internal Resistance (R_w) as a function of SOC for a gel lead acid battery [5]

5.7 Controller

To decide when to use the ICE, the DC motor or both, a controller is needed. The parameters of the controller can be altered to reach SOC balance at the end of a driving cycle.
The time that the use of the ICE or electric motor is allowed or not can be given. The threshold velocity below which the vehicle only uses the electric motor has to be entered. Another velocity threshold can be set to prevent the electric motor from generating.

6 Results

The performed simulations give a lot of output. In this chapter the most important data is presented. To make a fair comparison between different vehicles the method of simulation and comparison is explained.

6.1 Strategies

Classical drive trains are tested and simulated according to a driving cycle. Fuel consumption is measured in such driving cycle. For hybrid drives this approach cannot be used. For hybrid drives have two energy sources, petrol and electricity, both have to be taken into account to determine fuel consumption. The way to achieve this is to have the same state of charge of the batteries before and after the driving cycle. In total, all the energy came from the petrol and a fair comparison is made with conventional vehicles.
To achieve a so-called SOC balance is not trivial. Different SOC control strategies can be used, but for changing parameters a different or a modified SOC control has to be used. A trial-and-error method is used to obtain SOC balance. This makes comparing different parameters of the vehicle time consuming and to reach SOC balance, compromises have to be made, so that fuel consumption is not optimal.
Two different strategies are used.

1. Use pure electric drive for low speeds and conventional propulsion at higher velocities. At even higher velocities both drives are working. Decisions to change mode are purely based on the vehicle velocity.
2. Use electric drive for a certain time and then use strategy 1.

Regenerative braking is used at all strategies
In real road conditions this way of SOC balancing is not preferable. Never exact driving cycles will be driven and actual drivers act different than modeled.
Actual SOC management should not only be based on vehicle velocity and time but also on SOC, acceleration and even better, route information from a gps.

6.2 Results strategy 1

The first strategy comprises two different sets of parameters to achieve SOC balance. One possibility is shown here:

Velocity [km/h]	Means of propulsion
0-50	electric
50-58	ICE
58-90	hybrid

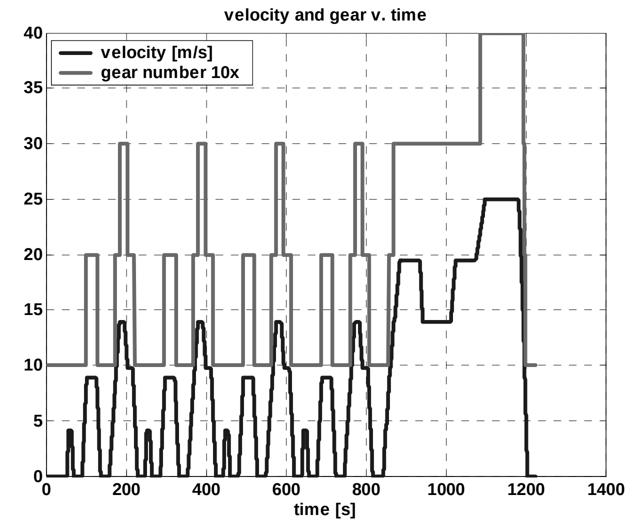


Figure 6.1 Velocity and gear number, velocity-strategy

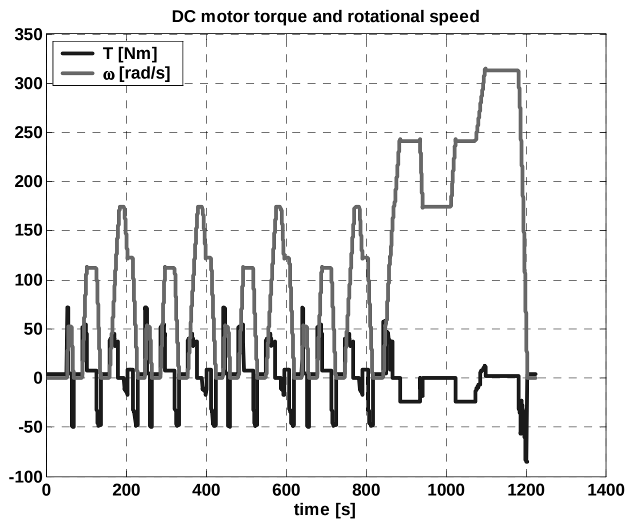


Figure 6.2 DC motor torque and rotational speed, velocity-strategy

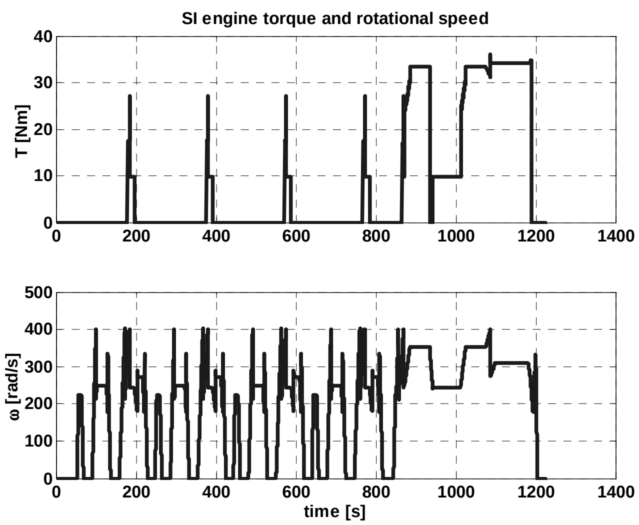


Figure 6.3 SI engine torque and rotational speed, velocity-strategy

In figure and it can be seen that the internal combustion engine rotates and shifts even when this drive is not used. For simplicity reasons the engine is programmed like that. It does not affect the rest of the simulation.

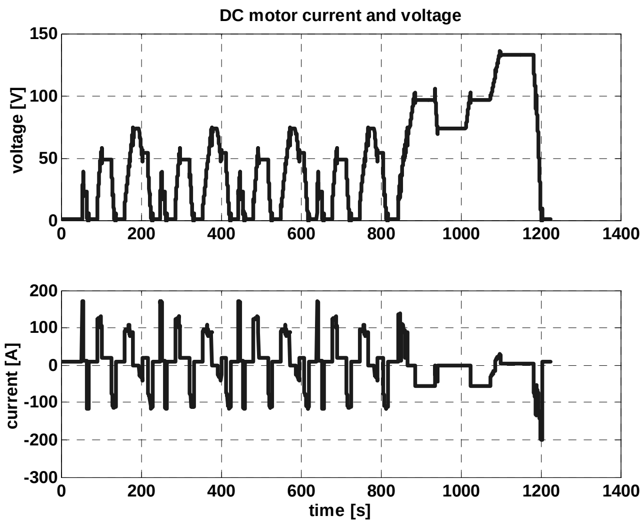


Figure 6.4 DC motor current en voltage, velocity-strategy

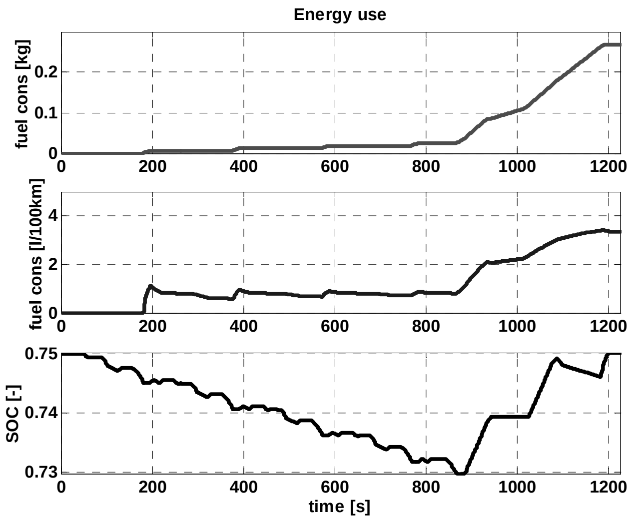


Figure 6.5 Energy use, velocity-strategy

The other parameters to achieve SOC balance are:

Velocity [km/h]	Means of propulsion
0-44	electric
44-70	ICE
70-90	hybrid

6.3 Results strategy 2

The second strategy states that for a certain time only the electric motor is used. This can be useful in a city centre, because there is no emission and little noise in this mode. Two ways of SOC balance have been found. The first is given in this table:

Time [s]	Velocity [km/h]	Means of propulsion
0-910	all	electric
910-1200	0-20	electric
910-1200	>20	hybrid

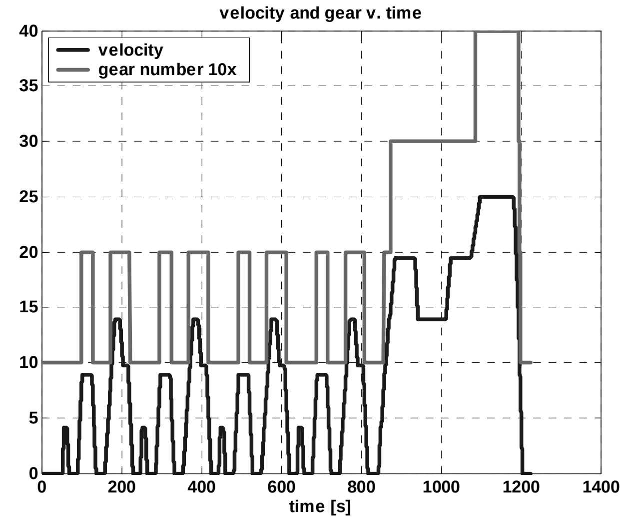


Figure 6.6 Velocity and gear number, time-strategy

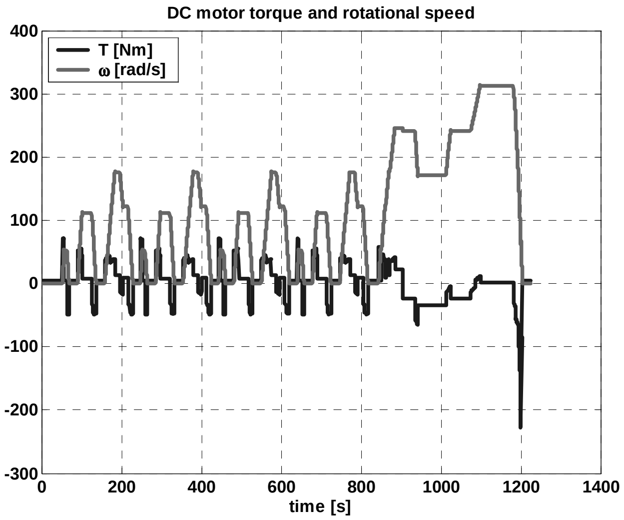


Figure 6.7 DC motor torque and rotational speed, time-strategy

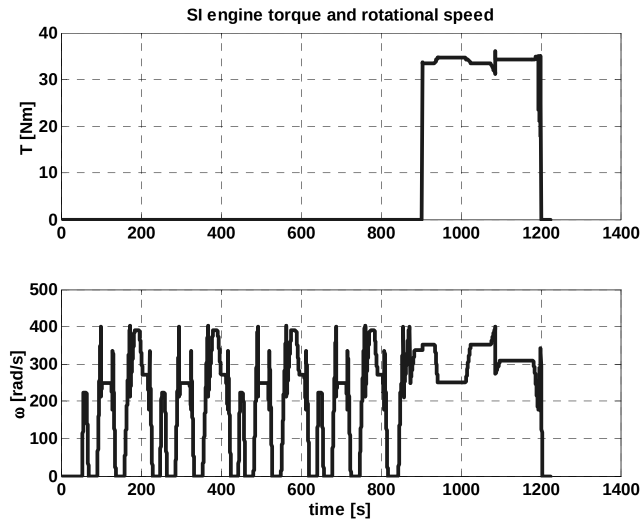


Figure 6.8 SI engine torque and rotational speed, time-strategy

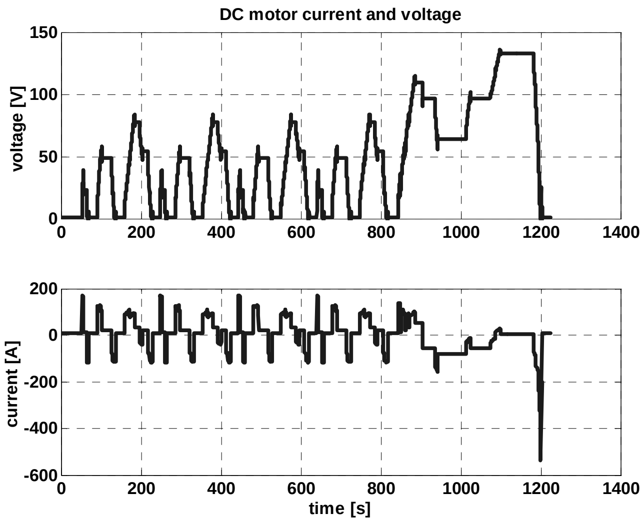


Figure 6.9 DC motor current and voltage, time-strategy

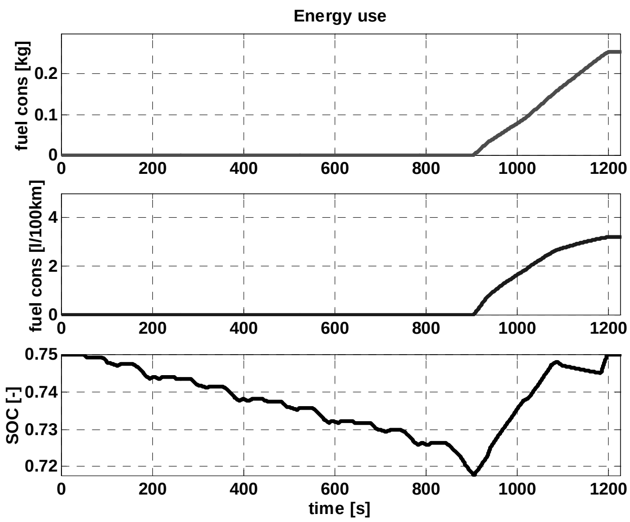


Figure 6.10 Energy use, time- and velocity-strategy

The other parameters to achieve SOC balance are:

Time [s]	Velocity [km/h]	Means of propulsion
0-630	all	electric
630-1200	0-20	electric
630-1200	20-52	ICE
630-1200	>52	hybrid

6.4 Pure ICE

To compare the simulated vehicle with a classical petrol driven vehicle, another simulation is made. The hybrid vehicle is tested in the same way but the electrical drive not function. The vehicle is purely driven by the engine, but the rest of the parameters are the same.

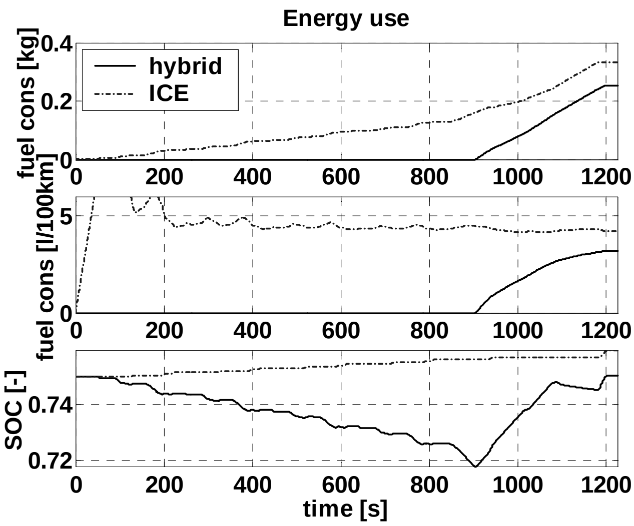


Figure 6.11 Enery use, hybrid versus ICE

This is not a fare comparison with it competitors, because they do not have the weight of the batteries. Therefore a simulation is done for a vehicle without batteries. The resulting fuel consumption is 4.0 l/100 km. In fFigure 6.12 the different fuel consumptions can be compared.

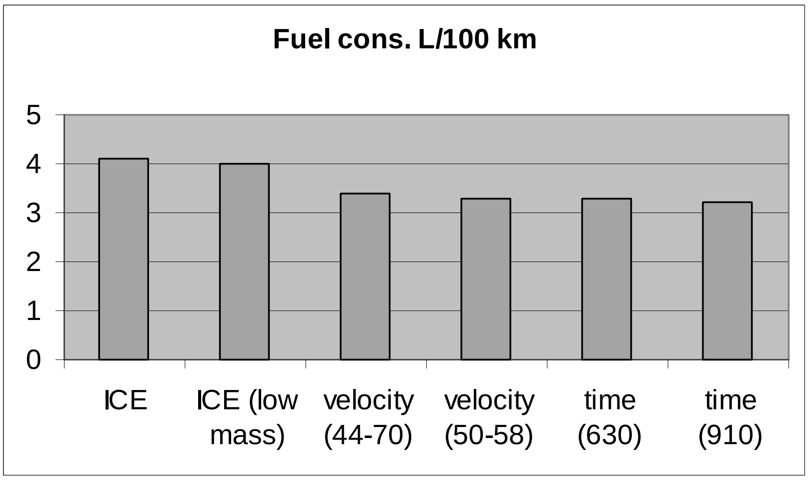


Figure 6.12 Comparison fuel consumption all simulated vehicles

6.5 Pure electric

The hybrid vehicle can be compared with a petrol driven one, but also with its full electric competitor. The same simulations are done, but only with the electric drive. Off course there is no SOC balance anymore but to measure its performance, the maximum range of driving can be measured at different constant speeds.

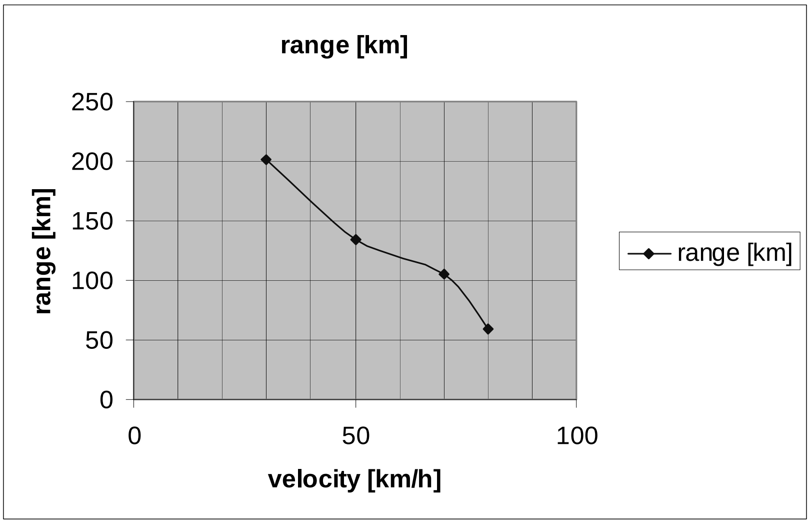


Figure 6.13 Travelling range pure electic driving at constant velocity

7 Conclusions and recommendations

From the results in chapter 6, one can conclude that the use of sectional hybrid drive can reduce the fuel consumption of a small city car. The range of travelling is extended largely compared to an electric vehicle and it is no longer dependent of the socket. In contrast to a purely petrol driven vehicle, it has the advantage to drive without emissions and with low noise for a certain time.

The kind of strategy does not have a big influence on the fuel consumption. For all strategies this is 3.2, 3.3 or 3.4 l/100 km. For pure ICE drive with the same weight it is 4.1 l/100 km, this is a reduction of almost 22 %. For an ICE-vehicle without batteries the fuel consumption is 4.0 l/100 km, still a reduction of 20%.

These values are purely based on simulation, so it is just an indication. To get better knowledge about this sectional drive a test bench can be made. The dynamic behaviour of the drive is not considered in this report, but it is expected that this is quite different from the dynamics known in other drive trains.

This kind of hybrid drive has almost twice the power of a comparable vehicle, because of the two drives. This makes higher accelerations and higher top speeds possible.

8 References

[1] http://www.minicruizer.nl/
[2] G. Lechner, H. Naunheimer: *Fahrzeuggetriebe: Grundlagen, Auswahl, Auslegung und Konstruktion*, Springer-Verlag, 1994
[3] A. Szumanowski, *Fundamentals of Hybrid Vehicle Drives*, Warsaw: Radom 2000
[4] Emadi, Ali, Mehrdad Ehsani, John M. Miller: *Vehicular Power Systems: Land, Sea, Air, and Space Vehicles*, New York: Marcel Dekker, Inc, 2004

9 Appendix

9.1 Specifications

9.1.1 Vehicle parameters

The matlab m-file with all necessary parameters:

```
load eudc_low.mat;
lomb_map;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% GENERAL
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

g=9.81; % [m/s^2] gravity constant
rho_a=1.225; % [kg/m^3] mass density of air

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% GEARS
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% INTERNAL COMBUTION ENGINE
i_1=4; % [-]
i_2=2.1; % [-]
i_3=1.3; % [-]
i_4=0.9; % [-]
i_diff_eng=4; % [-]
J_gb_1=0.0015;% [-] inertia of primairy gearbox shaft (estimated)
J_gb_2=0.0015;% [-] inertia of secondairy gearbox shaft (estimated)

% ELECTRIC MOTOR
% i_mot=0.5; % [-]
i_mot=0.94; % [-]
i_diff_mot=4; % [-]

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% WHEELS
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

r_w=0.30; % [m] wheel radius
J_w=0.5; % [kg*m^2] wheel inertia
load kappa_mu.mat; % slip table
f=0.01; % [-] coefficient rolling resistance

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% INTERNAL COMBUSTION ENGINE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

J_eng=0.09; % [kg*m^2] estimation (ford transit (2.5 l) is 5 times
bigger, so r scales down ...
```

```
                    ... with 5^(1/3)=1.71 and J goes with r^4. So
J=1.71^4=8.55 times J_ford...
                    ... J_ford is 0.80 so J_eng=0.09
load eng_map.mat; % engine map file. contains matrix e_map
N_idle=1500; %[rpm] idle speed of engine
N_low=180; % [rad/s] shift down at N_low
N_high=400; % [rad/s] shift up at N_high
% rho_fuel=0.83; % [kg/l] mass density of diesel fuel
rho_fuel=0.75; % [kg/l] mass density of petrol fuel

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% ELECTIC MOTOR
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% J_mot=0.014; % [kg*m^2] moment of inertia of electric motor
% flux=4.1187; % [] constant flux of pm motor
% L=0.015; % [H]
% R_mot=0.465; % [Ohm] internal resistance of motor

% 16 kW dc-motor
J_mot=0.01;
flux=0.423;
L=0.005;
R_mot=0.1;

% J_mot=0.015;
% flux=0.105;
% L=0.005;
% R_mot=0.15;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% BATTERY
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

n_bat=6; % [-] number of batteries
n_cell=12; % [-] number of cells per battery
% bat_mass=37.5; % [kg] mass of one battery
bat_mass=20;
m_bat=n_bat*bat_mass; % [kg] mass of batterypack
% cap_bat=185; % [Ah] capacity of one battery
cap_bat=50;
beta=0.325; % peukerts constant for this battery
init_k=0.75; % [-] initial State Of Charge of batterypack
int_res=[0.013 0.006 0.004 0.003 0.003 0.003 0.003 0.003 0.0035 0.004
0.005]; % internal resistance
e_force=[2.01 2.06 2.075 2.08 2.083 2.09 2.093 2.095 2.097 2.1 2.12];
% electric motive force

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% INVERTER
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

eff_inv=0.90; % efficiency of inverter

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% VEHICLE PARAMETERS
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

m_veh=300; % [kg] mass of vehicle
m_load=100; % [kg] mass of passengers and luggage
m=m_veh+m_load+m_bat; % [kg]
```

```
l=1.5; % [m] distance between front and rear axel
w=1.3; % [kg] whith of vehicle
cog_x=1.0; % [m] horizontal distance between front axel and center of gravity
cog_y=0.5; % [m] vertical distance between road and center of gravity
A=2.0; % [m^2] frontal area
Cw=0.5; % [-] drag coefficient
```

9.1.2 Engine specifications

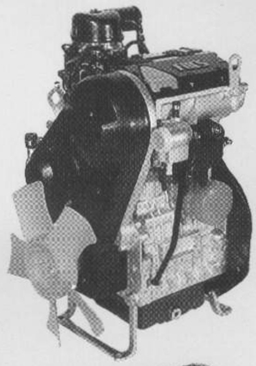
Sede di Reggio Emilia
ICIM
ISO 9001 Cert. n. 0446

LOMBARDINI **LGW 523 OHC**

CARATTERISTICHE

CARACTERISTIQUES TECHNIQUES - TECHNICAL FEATURES
KONSTRUKTIONSMERKMALE - CARACTERISTICAS

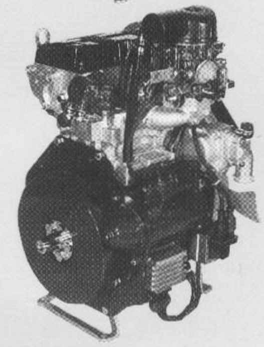
cm³ 505 - kW 15/ HP 20.4 - R.P.M. 5000



Motore ciclo Otto a 4 tempi con cilindri in linea; Raffreddamento a liquido; Accensione elettronica con dispositivo breakerless con variatore d'anticipo programmato; Carburatore a flusso verticale; Distribuzione monoalbero in testa; Comando distribuzione con cinghia dentata; Doppia presa di forza sull'albero motore; Presa di forza sulla distribuzione; Rotazione antioraria; Lubrificazione forzata con pompa a lobi sull'albero motore; Filtro olio esterno a passaggio totale; Monoblocco in alluminio open-deck con canne a secco rialesabili; Testa in alluminio conchigliata.

Moteur à essence 4 temps avec cylindres en ligne; Refroidissement par liquide; Allumage électronique avec dispositif breakerless; Carburateur à flux vertical; Distribution par un arbre à cames en tête; Commande de distribution par courroie dentée; Double prise de force sur le vilebrequin; Prise de force sur la distribution; Rotation antihoraire; Graissage sous pression avec pompe à lobes sur le vilebrequin; Filtre à huile extérieur à passage total; Monobloc carter-cylindres en aluminium open-deck avec chemises réalésables; Culasse en aluminium moulé sous pression.

4-stroke Otto cycle engine with cylinders in line; Fluid-cooled; Electronic ignition with breakerless device with programmed phase transformer; Vertical flow carburetor; Single-shaft distribution in head; Distribution control with timing belt; Double pto on the crankshaft; Pto on the distribution; Counterclockwise rotation; Forced lubrification with vane pump on the crankshaft; Total passage external oil filter; Aluminium engine block open deck with reborable dry liners; Chilled cylinder head in aluminium.



4-Takt Otto-Reihenmotor; Flüssigkeitskühlung; Unterbrecherlose elektronische Zündanlage; Flachstromvergaser; Zahnriemenangetriebene Nockenwelle im Zylinderkopf; 1 und 2 Kraftabnahme an der Kurbelwelle; Drehrichtung der Kubelwelle entgegen dem Uhzeigersinn; Druckschmierung mittels Rotationspumpe auf der Kurbelwelle; Hauptstromölfilter; Kühlmittelpumpe im Motorblock; Aluminium Motorblock - open deck - mit nachschleifbaren trockenen Laufbuchsen; Aluminium Zylinderkopf.

Motor Otto ciclo a 4 tiempos con cilindros en linea; Refrigeración por liquido; Encendido eléctronico con dispositivo "breakerless"; Carburador de flujo vertical; Distribución con eje de levas en la culata; Accionamiento de la distribución por correa dentada; Doble toma de fuerza sobre el cigüeñal; Toma de fuerza auxiliaria sobre la distribución; Rotación anti-horaria, Lubrificación forzada mediante bomba rotativa a lóbulos; Filtro aceite externo de paso total; Filtro aceite externo de paso total; Bloque motor de aluminio "open-deck" con cilindros secos rectificables; Culata en aluminio fundida en coquilla.

EQUIPAGGIAMENTO STANDARD

FOURNITURE STANDARD - STANDARD EQUIPMENT
STANDARDAUSRUESTUNG - EQUIPAMIENTO STANDARD

Filtro aria a secco
Filtro olio esterno
Collettore di scarico
Ventola aspirante
Avviamento elettrico con motorino e alternatore 12 V.
Stop elettrico
Valvola termostatica e termostato
Pompa alimentazione
Pompa acqua
Piastra di flangiatura
Volano con corona dentata
Verniciatura
Libretto uso, manutenzione e ricambi

Filtre à air sec
Filtre à huile extérieur
Collecteur échappement
Ventilateur aspirant
Démarrage électrique avec demarreur et allernateur 12V
Stop électrique
Clapet thermostatique et thermostat
Pompe d'alimentation
Pompe à eau
Plaque d'accouplement
Volant à couronne dentée
Peinture
Livret d'entretien-piéces détachees

Dry air cleaner
External oil filter
Exhaust manifold
Intake fan
Electric starter and 12V alternator
Electric stop
Thermostatic valve and thermostat
Fuel lift pump
Water pump
Flanging plate
Flywheel with ring gear
Paint
Use - maintenance - spare - parts booklet

Trokenluftfilter
Externer Ölfilter
Auspuffkrümmer
Ansauggebläse
Elektrischer Anlasser mit Motor und 12 V Lichtmaschine
Elektrischer Absteller
Thermostatenventil und Thermostat
Kraftstöffderpumpe
Wasserpumpe
Flanschplatte
Schwungrad mit Zahnkranz
Lackiert
Bedienungs - Wartungs - Ersatzteil - Liste

Filtro aire a seco
Filtro aceite externo
Colector escape
Soplador aspirante
Arranque eléctrico con motor y alternador 12V
Paro eléctrico
Válvula termostática y termostato
Bomba alimentación
Bomba agua
Placa de acoplamiento
Volante con corona engranaje
Pintura
Manual de uso, mantenimiento y recambios

ACCESSORI A RICHIESTA

ACCESSOIRES SUR DEMANDE - SPECIAL ACCESSORIES
SONDERZUBEHOER - ACCESORIOS BAJO DEMANDA

Protezioni richieste dal tipo d'impiego
Riduttori
Invertitori riduttori
Giunti elastici
Frizioni
Volani per frizioni
Flangiature
Predisposizioni per cambi
Predisposizioni per pompe oleodinamiche
Quadretto di comando
Alternatori di varie potenze
Radiatori
Ventola soffiante
Piedi di fissaggio
Serbatoi di varie capacità
Marmitte
Filtri aria a bagno d'olio
Prefiltri aria a ciclone
Coppe olio per forti inclinazioni
Impianto riscaldamento cabina
Strumenti

Protections necessaires selon l'emploi
Réducteurs
Inverseurs réducteurs
Joints élatiques
Embrayages
Volants pour embrayages
Brides
Prédisp.-boites vitesse
Prédisp.-pompes hydrauliques
Tableau de commande
Alternatours de puissances diverses
Radiateurs
Ventilateur soufflant
Pieds de fixation
Réservoirs de capacités diverses
Pots d'échappement
Filtres à air en bain d'huile
Pré-filtres à cyclone
Carter huile pour fortes inclinaisons
Installation de chauffage cabine
Instruments

Different guards according to use
Reduction gears
Reverse - reduction gears
Flexible couplings
Clutches
Clutch flywheels
Flanges
Transmission adaptors
Hydraulic pump adaptors
Panel board
Alternators
Radiators
Blowing fan
Engine feet
Fuel tanks
Mufflers
Oil-bath air-cleaners
Cyclonic precleaners
Oil sumps for steep slopes
Cab heating system
Instruments

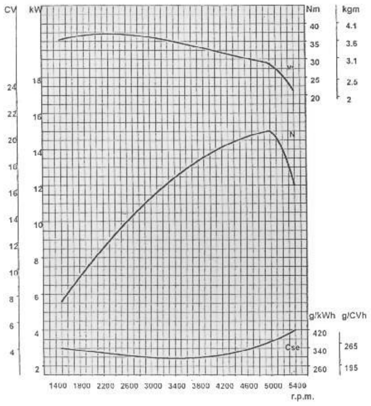
Abschirmung je nach Verwendungszwech
Untersetzungsgetriebe
Wende-Untersetzungsgetriebe
Elastische Kupplungen
Kupplungen
Schwungräder für Kupplungen
Flanschen
Anflanschungen für Getriebe
Hydraulikpumpenantriebe
Schaltkasten
Lichtmaschinen
Kühler
Druckgebläse
Motorfüsse
Kraftstofftanke
Auspuffdämpfer
Oelbad- Luftfilter
Zyklonvorabscheider
Ölwannen für starke Schräglagen
Kabinenheizung
Instrumente

Protecciones requeridas según el tipo de uso
Reductores
Inversores reductores
Acoplamientos elásticos
Embragues
Predisposiciones cambios
Predisposiciones bombas Oleodinámicas
Cuadro de mando
Alternadores
Radiator
Soplador
Pies de fijacón
Depósitos combustible de diversas capacidades
Silenciadores
Filtros aire en baño de aceite
Prefiltros aire a ciclón
Cárter aceite por fuertes inclinaciónes
Instalación calefacción cabina
Instrumentos

DATI TECNICI

DONNEES TECHNIQUES - TECHNICAL DATA
TECHNISCHE DATEN - DATOS TECNICOS

LGW 523



N (80/1269/CEE - 88/195/CEE - ISO 1585) - Le potenze, qui indicate, si riferiscono al motore munito di filtro aria, di marmitta standard, a rodaggio ultimato ed alle condizioni ambientali di 20°C e di 1 bar. La potenza massima è garantita con una tolleranza del 5%.
Le potenze si riducono dell'1% ogni 100 m. di altitudine e del 2% per ogni 5° al di sopra di 20°C.
Cse Consumo specifico di combustibile alla potenza N.
Mt. Coppia motrice alla potenza N.

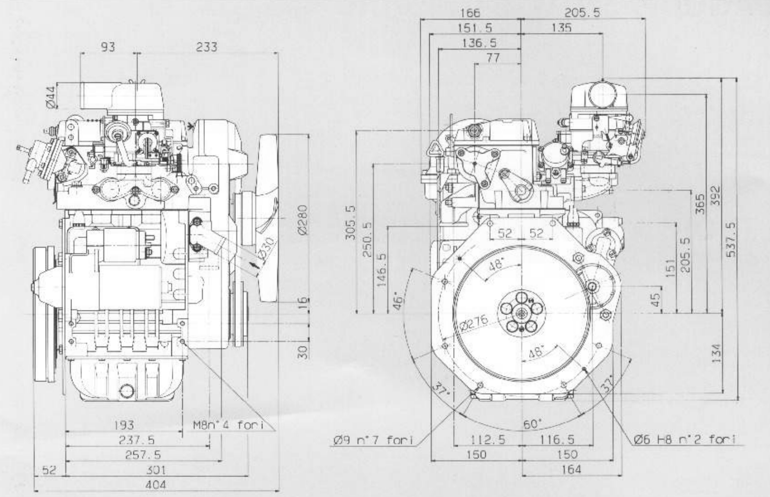
N (80/1269/CEE - 88/195/CEE - ISO 1585) - Les puissances indiquées se rapportent au moteur équipe de filtre à air, de pot standard, à rodage terminé et aux conditions ambiantes de 20° C et de 1 bar. La puissance maximum est garantie avec une tolérance de 5%.
Les puissances se réduisent de 1% chaque 100 m. d'altitude et de 2% chaque 5°C au dessus de 20 ° C.
Cse Consommation spécifique du carburant à la puissance N.
Mt. Couple moteur à la puissance N.

N (80/1269/CEE - 88/195/CEE - ISO 1585) - Rating refers to engine after run in with standard air cleaner and muffler and under environment conditions of 20° C and 1 bar. Max rating certified within 5%. Derating 1% approx. every 100 m. altitude and 2% approx. every 5° C beyond 20° C.
Cse Specific fuel consumption relates to the N rating.
Mt. Torque curve relates to the max N rating.

N (80/1269/CEE - 88/195/CEE - ISO 1585) - Angegebene Leistungen beziehen sich auf den eingelaufenen Motor mit Standardauspufftopf, Luftfilter u. unter Umgebungsbedingungen von 20°C u. 1 Bar. Max. Leistung garantiert mit 5% Abweichung. Verminderung ca. 1% je 100 m. Höhe u. ca. 2% je 5°C über 20° C.
Cse Spezifischer Kraftstoffverbrauch bezogen auf Leistung N.
Mt. Drehmoment bezogen auf Leistung N.

N (80/1269/CEE - 88/195/CEE - ISO 1585) - Las potencias indicadas se refieren al motor con filtro de aire y escape std.. con rodaje terminado y a las condiciones ambientales de 20° C. y de 1 bar. La maxima potencia es garantizada con una tolerancia del 5%. Las potencias se reducen de 1% aprox. cada 100 mt. de altitud y 2% aprox. cada 5°C sobre los 20°C de temperadura.
Cse Consumo especifico combustibile referido a la potencia N.
Mt. Par motor referido a la potencia N.

Cilindri - Cylindres - Cylinders - Zylinderzahl - Cilindros	N.	**2**
Cilindrata - Cylindrée - Displacement - Hubraum - Cilindrata	cm.3	**505**
Alesaggio - Alésage - Bore - Bohrung - Diámetro	mm.	**72**
Corsa - Course - Stroke - Hub - Carrera	mm.	**62**
Giri/min. - Tours/min. - R.P.M. - U/min - r.p.m.		**5000**
Potenza kW/CV Puissance kW/CH - Rating kW/HP Leistung kW/PS - Potencia kW/CV	N(80/1269/CEE - 88/195/CEE - ISO 1585)	**15 / 20.4**
Coppia massima - Couple maximum - Max. torque Max. Drehmoment - Par máximo	Nm.	**37 @ 2200**
Consumo combustibile minimo - Consommation minimum de carburant Min. feul consumption - Min. Brennstoftverbrauch - Consumo minimo de combustible	g/kW	**300**
Rapporto di compressione - Taux de compression Compression ratio - Verdichtungsverhältnis - Relación de compresión.		**8.7 : 1**
Capacità coppa olio - Contenance du carter d'huile - Oil sump capacity Schmierölfüllung - Capacidad cárter aceite	l.	**1.5**
Peso a secco - Poids à vide - Dry weight Trockengewicht - Peso en seco	Kg	**52**



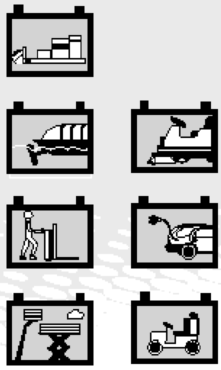
LOMBARDINI
42100 Reggio Emilia, Italy - Via Cav. del Lavoro Adelmo Lombardini, 2
P.O. Box 1074 - Tel. 0522/3891 - Telex: 530003 Motlom I
Telefax 0522/389503 - Telegr: Lombarmotor

DICOM
MOD. 50 758/1
1/1998
Subject to alteration
Printed in Italy

9.1.3 Battery specifications

Sonnenschein

Motive Power Block Batteries
VRLA dryfit
GF-V range (dryfit traction Block)



Main technical features and benefits

- Maintenance-free (no topping up) motive power batteries in gel technology for high operating voltage
- Robust, safe and reliable
- Low self discharge
- Two types with double wall for effective thermal management
- Product range
  6V and 12V block batteries
  50 Ah up to 240 Ah (C_5)
  55 Ah up to 270 Ah (C_{20})
- 700 cycles according to IEC 254-1 with 75 % DOD.

Applications

The GF-V range of blocks are suitable for hard industrial use. This includes applications for advanced guided vehicles, mobile elevating work platforms, cleaning machines, walk-behind pallet trucks, electric cars and buses. With Exide Technologies as your partner for system solutions we can also offer optimized chargers for these blocks.

EXIDE TECHNOLOGIES
INDUSTRIAL ENERGY

dryfit Motive Power Block Batteries for hard industrial use GF-V range (dryfit traction Block)

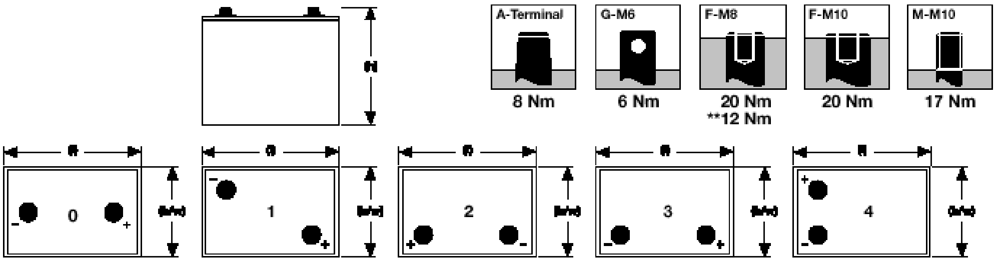
Sonnenschein

Technical characteristics and data

Type	Nominal voltage V	Nominal capacity C_5 Ah	Nominal capacity C_{20} Ah	Length (l) mm	Width (b/w) mm	Height (h) mm	Weight kg	Terminal	Terminal position
GF 06 095 V P 4*	6	95	106	248	124	242	19.0	**F-M8	0
GF 06 160 V 1	6	160	196	244	190	275	29.0	A-Terminal	1
GF 06 160 V P	6	160	196	244	190	275	29.0	F-M8	1
GF 06 160 V 2	6	160	196	264	183	270	33.0	A-Terminal	1
GF 06 180 V	6	180	200	244	190	275	31.0	A-Terminal	1
GF 06 180 V P	6	180	200	244	190	275	32.0	F-M8	1
GF 06 180 V Q	6	180	200	244	190	282	33.0	F-M10	1
GF 06 240 V	6	240	270	311	182	359	48.0	A-Terminal	1
GF 12 050 V	12	50	55	278	175	190	20.0	A-Terminal	3
GF 12 050 V G	12	50	55	278	175	190	20.0	G-M6	3
GF 12 070 V	12	70	79	330	171	236	28.0	A-Terminal	2
GF 12 085 V N 4*	12	85	96	244	200	275	32.4	M-M10	3
GF 12 090 V	12	90	98	513	189	219	39.0	A-Terminal	4
GF 12 105 V	12	105	120	345	172	283	40.0	A-Terminal	3
GF 12 110 V	12	110	120	513	223	219	48.0	A-Terminal	4
GF 12 160 V	12	160	196	518	274	242	64.0	A-Terminal	4

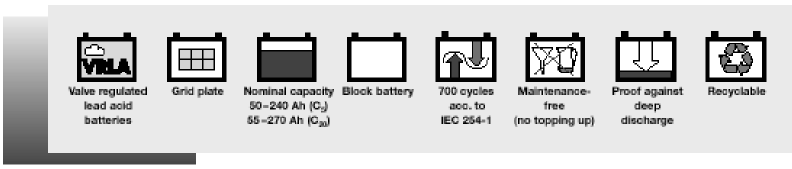
*With double wall for effective thermal management

Drawings with terminal position, terminal and torque



Not to scale!

Specifications



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MXSGVFEPDF0104 Subject to alterations.

www.industrialenergy.exide.com

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The type of battery used is the ‘GF 12 050 V’

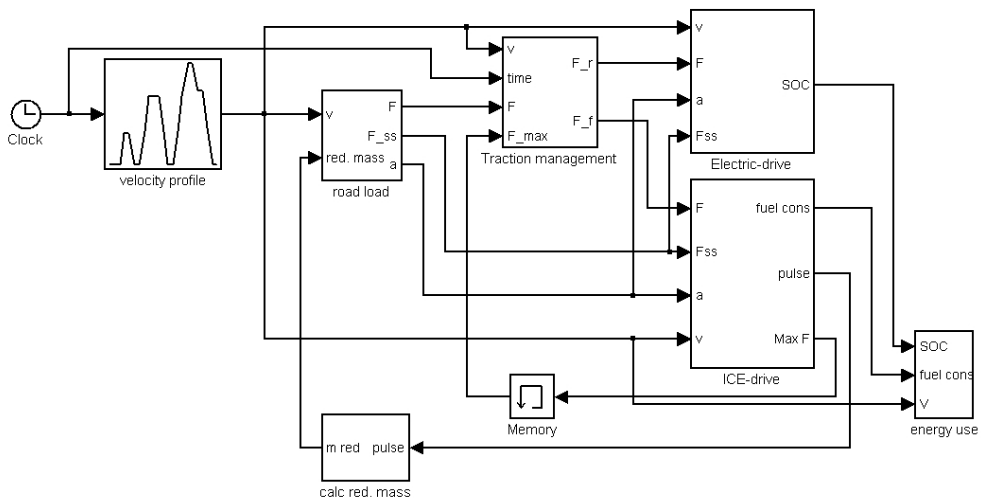
9.1.4 Engine map

RPM diagram of 0,5 liter lombardini engine

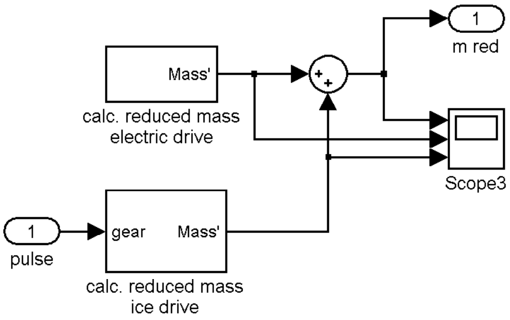
Torque (Nm)	1400	1900	2400	2900	3400	3900	4400	4900	5400
1,8	960	960	960	960	960	960	960	960	960
4	840	840	840	840	840	840	840	840	840
6,2	600	600	600	660	660	660	720	720	780
8,4	540	540	540	540	540	540	600	600	600
10,6	480	480	480	480	480	480	480	540	540
12,8	420	420	420	420	420	420	420	480	480
15	390	390	390	390	390	420	420	420	420
17,2	390	420	360	360	360	390	390	390	390
19,4	360	360	360	360	360	360	360	360	390
21,6	360	330	330	330	330	330	360	360	360
23,8	330	330	330	330	330	330	330	360	0
26	330	330	330	330	330	330	330	330	0
28,2	330	330	300	330	330	330	330	330	0
30,4	330	300	300	300	300	330	330	0	0
32,6	300	300	300	300	300	300	0	0	0
34,8	300	300	300	300	300	0	0	0	0
37	0	0	300	300	0	0	0	0	0

Engine map Lombardini 505 cc petrol engine, specific fuel consumption in g/kWh

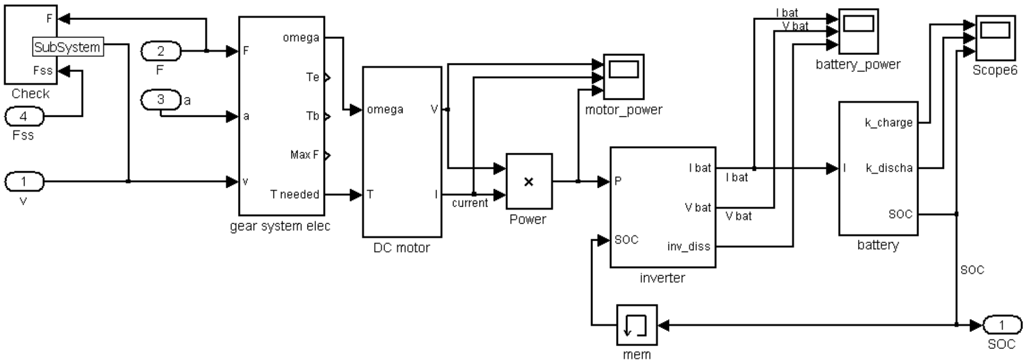
9.2 Matlab Simulink model



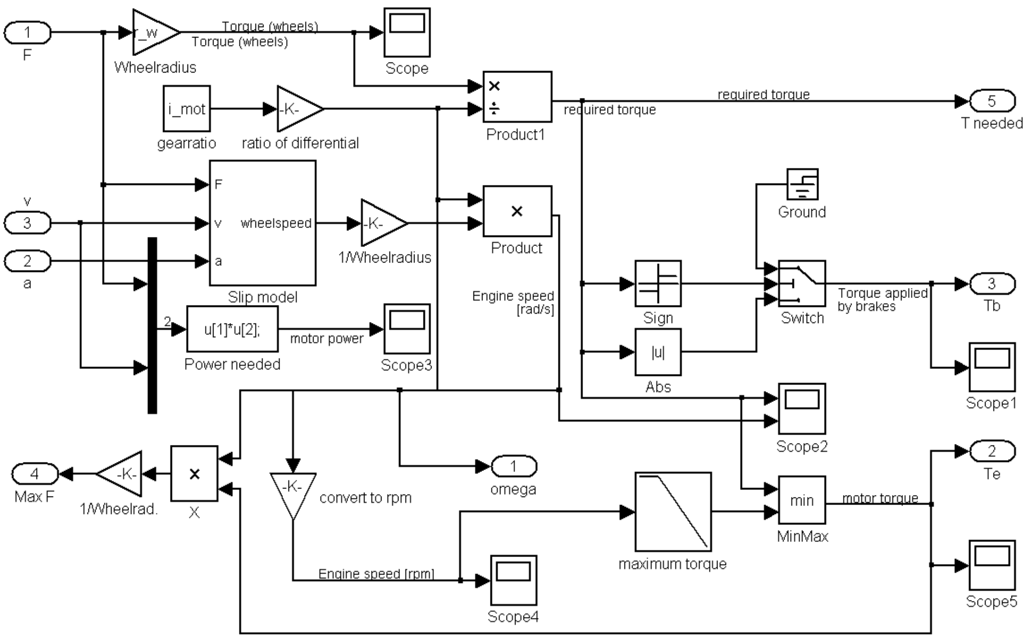
Main model



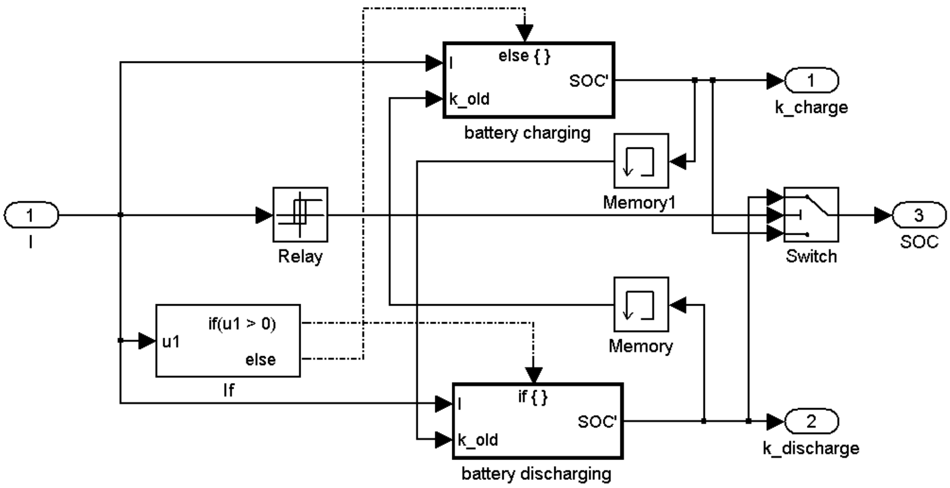
Calc. red. mass



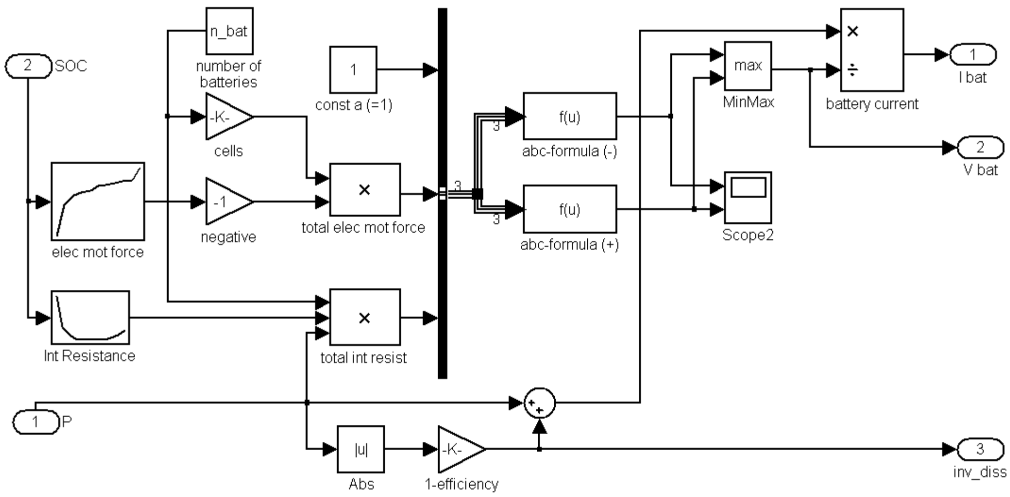
Electric-drive



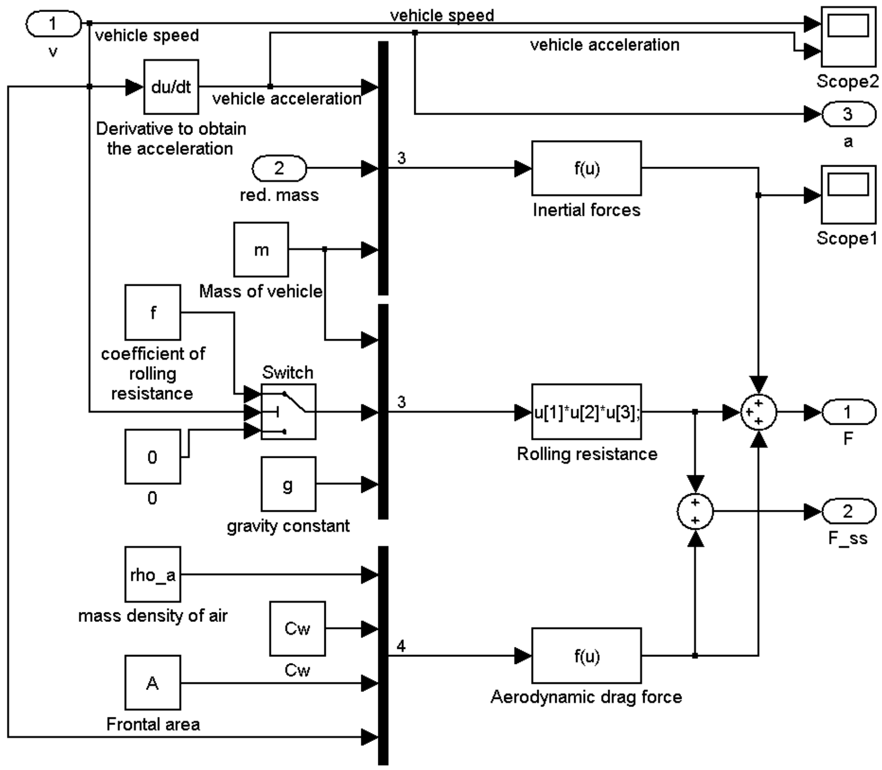
Electric-drive: gear system



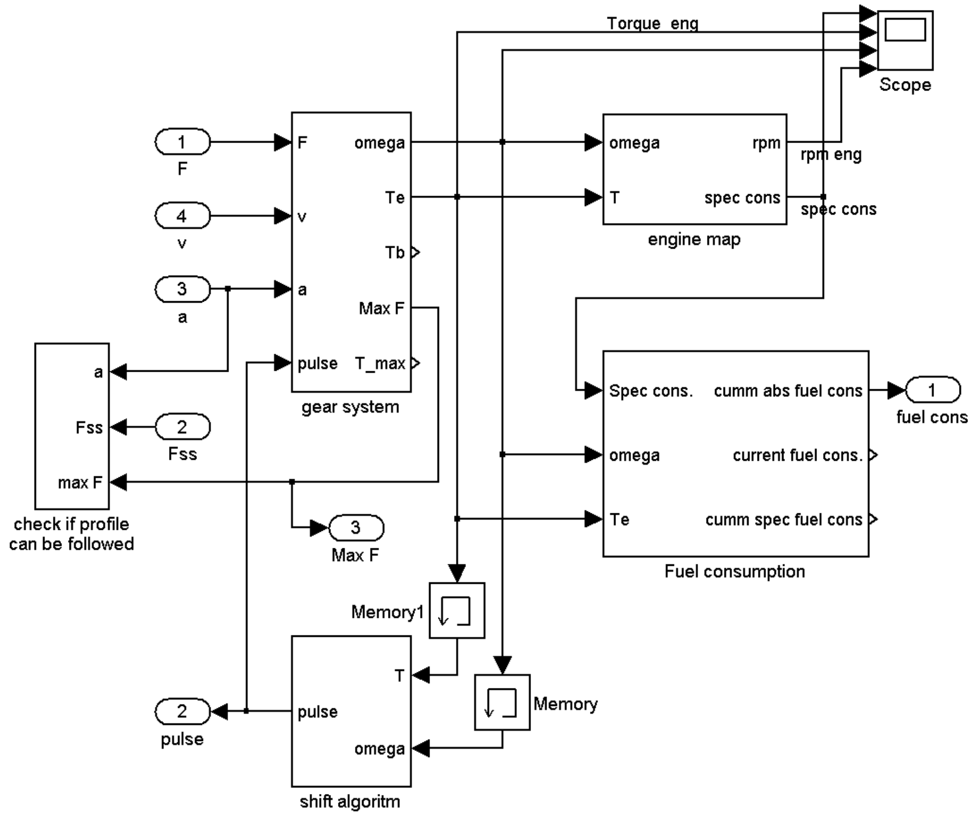
Electric-drive: Battery model



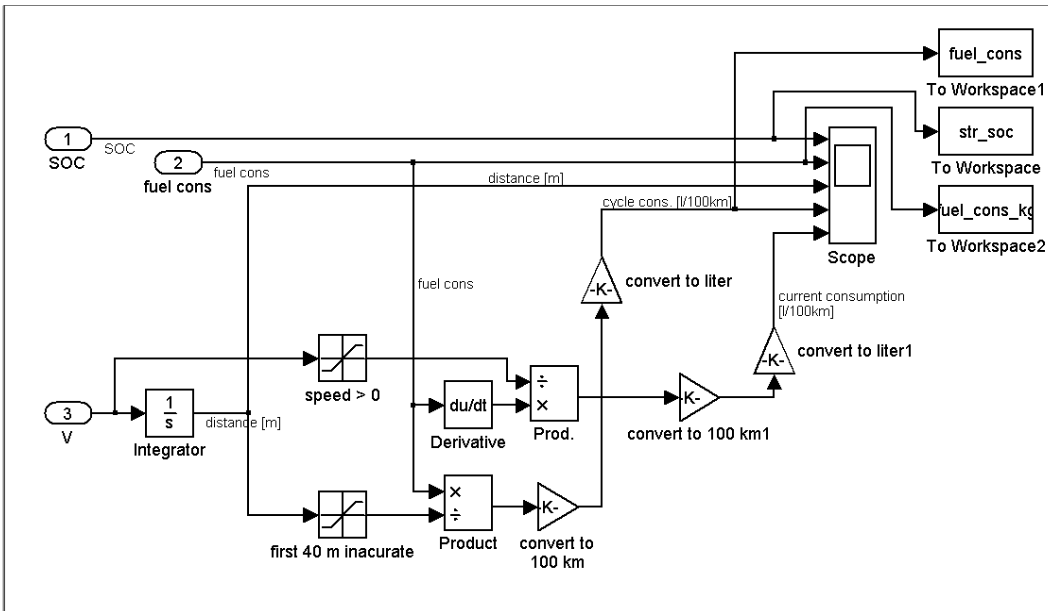
Electric-drive: Inverter model



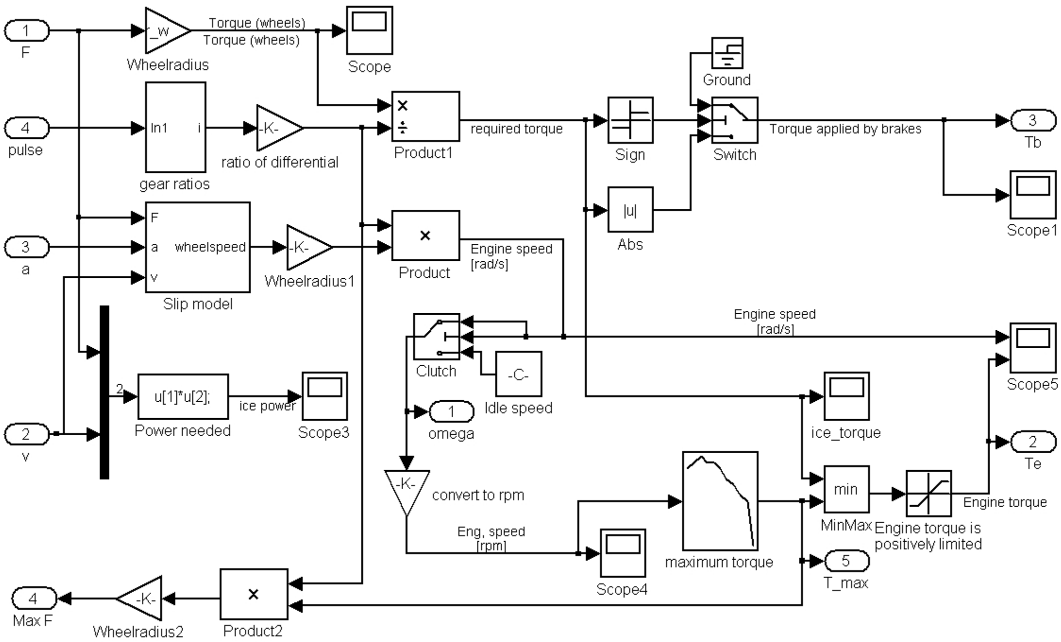
Road load



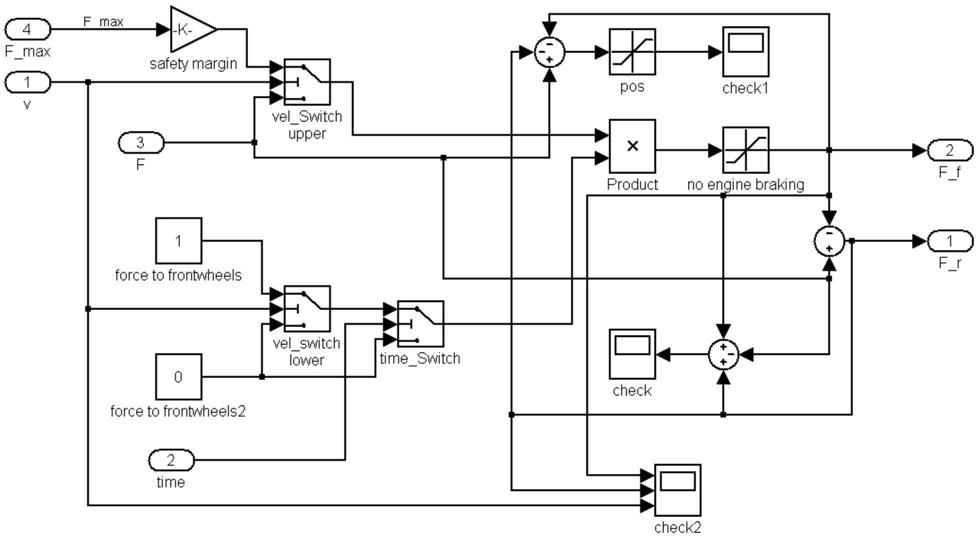
ICE-drive



ICE-drive: Fuel consumption



ICE-drive: Gear system



Traction management