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Equivalent consumption minimization strategies of series hybrid city buses

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1. Introduction

With ever growing concerns on energy crisis and environmental issues, alternative clean and energy efficient vehicles are favoured for public applications. Internal combustion engine(ICE)-powered series hybrid buses and fuel cell (FC) hybrid buses, respectively as a near-term and long-term strategy, have a very promising application prospect.

The series hybrid vehicle utilizes an ICE/FC as the main power source and a battery/ultra capacity (UC) as the auxiliary power source. The main power source supplies the average vehicle power, and the auxiliary power source functions during accelerating and decelerating. Because the battery/UC fulfills the transient power demand fluctuations, the ICE/FC can work steadly. Thus, the durability of the fuel cell stack could be improved compared with a pure FC-powered bus in the FC series hybrid bus. And the PM and NOx can be greatly lowered in the ICE series hybrid bus compared with a traditional city bus. Besides, the ability of the energy storage source to recover braking energy enhances the fuel economy greatly.

The hybrid configuration raises the question of energy management strategy, which chooses the power split between the two. The strategy is developed to achieve system-level objectives, e.g. fuel economy, low emission and battery charge-sustaining, while satisfying system constraints.

Energy management strategies in the recent literature can be generally categorized into two types: rule-based strategies and optimal strategies. A rule based strategy can be easily implemented for the real-time applications based on heuristics (N.Jalil, N.A.Kheir & M.Salman, 1997). Such a strategy could be further improved by extracting optimal rules from optimal algorithms (S.Aoyagi, Y.Hasegawa & T.Yonekura, 2001).

Optimal strategies differ from each other in the time range. Fuel consumption in a single control cycle is minimized in an instantaneous optimal strategy (G.Paganelli, S.Delprat & T.M.Guerra, 2002). And a global optimal strategy minimises it over a whole determined driving cycle using determined dynamic programming method (DDP) (Chan Chiao Lin et al., 2003), or over a undetermined driving cycle using stochastic dynamic programming method (SDP) (Andreas Schell et al., 2005). Other strategies minimize fuel consumption over an adaptive time span, which could be adjusted on the basis of vehicular speed, pedal

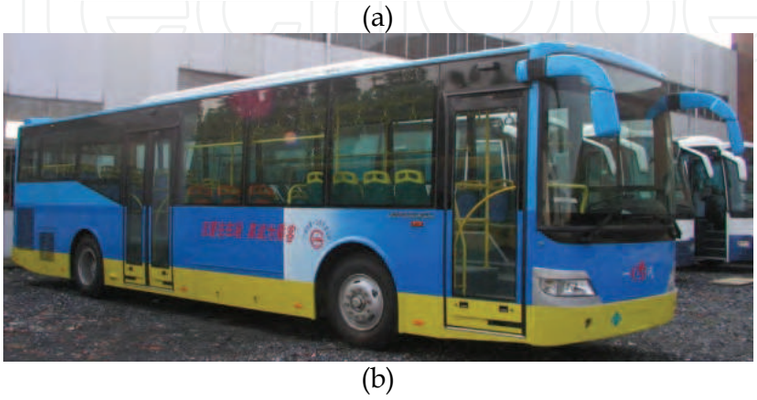
positions, historical vehicle power and power forcasting in the future (Bin He, Minggao Ouyang, 2006).
From a mathematical viewpoint, the optimal problem could be solved using different methods. Energy management strategies based on DDP, SDP, fuzzy logic (Schouten N J, Salman M A & Kheir N A, 2002), neural network optimal algorithm (Amin Hajizadeh, Masoud Aliakbar Golkar, 2007), genetic algorithm (Vanessa Paladini et al., 2007) and wavelet algorithm (Xi Zhang et al., 2008) have been proposed by different researchers.
This chapter describes the implementation of an equivalent consumption minimization strategy in a FC+battery city bus and an ICE+battery city bus. It belongs to the instantaneous optimization strategies. The strategy is based on an equivalent consumption model, which was firstly proposed by Paganelli G (Paganelli G et al., 2002) to evalutate the battery electrical energy consumption. The analytical solutions to the optimal problems are given, avoiding using complex mathematical tools.
The charpter proceeds as follows. Section 2 describes the powertrain systems of the FC/ICE-powered hybrid city buses. Section3 details the equivalent consumption model. Section 4 gives the equivalent consumption minimization strategy (ECMS) on the basis of the analytical solutions. Section 5 discusses the results in the "China city bus typical cycle" testing. Section 6 is the conclusions.

2. The series hybrid powertrains

In the 11th Five-Year Plan of China, a series of hybird city buses have been developed. Fig. 1 (a) and (b) show a fuel cell city bus and a diesel engine hybrid city bus respectively.



(a)



(b)

Fig. 1. (a) Fuel cell city bus (b) Diesel engine series hybrid city bus

The series hybrid powertrain under discussion is mainly composed of a power unit (PU), an auxiliary power source and an alternating current motor, as shown in Fig. 2 (a) and (b). A Ni-MH battery has the advantage of good charging / discharging characteristics compared with a Pb-Acid battery. And it is relatively cheap compared with a Li-ion battery. Thus, a Ni-MH battery is selected as the auxiliary power source. The two kinds of city buses differ in the PU configuration. In the fuel cell hybrid bus, the PU consists of a proton exchange membrane (PEM) fuel cell system and a direct current to direct current (DC/DC) converter, as in Fig. 2 (a). In the ICE hybrid bus, the PU consists of an internal combustion engine, a generator and a rectifier, as in Fig. 2 (b).

As an electrochemical device, the PEM fuel cell system converts hydrogen energy to electrical energy directly without mechanical processes. For the city bus in Fig. 1 (a), two stacks with a rated power of 40kW are installed. The city bus is powered by an AC motor with a rated power of 100kW. In order to fulfill the peak power during accelerating, a Ni-MH battery with a rated capacity of 80A.h, and a rated open circuit voltage of 380V is utilized. The fuel cell stack, the Ni-MH battery and the AC motor are connected as in Fig. 2 (a).

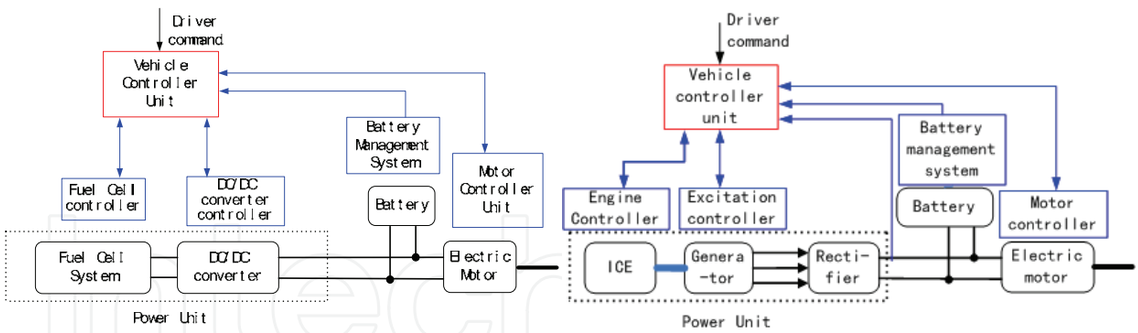
Compared with the FC-powered hybrid bus, the ICE-powered hybrid bus is much more popular in the market because of the price. The city bus in Fig. 1 (b) is equipped with a diesel engine SOFIM 2.8L. It reaches its maximal torque at 1500r.min^{-1}. Its lowest specific fuel consumption is 210g.kWh^{-1} at about 1600r.min^{-1}. A three-phase synchronous generator is connected with the diesel engine directly to convert the mechanical power into alternating current (AC). A three-phase rectifier is used to convert AC into direct current (DC). The AC motor and the battery are similar as in the FC city bus. The diesel engine, the generator, the rectifier, the battery and the motor are connected as in Fig. 2 (b).

Fig. 2 (a) and (b) also present the control systems of the hybrid powertrain. It is a distributed control system based on a time-triggered controller area network (TTCAN). The vehicle controller unit (VCU) is the “brain” of the control system. It receives driver commands (pedal positions, shift signals, on-off swithes et al.) through its digital/analog input channels, and sends control commands to other controllers.

In the FC+battery hybrid powertrain, the TTCAN consists of the VCU, a fuel cell controller, a DC/DC controller, a battery management system and a motor controller. The output torque of the motor and the output current of the DC/DC converter are controlled by the VCU to regulate the motor power and the fuel cell power respectively (Xu Liangfei, 2008).

In the ICE+battery hybird powertrain, the TTCAN is composed of the VCU, an engine controller, a excitation controller, a battery management system and a motor controller. The output power of the PU is controlled by a PWM signal from the VCU to the excitation controller, and the rotational speed of the diesel engine is controlled by a simulant throttle signal from the VCU to the engine controller (Cao Guijun, 2009).

Main parameters of the two city buses are presented in Table 1.



(a) (b)

Fig. 2. Series hybrid powertrain structure (He Bin, 2006) (a) PEM fuel cell+Ni-MH battery (b) Diesel engine+Ni-MH battery

Parameter (Unit)	Value
Fuel cell hybrid bus empty mass m (kg)	1.45×10^4
Diesel engine hybrid bus empty mass m (kg)	1.35×10^4
Frontal area A (m2)	7.5
Drag coefficient C_D	0.7
Rolling resistance coefficient	1.8×10^{-2}
Mechanical efficiency η_T (%)	95
Mass factor	1.1
PEM fuel cell rated power (kW)	80
DC/DC rated power (kW)	80
Style of the diesel engine	SOFIM 2.8L
Diesel engine lowest fuel consumption	$210 g.kWh^{-1}$
Style of the generator	4UC224G
Rated power of the generator	$68kW$ at $1500r.min^{-1}$
Style of the rectifier	three phase full bridge uncontrollable
Power range of the rectifier (kW)	10~120
Ni-MH battery rated capacity (A.h)	80 in Fig. 1 (a), 60 in Fig. 1 (b)
Electric motor rated power (kW)	100

Table 1. Main parameters of the two hybrid city buses

3. The equivalent consumption model

The concept of equivalent fuel consumption was proposed by Paganelli et al. for an instantaneous optimization energy management strategy (Paganelli G et al., 2002). In the two kinds of series hybrid vehicles, both the PU and the battery provide energy. The electrical energy consumption of the battery is transformed into an equivalent fuel consumption to make the two comparable. If some energy is drawn from the battery at the current sample time, the battery will have to be recharged to maintain the state of charge (SOC) in the future. The energy will be provided by the PU, or by the motor in braking regeneration. That will imply extra fuel consumption. Because the operating points of the PU and the battery in the future are unknown, the average values are used to calculate the battery equivalent hydrogen consumption C_{bat}.

$$C_{bat}=\delta P_{bat}C_{pu,avg}/(\eta_{dis}\eta_{chg,avg}P_{pu,avg}),\ P_{bat}\geq 0 \tag{1}$$

where:
P_{bat} is the battery power, kW.
$C_{pu,avg}$ is the PU mean fuel consumption, g.s^{-1}.
$P_{pu,avg}$ is the PU mean output power, kW.
η_{dis} is the battery discharging efficiency.
$\eta_{chg,avg}$ is the battery mean charging efficiency.
δ is a ratio factor that defines as follows.

$$\delta=E_{pu,chg}/(E_{pu,chg}+E_{recycle,chg}) \tag{2}$$

where:
$E_{pu,chg}$ is the battery charging energy provided by the PU. $E_{recycle,chg}$ is the battery charging energy which is recycled by the electric motor. The energy should be calculated over a certain time range, depending on the working conditions. If no braking energy is recovered, δ=1. If no PU energy is used to charge the battery, δ=0. The battery could not only be charged by braking energy, $0<\delta\leq 1$.
If the battery is recharged at the current sample time, a discharge of the battery is required to maintain the SOC. This discharge will lead to a reduction of the fuel consumption in the future. The battery equivalent consumption can be calculated as

$$C_{bat}=P_{bat}\eta_{chg}\eta_{dis,avg}C_{pu,avg}/P_{pu,avg},\ P_{bat}<0 \tag{3}$$

where:
η_{chg} is the battery recharging efficiency.
$\eta_{dis,avg}$ is the battery mean discharging efficiency.
The battery charging/discharging efficiencies are calculated based on the Rint model (V. H. Johnson, 2002), which is shown in Fig. 3. They can be formulated as

$$\begin{cases} \eta_{\text{dis}} = \dfrac{1}{2}\left(1+\sqrt{1-\dfrac{4R_{\text{dis}}P_{\text{bat}}}{U_{\text{ocv}}^2}}\right) & P_{\text{bat}} \geq 0 \\ \eta_{\text{chg}} = 2/\left(1+\sqrt{1-\dfrac{4R_{\text{chg}}P_{\text{bat}}}{U_{\text{ocv}}^2}}\right) & P_{\text{bat}} < 0 \end{cases} \tag{4}$$

where R_{dis} and R_{chg} are the battery discharging and charging resistance respectively, U_{ocv} is the open circuit voltage. All of them are functions of the battery SOC.
For the 80Ah Ni-MH battery, the relationship between $R_{\text{dis}}/R_{\text{chg}}$ and SOC is shown in Fig. 3 (b), as well as the relationship between U_{ocv} and SOC. Fig. 3 (c) presents the relationship between battery efficiency and P_{bat}, SOC. Fig. 3 (d) indicates the relationship between the battery equivalent consumption and P_{bat}, SOC, where δ=1.

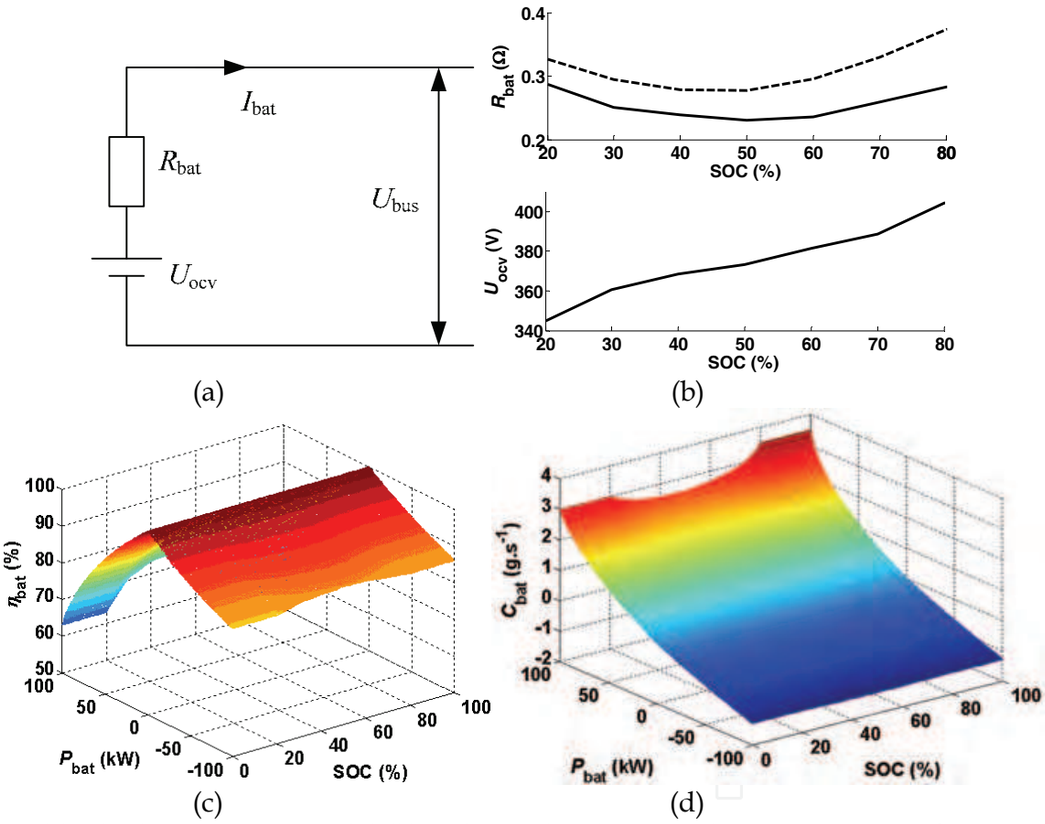
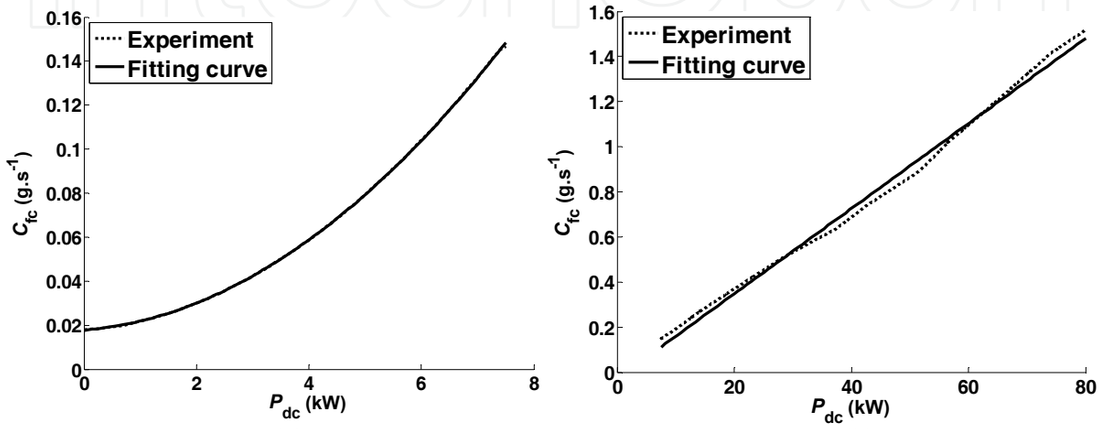


Fig. 3. (a) The battery Rint model (b) Relationship between battery resistance/open circuit voltage and SOC (solid line for charging, dashed line for discharging) (c) Battery efficiency v.s. battery power and SOC (d) Battery equivalent hydrogen consumption C_{bat} v.s. battery power and SOC, δ=1.

In the fuel cell + battery hybrid powertrain, the PU is composed of the fuel cell system and the DC/DC converter. In the following equations, C_{fc} is the fuel cell hydrogen consumption, and P_{dc} is the DC/DC output power. According to the experimental data, the fuel cell hydrogen consumption C_{fc} can be expressed as

$$C_{\mathrm{fc}} = \begin{cases} a_0 P_{\mathrm{dc}} + a_1, & P_{\mathrm{dc}} \geq P_{\mathrm{dc0}} \\ b_0 P_{\mathrm{dc}}^2 + b_1 P_{\mathrm{dc}} + b_2, & P_{\mathrm{dc}} < P_{\mathrm{dc0}} \end{cases} \tag{5}$$

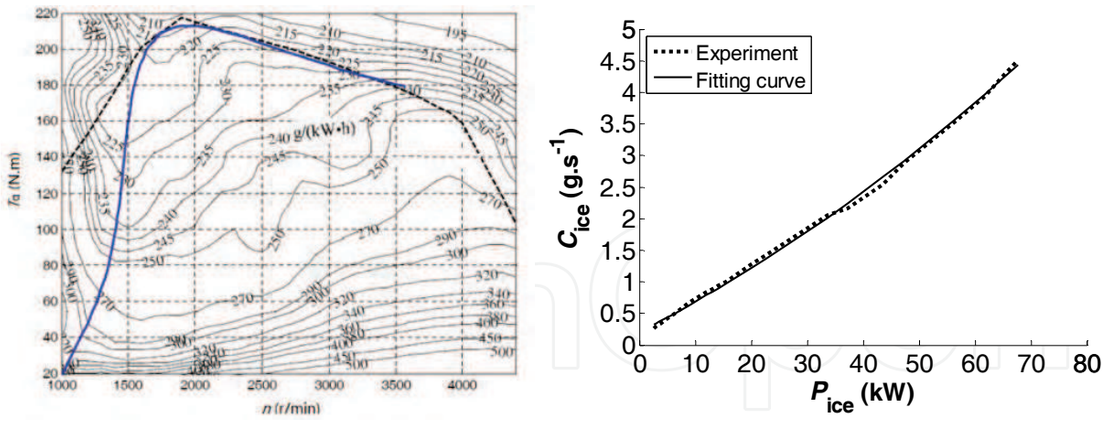
where a_i, b_i are fit coefficients, P_{dc0} is a critical value of P_{dc}.
The relationship between C_{fc} and P_{dc} is nonlinear when P_{dc} is smaller than the critical value P_{dc0}, and it is linear when P_{dc} is larger than P_{dc0}. Fig. 4 (a) and (b) compare the experiment curves and the fitting curves in the two cases. P_{dc0} is about 7.5kW for the hybrid powertrain under discussion.



(a) (b)

Fig. 4. (a) Relationship between fuel cell hydrogen consumption C_{fc} and DC/DC power P_{dc} when P_{dc}≤7.5kW (b) Relationship between fuel cell hydrogen consumption C_{fc} and DC/DC power P_{dc} when P_{dc}>7.5kW

In the diesel engine + battery hybrid powertrain, the PU is composed of the diesel engine, the generator and the rectifier. In the following equations, C_{ice} is the diesel engine fuel consumption, and P_{rec} is the rectifier output power. The specific fuel consumption of the diesel engine is a complex function of torque and speed. Fig. 5 (a) gives an example of a TDI 1.9 L diesel engine. The engine can work at different working points when the output power is P_{ice}. Among these points there is an optimal working point, where the specific fuel consumption is minimal. The optimal working points compose an optimal curve, as shown in Fig. 5 (a). According to the optimal curve in Fig. 5 (a), we can find the relationship between the diesel engine output power P_{ice} and the minimal fuel consumption C_{ice}, as in Fig. 5 (b).



(a) (b)

Fig. 5. (a) The relationship between specific fuel consumption, torque and rotational speed of TDI 1.9L Diesel Engine. The dashed is the external characteristic, and the solid blue line is the optimal curve. (He Bin, 2006) (b) The minimal fuel consumption when the engine output power is P_{ice}

The fitting curve in Fig. 5 (b) can be expressed as:

$$C_{ice} = c_0 P_{ice}^2 + c_1 P_{ice} + c_2 \tag{6}$$

where c_i, i=0~2 are fitting coefficients. For the TDI 1.9L engine, c_0=0.0002g.s^{-1}.kW^{-2}, c_1=0.0456 g.s^{-1}.kW^{-1}, c_2=0.2036g.s^{-1}. The output power of the rectifier is calculated as:

$$P_{rec} = P_{ice}\eta_{gen}\eta_{rec} \tag{7}$$

where η_{gen} and η_{rec} are the generator and rectifier efficiencies respectively.
Then, the total fuel consumption C of the hybrid powertrain can be written as

$$C = C_{pu} + C_{bat} \tag{8}$$

4. The equivalent consumption minimization strategy (ECMS)

In the instantaneous optimization algorithm, an optimal output power of the PU is calculated to minimize the powertrain fuel consumption in one control cycle. It can be formulated mathematically as follows.

$$P_{pu,opt} = \arg\min_{P_{pu}} C = \arg\min_{P_{pu}} \left(C_{pu} + C_{bat} \right)$$

$$\text{subject to:} \quad \begin{cases} SOC_L \le SOC \le SOC_H \\ U_{bus,min} \le U_{bus} \le U_{bus,max} \\ 0 \le P_{pu} \le P_{pu,max} \end{cases} \tag{9}$$

where $U_{bus,min}$ and $U_{bus,max}$ are the minimal and maximal value of bus voltage, $P_{pu,max}$ is the maximan of P_{pu}, C_{pu} equals to C_{fc} in the fuel cell hybrid bus, C_{pu} equals to C_{ice} in the diesel engine hybrid bus.

4.1 ECMS for the fuel cell hybrid powertrain

As for the fuel cell city bus under discussion, the vehicle auxiliary power P_{aux}, which is consumed by the cooling system, the electric assistant steering system et al., is about 5kW (without the air condition) or 17kW (with the air condition). Therefore, the possibility of P_{dc}<7.5kW is very small. That means, the relationship between the fuel cell hydrogen consumption C_{fc} and the DC/DC power P_{dc} could be regarded as linear in most of the time. Then, the optimized problem defined in Equation (9) could be simplified and the analytic solution to the problem is as follows.

$$P_{bat,opt} = \min\left(\frac{U_{ocv}^2\left(1-\delta^2\right)}{4R_{dis}}, \frac{U_{bus,min}\left(U_{ocv}-U_{bus,min}\right)}{R_{dis}}\right) \tag{10}$$

where $P_{bat,opt}$ is the optimal battery power. If no braking energy is recovered, δ=1, then $P_{bat,opt}$=0. This is because the relationship between the hydrogen consumption and the DC/DC power is linear, any charging/discharging process of the battery will cost an extra energy.

With such a strategy, the battery SOC will fluctuate around the initial value. But usually we want to keep the SOC around a target value SOC_{tg}. Thus, a balance power $P_{bat,balance}$ is defined as follows.

$$P_{bat,balance} = k\left(\text{SOC-SOC}_{tg}\right) \tag{11}$$

where k is a coefficient, k>0. Then, the DC/DC target power $P_{dc,tg}$ is calculated as follows.

$$P_{dc,tg} = \max\left(\min\left(P_{demand} - P_{bat,opt} - P_{bat,balance}, P_{dc,max}\right), 0\right) \tag{12}$$

where P_{demand} is the powertrain demand power, including the electric motor power and the vehicle accessorial power. The VCU calculates the DC/DC target voltage/current according to $P_{dc,tg}$, sends the signal to the DC/DC controller through TTCAN. There is a time-delay between the DC/DC target signal and its actual output. This is because the fuel cell can't response quickly to dynamic loads. The fuel cell voltage drops with increasing current. A reactant starvation occurs at high currents and dynamic loads because the transport of reactant gases is not able to keep pace with the amount used in the reaction (Xu Liangfei et al., 2008).

4.2 ECMS for the diesel engine hybrid powertrain

According to equations (6) and (7), the relationship between the C_{ice} and P_{rec} is.

$$\begin{cases} C_{ice} = c_0^{'} P_{rec}^2 + c_1^{'} P_{rec} + c_2 \\ c_0^{'} = c_0 \left(\eta_{gen} \eta_{rec} \right)^2 \\ c_1^{'} = c_1 \eta_{gen} \eta_{rec} \end{cases} \tag{13}$$

The analytic solution for the optimized problem defined in Equation (9) can be written as follows.

$$P_{bat,opt} = \begin{cases} \dfrac{U_{bus,min}\left(U_{ocv} - U_{bus,min}\right)}{R_{dis}}, K \le dx_{min} \\ \dfrac{U_{ocv}^2}{4R_{dis}}\left(1 - \dfrac{K^2}{a^2}\right), dx_{min} < K \le d \\ 0, d < K \le d / \left(\eta_{chg,avg}\eta_{dis,avg}\right) \\ \dfrac{U_{ocv}^2}{4R_{chg}}\left(1 - \dfrac{\left(K\eta_{chg,avg}\eta_{dis,avg}\right)^2}{a^2}\right), \dfrac{d}{\eta_{chg,avg}\eta_{dis,avg}} < K < \dfrac{dx_{max}}{\eta_{chg,avg}\eta_{dis,avg}} \\ -\dfrac{U_{bus,max}\left(U_{bus,max} - U_{ocv}\right)}{R_{chg}}, K \ge \dfrac{dx_{max}}{\eta_{chg,avg}\eta_{dis,avg}} \end{cases} \tag{14}$$

where d, K, x_{min}, x_{max} are coefficients defined as follows.

$$\begin{cases} d = c_1^{'} + 2c_0^{'} P_{demand} \\ K = \begin{cases} \delta C_{fc,avg} / \left(\eta_{dis,avg}\eta_{chg,avg}\right), P_{bat} \ge 0 \\ C_{fc,avg} / \left(\eta_{dis,avg}\eta_{chg,avg}\right), P_{bat} < 0 \end{cases} \\ x_{min} = \sqrt{1 + 4U_{bus,min}\left(U_{bus,min} - U_{ocv}\right) / \left(U_{ocv}^2\right)} \\ x_{max} = \sqrt{1 + 4U_{bus,max}\left(U_{bus,max} - U_{ocv}\right) / \left(U_{ocv}^2\right)} \end{cases} \tag{15}$$

Equations (14) and (15) indicate that, the battery optimal power $P_{bat,opt}$ is a function of vehicle power demand P_{demand}, battery SOC and the ratio coefficient δ. $P_{bat,opt}=f(P_{demand}, SOC, \delta)$. In real-time application, this function can be calculated and stored in the ECU memory. The target power of the rectifier $P_{rec,tg}$ is calculated using a similar formula as Equation (12).

$$P_{rec,tg} = \max\left(\min\left(P_{demand} - P_{bat,opt} - P_{bat,balance}, P_{rec,max}\right), 0\right) \tag{16}$$

The output power of the rectifier is controlled by a PWM signal from the VCU to the excitation controller. According to $P_{rec,tg}$ and the optimal curve in Fig. 5 (a), the optimal working point (ω_{eng}, T_{eng}) can be found. The target rotational speed of the diesel engine ω_{eng} is controlled by a simulant throttle signal from the VCU to the engine controller. In order to reduce the emission during dynamic loads, there is a time-delay between the command of VCU and the actual output of the engine (He Bin, 2006).

5. Results in the cycle testing

The instantaneous optimal energy management strategies have been successfully implemented in the two hybrid city buses. The hybrid powertrains were tested on the test bench with "China city bus typical cycle". Results are presented in Fig. 6 (a)~(d).

Fig. 6 (a) and (b) presents the results of the fuel cell hybrid city bus in the cycle testing, δ = 0.6. The vehicle velocity is shown in Fig. 6 (a). The test lasts about 20mins, and the maximal speed is 60km.h^{-1}. The battery SOC was kept around 70%.

Fig. 6 (b) shows the power split between the electric motor, the battery and the PU (Fuel cell + DC/DC converter). Part of the braking energy was recycled. In this figure, P_m stands for the electric power of the motor. The electric power ranged from -50kW to 100kW. Because of the time-delay between the DC/DC target command and its actual output, the DC/DC output power changed much more slowly than the motor electric power. The battery functioned during accelerating and decelerating. It was kept charge-sustaining.

Fig. 6 (c) indicates the energy flow diagram. The hydrogen energy is calculated on the basis of its low heat value. The average efficiencies of the fuel cell system, the DC/DC converter and the electric motor were 50%, 96% and 85% respectively. About 5.5% of the whole energy was consumed by the vehicle auxiliary components, e.g. the air condition. About 45.2% of the hydrogen energy was output from the electric motor, and about 9.5% of the hydrogen energy was recycled. The battery slightly discharged. The fuel economy of the city bus was about 7.4kg.100km^{-1}.

The fuel consumption increases with δ increases. Testing results show that, their relationship is as follows.

δ=0.6, fuel economy = 7.4kg.100km^{-1};

δ=0.85, fuel economy = 8.9kg.100km^{-1};

δ=1, fuel economy = 9.7kg.100km^{-1}.

The energy flow diagram of the diesel hybrid powertrain, but not the city bus, is shown in Fig. 6 (d). The average diesel engine efficiency was about 33.5%, which is lower than the fuel cell engine. The total efficiency of the generator and the rectifier was about 85%. There were no vehicle auxiliary components, because the testing was carried out on a test bench. About 33.1% of the whole energy was output from the electric motor, and about 11% of the energy was recycled. The battery slightly discharged. As a result, the fuel economy was 30L.100km^{-1}, the NOx emission was 8.5g.km^{-1}, and the PM emission was 0.1g.km^{-1} (Cao Guijun, 2009).

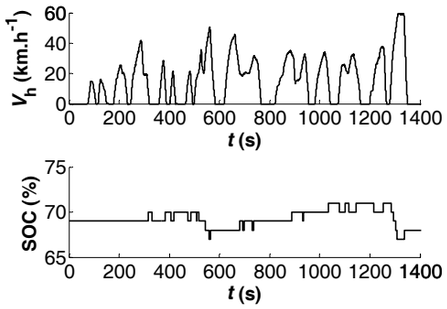
6. Conclusions

This chapter proposes an Equivalent Consumption Minimization Strategy (ECMS) for the series hybrid city buses with two different powertrain configurations, Fuel cell + battery and diesel engine + battery.

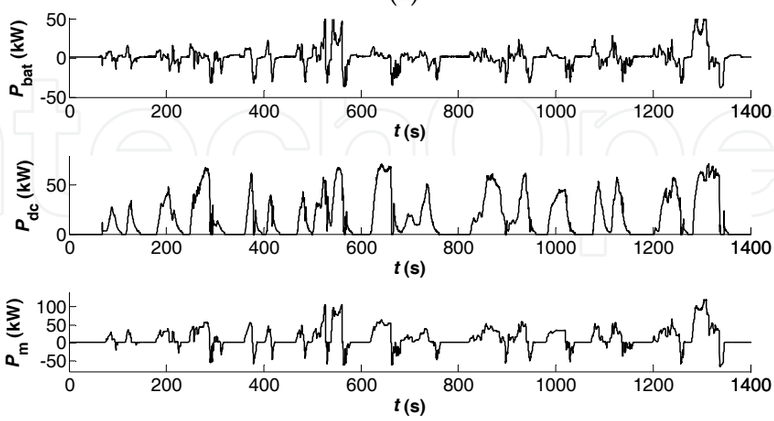
An equivalent consumption model is firstly introduced, incorporating the fuel consumption of power unit and the battery equivalent consumption. The concept of the equivalent consumption is further developed compared with its origin. The ECMS is developed based on the analytical solution to the instantaneous optimization problem.

Because of the linear relationship between the fuel consumption and the DC/DC power, the battery optimal power is a function of the battery SOC and the ratio coefficient δ.

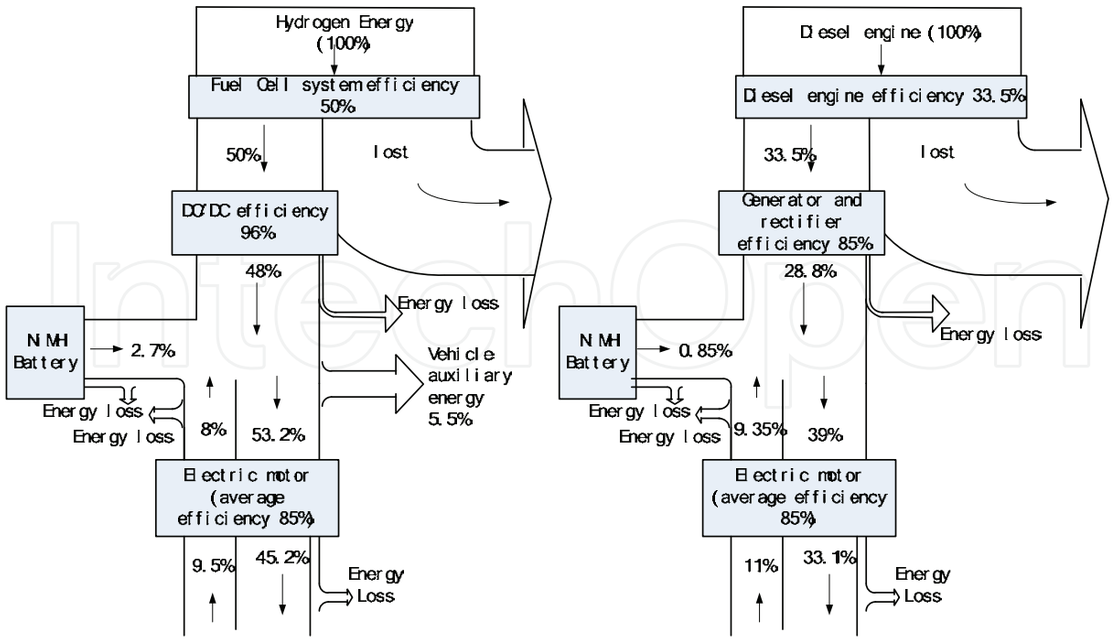
The ratio coefficient δ depends on the braking regeneration strategy. And it changes with the working conditions of the powertrain system. It is the key parameter of the ECMS, and changes with time. Besides, a battery balance power is introduced to keep the battey SOC around a target value.



(a)



(b)



(c) (d)

Fig. 6. (a) Vehicle velocity and the battery SOC in the "China city bus typical cycle" (b) Power split of the fuel cell hybrid city bus, δ = 0.6 (c) energy flow diagram of the fuel cell hybrid city bus (d) energy flow diagram of the diesel hybrid powertrain, δ = 0.6

The ECMS of the diesel hybrid powertrain is a little complex, because there is a quadratic relationship between the fuel consumption and the engine power. The battery optimal power is a function of powertrain demand power, battery SOC and the ratio coefficient δ. For the same reason, the balance power is introduced to calculate the target power of the rectifier.

The fuel cell + battery city bus was tested in the "China city bus typical cycle". Results show that, the battery SOC was kept around 70%, and the fuel economy was 7.4kg.100km^{-1}. Fuel consumption increases with the ration coefficient δ increases.
The diesel + battery powertrain was tested in lab with the same cycle. Results show that, the battery SOC was kept in balance, and the fuel economy was 30L.100km^{-1}.

In this chapter, we only consider the fuel economy in the optimal strategy. However, the fuel cell durability and the exhaust emission should also be included in the optimized strategy.

Because of the linear characteristics of the fuel cell system, the fuel economy is mainly determined by the ratio coefficient δ. It means that, the braking regeneration strategy contributes much more than the power split strategy. Thus, the primary challenge in power split strategy is to prolong the fuel cell durability, while fulfill the powertrain power demand.

The fuel economy of the diesel engine hybrid bus is determined by δ, SOC and vehicle power demand. The braking regeneration strategy is also very important. The primary challenge of the control system is to make the engine work on the optimal curve, as in Fig. 5 (a). Actually we use a feedforward + feedbackward method to control the engine working point so as to lower the fuel consumption and the exhaust emission (Cao Guijun, 2009). This control problem is valuable to be studied in future.

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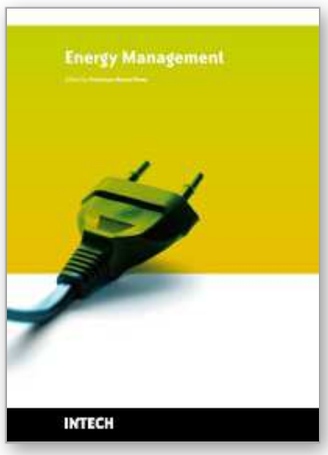
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Forecasts point to a huge increase in energy demand over the next 25 years, with a direct and immediate impact on the exhaustion of fossil fuels, the increase in pollution levels and the global warming that will have significant consequences for all sectors of society. Irrespective of the likelihood of these predictions or what researchers in different scientific disciplines may believe or publicly say about how critical the energy situation may be on a world level, it is without doubt one of the great debates that has stirred up public interest in modern times. We should probably already be thinking about the design of a worldwide strategic plan for energy management across the planet. It would include measures to raise awareness, educate the different actors involved, develop policies, provide resources, prioritise actions and establish contingency plans. This process is complex and depends on political, social, economic and technological factors that are hard to take into account simultaneously. Then, before such a plan is formulated, studies such as those described in this book can serve to illustrate what Information and Communication Technologies have to offer in this sphere and, with luck, to create a reference to encourage investigators in the pursuit of new and better solutions.

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