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A New Supercapacitor and Li-ion Battery Hybrid System for Electric Vehicle in ADVISOR

Xiao Peng[1,2], Quan Shuhai[1,2] and Xie Changjun[2]

[1]School of Automotive engineering, Wuhan University of Technology, Wuhan, 430070, China;
[2]School of Automation, Wuhan University of Technology, Wuhan, 430070, China

xp@whut.edu.cn

Abstract. The supercapacitor (SC) and Li-ion battery(BT) hybrid energy storage system(HESS) electric vehicle(EV) is gaining universal attention. The topology is of importance for the SC/BT HESS.A new SC/BT topology HESS with a rule-based energy management strategy for EV was proposed. The BT pack is connected directly to the DC link via a controlled switch. The SC pack is connected to the DC link via a controlled switch. A uni-directional DC/DC converter is connected between the SC pack and the BT pack. The braking regeneration energy is all harvested by the SC pack.The output power of BT pack is limited. The different SC/BT configurations with varied BT maximum Ah capacity factor and SC maximum capacity factor are simulated in ADVISOR.Simulation results show that BT maximum Ah capacity factor has little impact on vehicle acceleration performance and maximum speed. SC maximum capacity factor has significant impact on vehicle acceleration performance and maximum speed.The fuel economy isn't affected.

1. Introduction

Due to clean and efficient power generation, EV have received increased attention[1].At the same time, challenges such as vehicle performance and cost of EV are yet to be overcome. Li-ion BT is with high energy density and low power density[2,3,4,5].SC is well known for its extremely high power density, high cycle lifetime, cycling efficiency and low energy density[6,7,8]. A BT/SC HESS EV is a possible solution to enhance the energy density and power density at the same time.

The topology of BT/SC HESS is important. A SC/BT topology with a bi-directional DC-DC converter is studied[9,10,11,12,13].A BT/SC topology is developed with a bi-directional converter[14].A BT/SC topology for tramway with two converters is adopted[15].

2. A New SC/BT HESS topology

A proposed new SC/BT HESS topology with two controlled switches is proposed as figure 1. The features are that a uni-directional DC/DC converter is used and all the braking regeneration energy is harvested by the SC pack .The controlled switch 1 is off all the time to protect BT pack isolated from charging current. The controlled switch 2 is on when EV is in braking regeneration phase.The controlled switch 2 is off when the EV is in traction phase. The voltage of SC pack is lower than that of BT pack. The voltage of SC pack is boosted by the DC/DC converter to supply power.

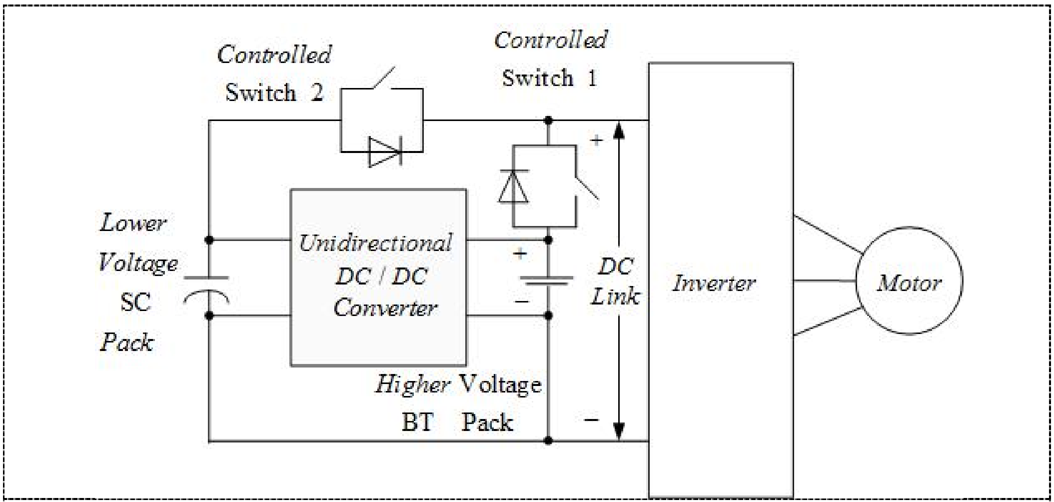

Figure 1. A proposed new SC/BT HESS topology.

3. Rule-based energy management strategy

The power allocation between BT and SC is of importance in the HESS.The power allocation scheme is shown in figure 2.

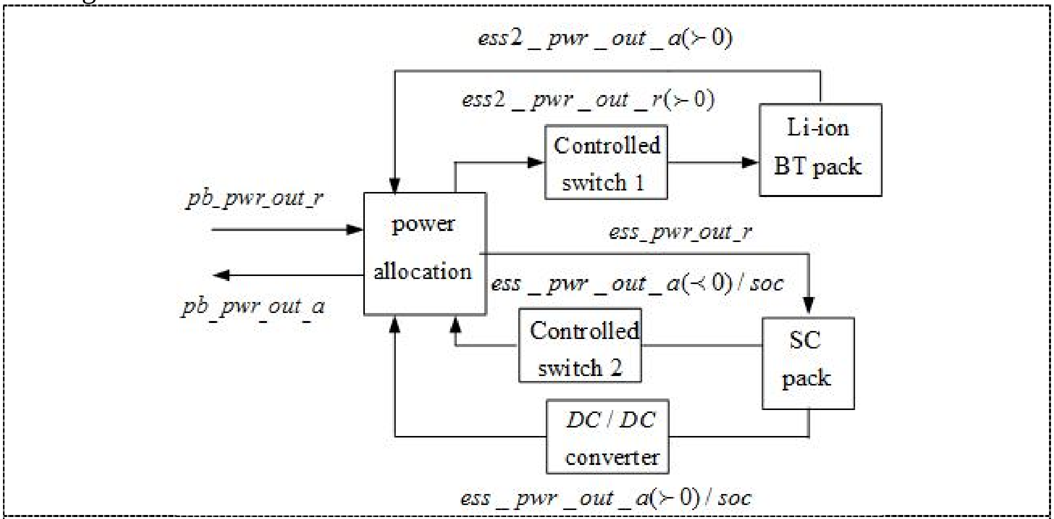

Figure 2. HESS power allocation scheme in ADVISOR.

$pb\_pwr\_out\_r$ is power requested for EV. $pb\_pwr\_out\_a$ is HESS output power for EV. $ess2\_pwr\_out\_r$ is power requested from Li-ion BT pack. $ess2\_pwr\_out\_a$ is output power from Li-ion BT pack. $ess\_pwr\_out\_r$ is power requested from SC pack. $ess\_pwr\_out\_a$ is output power from SC pack. η_{DC} is the constant efficiency of the DC/DC converter. The power allocation is as (1),(2).

$$pb\_pwr\_out\_r = ess2\_pwr\_out\_r + ess\_pwr\_out\_r \quad (1)$$

$$pb\_pwr\_out\_a = ess2\_pwr\_out\_a \cdot \eta_{DC} + ess\_pwr\_out\_a \quad (2)$$

The rule-based energy management strategy is as:

(1) $ess2\_pwr\_out\_a$ is limited between the minimum operating power $cs\_\min\_pwr$ and the maximum operating power $cs\_\max\_pwr$.

(2)When EV is in traction phase, $ess2\_pwr\_out\_\mathrm{a}$ is as (3).
(3) When EV is in braking regeneration phase, SC pack receives all braking regenerative power.
(4)The SC state of charge (SOC) is maintained near the goal SOC $SOC_{\_goal}$ (As (4)).

$$ess2\_pwr\_out\_\mathrm{a} = pb\_pwr\_out\_\mathrm{r} + pwr_{\_additional} \tag{3}$$

Where $pwr_{\_additional}$ (as(5)) is additional power to maintain the SC SOC in equilibrium.

$$SOC_{\_goal} = 0.5 \cdot (cs\_hi\_soc + cs\_lo\_soc) \tag{4}$$

$$pwr_{\_additional} = \frac{SOC_{\_goal} - SOC}{0.5 \cdot (cs\_hi\_soc - cs\_lo\_soc)} \cdot cs\_charge\_pwr \tag{5}$$

Where cs_hi_soc is the SC SOC high limit. cs_lo_soc is the SC SOC low limit. cs_charge_pwr is charge power.

4. Simulation and results

A Saft VL45E LiFePO4 BT [12] and a Maxwell BACP3000 SC are used .The SC/BT HESS EV is simulated based on secondary development in ADVIOSR . Vehicle components parameters for simulation is as table 1. veh_cargo_mass represents cargo mass. veh_glider_mass represents vehicle mass without powertrain. ess2_parallel_mod_num represents the number of BT in parallel.

Table 1. Vehicle components parameters for simulation.

Component	Parameter
Vehicle	veh_cargo_mass 136kg veh_glider_mass 592.4kg
Li-ion BT	ess2_parallel_mod_num 1
SC	ess_module_num 130
Powertrain Control	cs_hi_soc 0.9 cs_min_pwr 1500W cs_lo_soc 0.7 cs_max_pwr 9500W
Motor	continuous power 30kW,peak power 45kW
DC/DC converter	efficiency 0.98

The configurations with varied $ess2\_cap\_scale$, ess_cap_scale, ess_parallel_mod_num are used to observer the vehicle performance when ess_module_num is 130. Vehicle performance ($ess2\_cap\_scale$ = 1, ess_cap_scale = 0.5) is shown in table 2.Vehicle performance ($ess2\_cap\_scale$ =2, ess_cap_scale =0.5) is shown in table 3. Vehicle performance ($ess2\_cap\_scale$ =1, ess_cap_scale =1) is shown in table 4. Vehicle performance ($ess2\_cap\_scale$ =2, ess_cap_scale =1) is shown in table 5. ess_parallel_mod_num is the number of SC string in parallel. ess_module_num is the SC number in series. ess2_module_num is the BT number in series. $ess2\_cap\_scale$ is the factors of BT max. capacity. ess_cap_scale is the factors of SC max. Capacity.

Table 2. Vehicle performance ($ess2\_cap\_scale$ =1, ess_cap_scale = 0.5).

BT Units	SC Units	Fuel Economy (mpgge)	Acceleration(s) 0-60(mph)	Max. Speed (mph)
ess2_module_num=110	ess_parallel_mod_num=1	128.7	N/A	44.9
ess2_module_num=110	ess_parallel_mod_num=2	129.3	10.7	63.7
ess2_module_num=110	ess_parallel_mod_num=3	129.3	8.8	74.7
ess2_module_num=110	ess_parallel_mod_num=4	129.3	8.3	82

Table 3. Vehicle performance ($ess2\_cap\_scale$ =2, ess_cap_scale = 0.5).

BT Units	SC Units	Fuel Economy (mpgge)	Acceleration(s) 0-60(mph)	Max. Speed (mph)
ess2_module_num=110	ess_parallel_mod_num=1	128.9	N/A	43.9
ess2_module_num=110	ess_parallel_mod_num=2	128.9	10.9	64.6
ess2_module_num=110	ess_parallel_mod_num=3	128.8	8.9	72.7
ess2_module_num=110	ess_parallel_mod_num=4	125.5	8.2	81.3

Table 4. Vehicle performance ($ess2\_cap\_scale$ =1, ess_cap_scale = 1).

BT Units	SC Units	Fuel Economy (mpgge)	Acceleration(s) 0-60(mph)	Max. Speed (mph)
ess2_module_num=110	ess_parallel_mod_num=1	132.2	N/A	56.4
ess2_module_num=110	ess_parallel_mod_num=2	132.2	9.4	68.9
ess2_module_num=110	ess_parallel_mod_num=3	131.1	8.4	78.8
ess2_module_num=110	ess_parallel_mod_num=4	132	8.1	85.5

Table 5. Vehicle performance ($ess2\_cap\_scale$ =2, ess_cap_scale = 1).

BT Units	**SC Units**	**Fuel Economy (mpgge)**	**Acceleration(s) 0-60(mph)**	**Max. Speed (mph)**
ess2_module_num=110	ess_parallel_mod_num=1	132.1	N/A	56.1
ess2_module_num=110	ess_parallel_mod_num=2	132.1	9.7	68.1
ess2_module_num=110	ess_parallel_mod_num=3	131	8.6	78.1
ess2_module_num=110	ess_parallel_mod_num=4	130.3	8.3	84.6

It can be seen in table 2 and table 3,when ess_cap_scale =0.5, $ess2\_cap\_scale$ is increased from 1 to 2, the vehicle acceleration performance is decreased by 1.1%-1.8% and max. speed is decreased by 0.86%-2.2%.

It can be seen in table 4 and table 5,when ess_cap_scale =1, $ess2\_cap\_scale$ is increased from 1 to 2, the vehicle acceleration performance is decreased by 2%-3% and max. speed is decreased by 0.5%-1.2%.

It can be seen in table 2 and table 4,when $ess2\_cap\_scale$ =1, ess_cap_scale is increased from 0.5 to 1,the vehicle acceleration performance is improved by 2.4%-13.8% and max. speed is improved by 4.2%-25.6%.

It can be seen in table 3 and table 5,when $ess2\_cap\_scale$ =2, ess_cap_scale is increased from 0.5 to 1,the vehicle acceleration performance is improved by 1.2%-12.3% and max. speed is improved by 4%-27%.

The fuel economy isn't affected.

5. Conclusion

A new SC/BT topology HESS with a rule-based energy management strategy for EV was proposed. The braking regeneration energy is all harvested by the SC pack. A uni-directional DC/DC converter is used.EV performance are studied . BT maximum Ah capacity factor has little impact on vehicle acceleration performance and maximum speed. SC maximum capacity factor has significant impact on vehicle acceleration performance and maximum speed.The change of fuel economy isn't obvious.The conclusion is beneficial to the EV sizing and optimization.

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