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LOOK –AHEAD MODEL FOR HYBIRD TRUCK FUEL ECONOMY IMPROVEMENT, STANDARD AND REAL WORD DRIVING CYCLES' CONDITION

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ABSTRACT: In the presented work, the vehicle propulsion controller (VPC) for parallel hybrid truck model has been modified to manage auxiliary power in advance based on the forthcoming traffic information. To simulate standard and real world conditions, constant highway driving cycles and real world driving cycles with different terrain types have been used to show the impact of looking-ahead control strategy on managing energy storage system and fuel economy improvement. The results revealed that the proposed looking-ahead control strategy for parallel hybrid truck has substantial contribution in preparing the system for forthcoming power demand. Fuel economy change for the model with looking-ahead control strategy has been improved from 0.5 to 3% for different terrain types comparing to the same parallel hybrid truck model without looking-ahead strategy. Furthermore, reducing equipment sizes while maintaining adequate power and improved fuel economy was one of the potential findings from the proposed model.

1. INTRODUCTION

About one-third cost of heavy diesel truck's life cycle comes from fuel expenses[1]. This cost, alongside with salaries, is the largest portion share of the total cost to the owner of the truck. Therefore, increased worry about the fuel economy and emissions from vehicles has directed to interest in the use of hybrid electric powertrains and the starter of several production vehicles in both heavy duty and light duty applications [2]. Hybrid electric vehicles (HEVs) use a combination of electric motor and another power source such as an internal combustion engine (ICE) or fuel cell [3-5]. While these vehicles show great potential for use in a wide variety of driving situations, the optimization of components and control strategies is somewhat complex. One of the potential optimization methods is the looking-ahead strategy.

Heavy duty parallel Hybrid Electric Vehicle (HEV) is a system which uses multi power sources. The main power source is the regular fuel like diesel, or natural gas. The secondary power source is the electric power which is stored in an Energy Storage System (ESS)[6]. Energy stored in the ESS is coming either from the engine or from captured energy while using brake system[6-8]. Several studies have proved that the benefits from parallel HEVs are limited on flat highway and that due to the few numbers of using brake system [9, 10]. However, these assessments might not apply on a heavy duty HEV and that is because of that the heavy duty vehicle's engine runs most time near the peak load, and the heavy duty vehicle has big moment of inertia comparing to light-duty vehicles [11]. A big moment of inertia for heavy duty vehicle is due to its relatively big mass. It is expected that a heavy duty vehicle needs an additional power for acceleration or ascending hill (especially with 100%

full load or 50% full load of cargo). Also, it is expected that the brake system for a heavy duty truck will be using much more than a regular light duty vehicle to compromise speed or slow down[12]. Going uphill and downhill terrains may represent the major reason to encourage using hybridization systems as auxiliary power source for a parallel heavy duty HEV. Heavy duty parallel HEVs have attracted substantial interest in recent years due to their potential for decreasing fuel consumption[13]. Furthermore, a parallel hybrid electric vehicle architecture expected to improve energy conversion efficiency [14].

Predicted controller strategy for a HEV has analyzed in several studies [1, 15, 16]. Different simulations and measurements have been proved the possible benefits from knowing the forthcoming traffic conditions [17, 18]. The knowledge of traffic conditions ahead can be available by communicating the vehicle with infrastructure and collecting information[19]. However, most these studies either were for light-duty HEVs to manage hybrid power system in advance [20]. The vehicle propulsion controlling improvement show a very strong impact on fuel economy for hybrid electric vehicle [21]. This study suggested an algorithm which may be more proper for heavy duty HEVs configuration and it's effective at the same time. The ultimate goal of this proposed strategy is to manage ESS State off Charge (SOC).

Since the Global Positioning System (GPS) is already established, the intelligent transportation systems (ITS) to communicate with vehicle does not need an expensive equipment[1, 22]. Looking-ahead strategy is to know the forthcoming traffic condition regarding congestion and road grade to prepare the system in advance. Preparing heavy duty HEV in advance is by ensuring a maximum capacity in the ESS for forthcoming power from using brake system or maximum power (limited by ESS capacity) to assist the engine for the forthcoming additional power demand. The ultimate goal of this study is to analyze the impact of looking-ahead strategy on heavy duty parallel HEVs.

In this work,a50% full load (26000 kg) parallel direct pre-transmission hybrid electric vehicle configuration with and without looking ahead strategy has been investigated under three different motor power capacities (100, 150, 200 kW) and three different battery energy capacities (5, 10, 15 kWh) to study the impact of hybridization equipment sizes on fuel economy. Constant highway driving cycles with different terrain types in parallel with five real world highway driving cycles have been used to show the impact of looking-ahead control strategy on managing energy storage system and fuel economy improvement.

2. MODELING WORK FOR A DIRECT PARALLEL PRETRANSMISSION HEV

2.1 Powertrain controller strategy

The main component of parallel HEV is the electric motor, energy storage system, and controller. Figure (1) shows the schematic of pre transmission parallel HEV[23]. The control strategy for vehicle propulsion controller (VPC) is working basically on gathering all input parameters (driver acceleration demand, driver braking demand, maximum engine torque, SOC). The parallel pre transmission HEV configuration is considering the engine as main power source and the electric motor working as auxiliary power unit.

The default energy storage system SOC is sustained at 60% (target battery SOC)[24] and it will be charged if the SOC got below that threshold, otherwise, the VPC will use the power available above the threshold SOC. Electric motor can assist the engine when it reached the peak load as long as the battery SOC above the minimum SOC, which is 30% in this model. The electric motor can drive the vehicle alone and turn off the engine if the power demands less than the motor peak power (usually at low speed), and if there is enough energy in the ESS.

A conventional heavy duty vehicle was modeled and validated using Autonomie® software[24], and the main equipment sizes are listed in table (1). A hybrid electric heavy duty vehicle model was built using Autonomie software also. The parallel hybrid electric heavy duty vehicle configuration was chosen for this study. The hybridization depth varied from 100 kW electric motor size and 5 kWh battery pack energy to 200 kW electric motor sizes and 15 kWh battery energy pack. For this model the gross vehicle weight rate (GWVR) is 26000 kg which represents 50% full load. The assistance system (electric motor and the battery pack) weight about 500 kg and cost about $25,000 .

2.2 Looking-ahead VPC strategy to manage battery SOC

For this study the modification will be in the subsystem control strategy to calculate the engine torque demand. The original control strategy for engine torque calculation is basically working by inputting the parameters (wheel torque demand, wheel speed demand, SOC, accessories power, engine speed, and maximum engine torque). Figure (2) shows the subsystem schematic of the calculation sequence for engine torque demand[24].

In this work, the engine torque demand calculations for looking-ahead strategy (Intelligent Transportation System) is working basically by opening a time window in the future and calculate the power demand (figure 3), then based on that calculation the engine torque demand will be recalculated to manage the battery SOC in advance. The symbols **x** and **y** in the figure are referring to the beginning and ending of the looking ahead period. All over this work the future window period was chosen to be constant as 1 minute.

Figure (4) shows the diagram of looking-ahead subsystem schematic control strategy for direct parallel pre transmission HEV to manage battery SOC and calculate the new engine torque demand

2.3 Algorithm of suggested modification on vehicle propulsion controller

Following is the algorithm for looking ahead model to manage battery SOC and calculate the new engine torque demand.

1- Open a time window in the future (1 minute period) to calculate the average vehicle speed and the average road grade ahead.
2- Calculate the average current and ahead road grade.
3- Use road load equation to calculate the negative road grade when the vehicle starts using brake system as shown in equation 1.

$$P_t = \left(m\frac{dv}{dt} + \frac{1}{2}C_D\rho A v^2 + \mu\mathrm{mg} + \mathrm{mg}\sin(\theta)\right)v \quad \text{………………….. Equation 1}$$

Where P_t is the total power (W), m is the vehicle mass (kg), dv/dt is the vehicle speed change (acceleration/deceleration) (m/sec^2), C_D is the aerodynamic drag coefficient, ρ is the air density (kg/m^3), A is the vehicle frontal area (m^2), v is the vehicle speed (m/sec), μ is the rolling resistance coefficient, g is the gravitational acceleration (9.806 m/sec^2), and Θ is the road grade (radian).

Equation 2 assuming that the vehicle propulsion power demand become zero before start becoming negative, and it's assuming that the vehicle is using a cruise system to control the vehicle speed (i.e. the acceleration or deceleration =0), i.e.:P_t =0 and $\frac{dv}{dt}$ =0.

To calculate negative road grade (radian) ahead, which will make driver using brake, with considering the forthcoming vehicle speed and massas variables, the equation will be as following.

$$\theta = sin^{-1}\left(\left(-\frac{1}{2}C_D\rho A v^3 - \mu\mathrm{mg}v\right)/(mgv)\right) \quad \text{…………………………Equation 2}$$

4- If the road grade ahead is less than calculated negative road grade equation 2, then open a dynamic window to calculate the entire expected power ahead and manage the battery SOC to guarantee enough battery capacity to capture upcoming free energy (from using brake system) as much as possible.
5- If the grade ahead is greater than zero, then calculate the power needed to go uphill. If the power demand to go uphill will surpass engine peak power, then open a dynamic window

to calculate the entire power demand and charge the battery as same as energy demand ahead if the battery has no enough energy for that energy demand ahead.

6- For both charging or discharging status, if the equipment has no power to respond, then the controller will make them working at maximum possible working zone considering all limitations to simulate the vehicle performance in real live as Autonomie software is doing.
7- This procedure is keep repeating every second during the trip to manage battery SOC in advance.
8- The engine power management is going to work on guaranteeing that the power from the engine and the battery together will be adequate for next event as much as possible.
9- The communication between infrastructures to vehicle (I2V) assumed to be continuous like GPS is doing and the information will be updating regularly.

2.4 Impact of suggested looking-ahead strategy on battery capacity effectiveness

Looking-ahead VPC strategy or Intelligent Transportation System (ITS) can improve the energy storage effectiveness by guaranteeing as much as possible energy to assist the powertrain system when the vehicle going uphill terrain. On the other hand, looking-ahead VPC strategy can guarantee capacity to capture as much as possible of the expected energy coming from using brake system. For example, the 5kWh energy storage system (ESS) with looking-ahead strategy can work almost as same as 10 kWh ESS without looking-ahead control strategy.

The battery used in this work is NiMH (nickel metal hydride) battery type, with default SOC safety limits 90% maximum and 30% minimum [25]. So, the typical energy capacity available of the battery is about 60% of the battery size. Figure (5) shows the capacity available for charging/discharging for both (with looking-ahead and without looking-ahead) control strategies. For proposed strategy, the VPC will discharge the battery down till 35% if there is expected energy capturing ahead. Besides, the VPC will charge the battery up till 85% if there is expected extra power demand due to ascending a hill.

2.4.1 Calculation of time needed for charging/discharging electric storage system

To specify the time window needed for charging or discharging energy storage system, an equation has been formulated based on the equipment capacity design.Where, the rough estimation of charging and discharging efficiency could be assumed as 80% for the electric motor and 95% for the battery pack. On the other hand, during simulation the equipment efficiency will be calculated more accurately based on their efficiency maps using Autonomie software[26]. The maximum effective capacity of the battery pack to be charged or discharged represents about 55% of the battery pack size. Since the battery cannot be discharged below the safety limit, which is 30%, and cannot accede 90%[27]. The time needed for charging or discharging energy storage system is calculated using equation 3.

$$\boldsymbol{Time}_{(\boldsymbol{minutes\ for\ charge\ or\ discharge})} = \frac{\mathbf{60*0.55*}\boldsymbol{Battery\ size}\ \mathbf{/0.95}}{\boldsymbol{motor\ power}\mathbf{*0.8}} \quad \text{......................equation 3}$$

Where the battery size and motor power used in this work are given in table 1.

2.5 Driving cycles used in this study

2.5.1 Constant speed driving cycles

The vehicle activity and terrain type may represent the crucial factors affecting on improving fuel economy when using hybrid vehicle instead of conventional vehicle. Constant speed highway driving cycles with different ascending/descending hill have been used to investigate the looking-ahead impact on fuel economy improvement. Figure(6 a-d) shows the constant speed driving cycles with different terrain types. Ascending/descending hill terrain types have been generated using Matlab® software. Where the up-downhill terrains (figures 6 a-c) are simulating a 3% road grade. Different road grades (0.5, 2, and 3%) (figure 9) have been generated to analyze the sensitivity of looking-ahead control strategy regarding forthcoming vehicle power demand.

2.5.2 Real world driving cycles

In addition to the basic driving cycles presented in this study, real world driving cycles have been used to evaluate the impact of looking-ahead control strategy on fuel economy improvement. Five routes have been selected for studying. These routes may represent the most possible different driving patterns with different road grades starting from flat terrain to uphill or downhill terrain. The data source, which is used in this study,for real world measurements achieved by PEMS and WVU MEMS units[28].

The real world driving cycles used in this work have been taken from two different routes which can be summarized as the following:-

- Columbus, OH to Indianapolis, IN (Clmbs2Ind) route: This route represented a highway and flat terrain journey on I-70 for about 170 miles.
- Las Vegas, NV to Halloran Summit Road, Nipton, CA (Las2Hall) route: This route represented uphill driving on highway I-15 journey for about 70 miles.
- Halloran Summit Road, Nipton, CA to Barstow, CA (Hall2Bar) route: This route represented downhill driving on highway I-15 journey for about 80 miles.
- Sabraton, WV to Bruceton Mills, WV (Sab2BM): The route created at the West Virginia University Sabraton facility near to the entrance ramp on I-68 east, and nonstop on I-68 where a climb of a constant 5% grade existed, tailed by transient road grades to the reversal point at Bruceton Mills, WV
- Bruceton Mills, WV to Sabraton, WV: (BM2Sab): This cycle represent the going back home as reversing of Sab2BM driving cycles.

These real world driving cycles are presented in figure (7 a-e)[28].

Matlab software has been used to calculate the real world driving cycles characteristics in order to illuminate the working conditions of different terrain types(Table 2). The 1% and -2% road grade have been selected because the driver between these values does not need to depress gas pedal or hit brake to maintain vehicle speed as shown in previous study [13].

This work is based on high resolution for the forthcoming traffic information which means that the vehicle speed and road grade ahead were pretty precise.

3. SIMULATION RESULTS AND DISCUSSION

3.1 Standard cycles

The eventual goal of this work was learning the impact of terrain types on fuel economy of parallel heavy duty HEV. Different up-downhill terrains were used to study that impact. All terrain types were with constant highway speed to mimic the highway way terrain.

3.1.1Energy storage system management

The battery SOC management may represent an important reflection on the proposed looking-ahead strategy effectiveness. The best way to show impact of looking-ahead strategy on the powertrain system is by using constant speed driving cycles with different terrain types (figures 6 a-d) and understands how the vehicle propulsion controller (VPC) will behave. The VPC strategy is working basically by opening a time window ahead for 1 minute period and detects the traffic conditions regarding vehicle speed and road elevation ahead.

Figures (8-11) reveal the VPC managing for the energy storage system with and without looking-ahead strategy (ITS) for a 150kW and 10kWh electric motor and battery pack energy respectively.

Figure (8) (constant speed -uphill) presents the looking-ahead VPC management for the battery SOC in advance to prepare the system for forthcoming addition power demand. It can be noticed that at the beginning of the trip the VPC depleted the battery SOC and that because of the electric mode at low speed is better than conventional mode[13]. The VPC charged the battery as much as possible to prepare enough power when the vehicle ascending hill. Whereas, the VPC without looking-ahead strategy kept the battery SOC at the default threshold (60%) and hence there was no enough auxiliary power during ascending all the hill. Figure (9) shows how the VPC guaranteed as much as possible capacity to capture the forthcoming free energy from using brake system while descending hill by depleting the battery SOC. However, the default VPC maintained the battery SOC at 60% which led to full the battery early and losing the opportunity of capturing more free energy.

It can be shown from figure (10) which represents the behave of VPC when vehicle going down-uphill terrain that it is guaranteed enough power or enough capacity for upcoming events which can be contributed to the maintaining battery SOC within the safety limits. The VPC looking-ahead strategy doesn't charge/discharge the battery system unless there was a need for that action (to avoid charging/discharging efficiencies losses).

The looking-ahead strategy has shown a strong trend in managing auxiliary power source. In other words, the looking-ahead VPC sustained the battery SOC around 75% (after finishing descending hill) and didn't charge it to the maximum battery SOC because there was no need for that. In contradiction of that, the default VPC depleted the battery SOC after finishing descending hill to reach the 60% (default SOC) without real need for that auxiliary power.

Figure (11) shows the response of VPC when the vehicle forthcoming traffic is going small ascending/descending hill. It can be shown from this figure that the looking-ahead power demand calculation is accurate enough in detecting the upcoming power demand and take action based on that estimation. Where, at ascending/descending hills with 0.5% and 2% road grade, powertrain didn't need an extra power from the auxiliary power system and the driver didn't need to hit the brake pedal to compromise the vehicle speed, which elucidates why the VPC has done no action. Furthermore, increasing road grade to 3% ascending/descending hill, boosted the VPC to takea proper action (didn't charge too much or depleted too much also) based on that demand

3.1.2 Fuel economy change at standard driving cycles

The fuel economy has been calculated using Autonomie® software for different terrain types, and three different vehicles features (conventional, parallel HEV without ITS, and parallel HEV with ITS)

The equation used to calculate the percentage change of fuel economy is as following:

$$\boldsymbol{Percentage\ change} = \frac{\boldsymbol{FE_{ITS} - FE_{NoITS}}}{\boldsymbol{FE_{NoITS}}} * \mathbf{100} \qquad \text{…….. Equation 4}$$

$$\boldsymbol{Percentage\ change} = \frac{\boldsymbol{FE_{NoITS} - FE_{conv}}}{\boldsymbol{FE_{conv}}} * \mathbf{100} \qquad \text{… . Equation 5}$$

$$\boldsymbol{Percentage\ change} = \frac{\boldsymbol{FE_{ITS} - FE_{conv}}}{\boldsymbol{FE_{conv}}} * \mathbf{100} \qquad \text{.. Equation 6}$$

Where FE_{ITS} is the fuel economy for different vehicles configurations with looking-ahead strategy, FE_{NoITS} is the fuel economy for different vehicle configuration models without looking-ahead strategy, and FE_{conv} is for conventional vehicle configuration.

One of the most important factors when implementing a comparison between different vehicle configurations (conventional vehicle, conventional parallel HEV, and looking-ahead parallel HEV models) is the fuel economy improvement.

Figure (12) shows the fuel economy change for a parallel HEV (without looking-ahead) and conventional vehicle model at 50% full load and different terrain types with constant highway speed driving cycles. The results revealed that the fuel economy change was positive on descending hill terrain. However, the fuel economy change for ascending hill was negative, which could be explained by the extra power needed from the auxiliary power system (battery pack). Moreover the parallel HEV model was able to maintain adequate power more than conventional model while ascending hill [6].

Figure (13 and 14) represent the fuel economy change for parallel HEV with looking-ahead strategy and conventional vehicle model, and parallel HEV with and without looking–ahead respectively. It can be seen from this figure that there is no change in the trend of ascending hill terrain between parallel HEV with and without looking-ahead when comparing both of them with conventional vehicle model. On the other hand, in the case of parallel with looking-ahead configuration it has been shown that the auxiliary power doubled as mentioned in the explanation of figure (5).

Figure (14) proves that the fuel economy improvement with looking-ahead control strategy is better for the downhill, down-uphill, and different road grade terrain types. This fuel economy improvement could be elucidated for the auxiliary power system which is prepared as much as possible to capture the free energy using brake system at descending hill. The most fuel economy improvement is detected on the long downhill terrain, and that due to the amount of free available energy.

Depth of hybridization (100kW-5kWh, 150kW-10kWh, and 200kW-15kWh) had different impact on fuel economy change. HEV-3 had the better fuel economy change at downhill terrain type. However, the fuel economy change was limited for HEV-3 at the rest of terrains. Finally figures (13 through 15) reveal that a big hybridization equipment energy sizes can limit the impact of looking-ahead strategy unless there is a long descending hill terrain.

3.2 Fuel economy change for real world driving cycles

Figure (15) shows the fuel economy change for the five different real world driving cycles (which are previously presented in table 2 and figure 7a-7e) with looking-ahead and without looking-ahead strategy. The results have shown that the fuel economy for looking-ahead control strategy can be improved up till 3% comparing to the same parallel HEV model without looking-ahead strategy. Nonetheless, the looking-ahead control strategy beneficial regarding fuel economy improvement was limited on Las2Hall route, and that was predictable due to the ascending hill for the most trip period. The parallel HEV with small hybridization equipment (HEV-1) has shown more sensitivity for looking-ahead strategy during descending hills, and that is due to limited capacity of ESS comparing to the other HEVs.

On the other hand, using the parallel HEV model with big equipment size (HEV-3) has shown limited fuel economy improvement, and hence lower fuel economy change in most real world cycles. This limitation in fuel economy change in the case of big equipment size (HEV-3) is elucidated to the ESS capacity size, where, the battery will be capable to capture upcoming free energy using brake system even without managing the ESS in advance (i.e. with default battery SOC). Furthermore, this tendency in looking-ahead control strategy (downsizing equipment with maintaining as same as fuel economy benefits and total powertrain power) will open the doors widely into reduce the engine size and redesign the powertrain power while maintaining adequate power.

4. CONCLUSIONS

In this work, a parallel direct pre transmission hybrid electric vehicle configuration with and without looking ahead strategy has been investigated under different equipment sizes to study the impact of hybridization equipment sizes on fuel economy. The results revealed that, looking-ahead control strategy for heavy duty parallel HEV can contribute significantly in preparing the system for forthcoming traffic condition regarding vehicle speed and road elevation. The other specific findings of the study can be summarized as follows:

- The results of constant highway driving cycle with different terrain types have revealed a proper response between the proposed algorithm and the forthcoming power demand.
- The looking-ahead strategy has shown a strong trend in managing auxiliary power source. In other words, the looking-ahead VPC switches between sustaining and depleting battery SOC strategy based on the forthcoming traffic conditions.
- For the parallel hybrid electric vehicle with 50%load, the fuel economy change with

looking-ahead control strategy has been improved from 0.5 to3% for different terrain types comparing to the same parallel HEV model without looking-ahead strategy.

- Reducing the equipment size has improved the looking-ahead strategy impact on fuel economy change from less than 0.2% to 3% for HEV_1 and HEV_3 respectively on the same terrain type (BM2Sab).
- Looking-ahead strategy has shown strong potential in downsizing equipment (both engine and ESS) while maintaining adequate power and improved fuel economy.

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Table (1): Conventional and hybrid truck model equipment sizes.

	Conventional	HEV-1	HEV-2	HEV-3
Engine Power (kW)	410	410	410	410
GVWR 50%load (kg)	26,000	26,400	26,500	26,600
Final Drive (ratio)	3.55:1	3.55:1	3.55:1	3.55:1
Tires (m radius)	305/70/R22.5	305/70/R22.5	305/70/R22.5	305/70/R22.5
Motor (kW)	--	100	150	200
Battery Energy (kWh)	--	5	10	15
Battery Power (kW)	---	100	150	200
Transmission	10 speed (14.8-1)	10 speed (14.8-1)	10 speed (14.8-1)	10 speed (14.8-1)
Mechanical Acc. (kW)	5.2	1	1	1
Elec. Acc. (kW)	0.3	3	3	3

Table (2): Characteristics of real world conditions cycles.

		Ave Speed	*Max Speed*	*Grade >1%*	*Grade<-2%*	*Distance*	*Duration*	*Time stop*
		mph	mph	%	%	mile	hour	%
1	Clmbs2Ind	61.21	70.17	6.80	1.17	170.61	2.78	0.25
2	Las2Hall	57.94	70.53	25.17	5.54	81.69	1.41	0.49
3	Hall2Bar	53.96	65.9	20.20	27.82	72.58	1.34	0.53
4	BM2Sab	31.08	70.32	30.9	35.66	20.29	0.65	10
5	Sab2BM	33.02	71.71	42.52	25.20	20.66	0.62	15.75

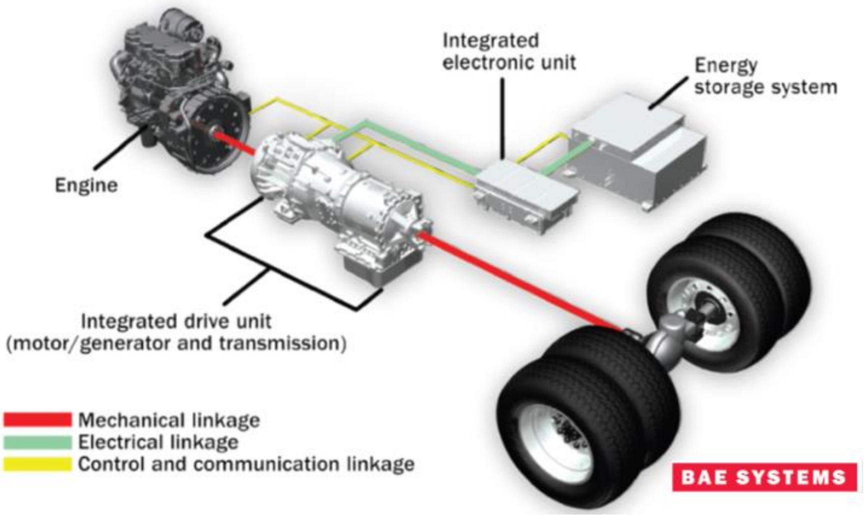

Figure 1: Schematic of pre transmission parallel HEV

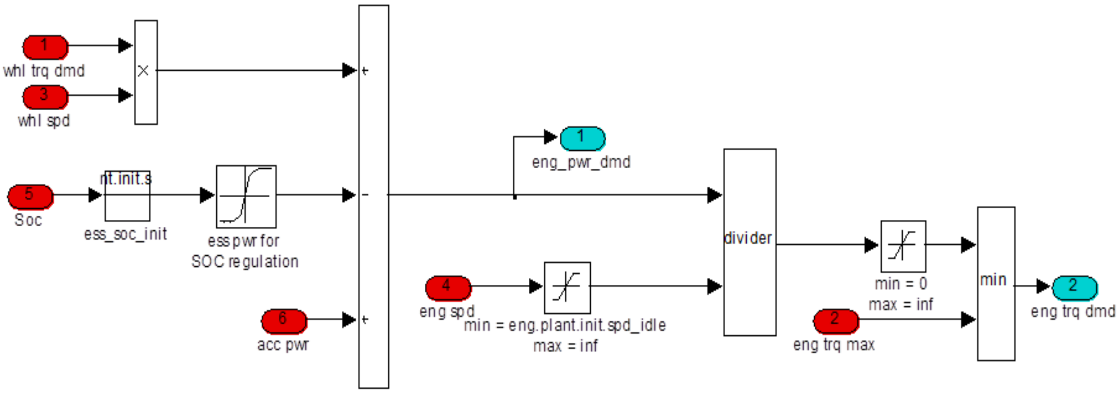

Figure 2: Simulink diagram of engine torque calculation sequence

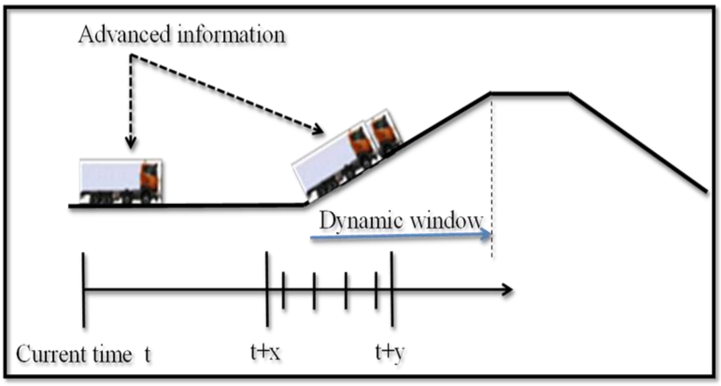

Figure 3: Scheme of looking-ahead strategy for forthcoming traffic conditions.

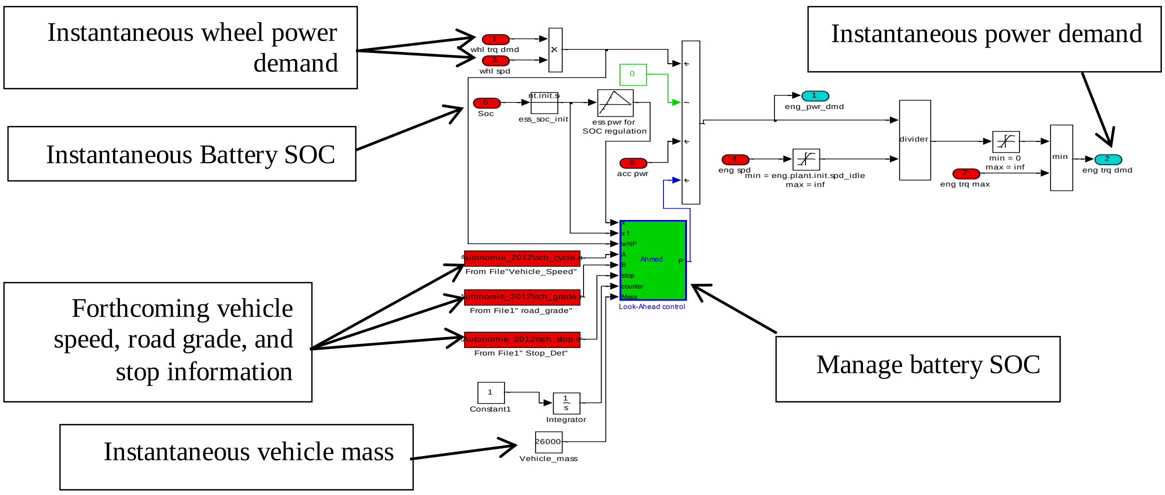

Figure 4: Simulink diagram of new engine torque calculation sequence

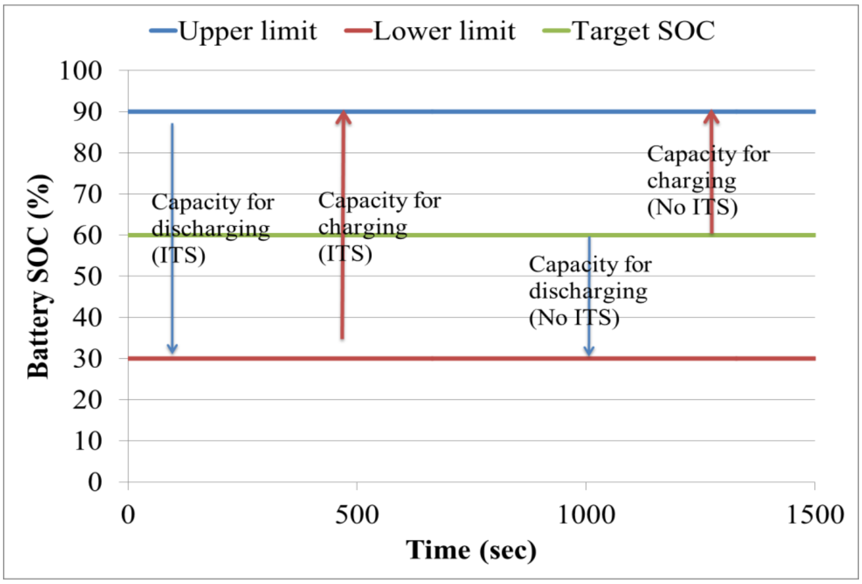

Figure 5: The battery capacity for charging and discharging with and without looking-ahead strategy

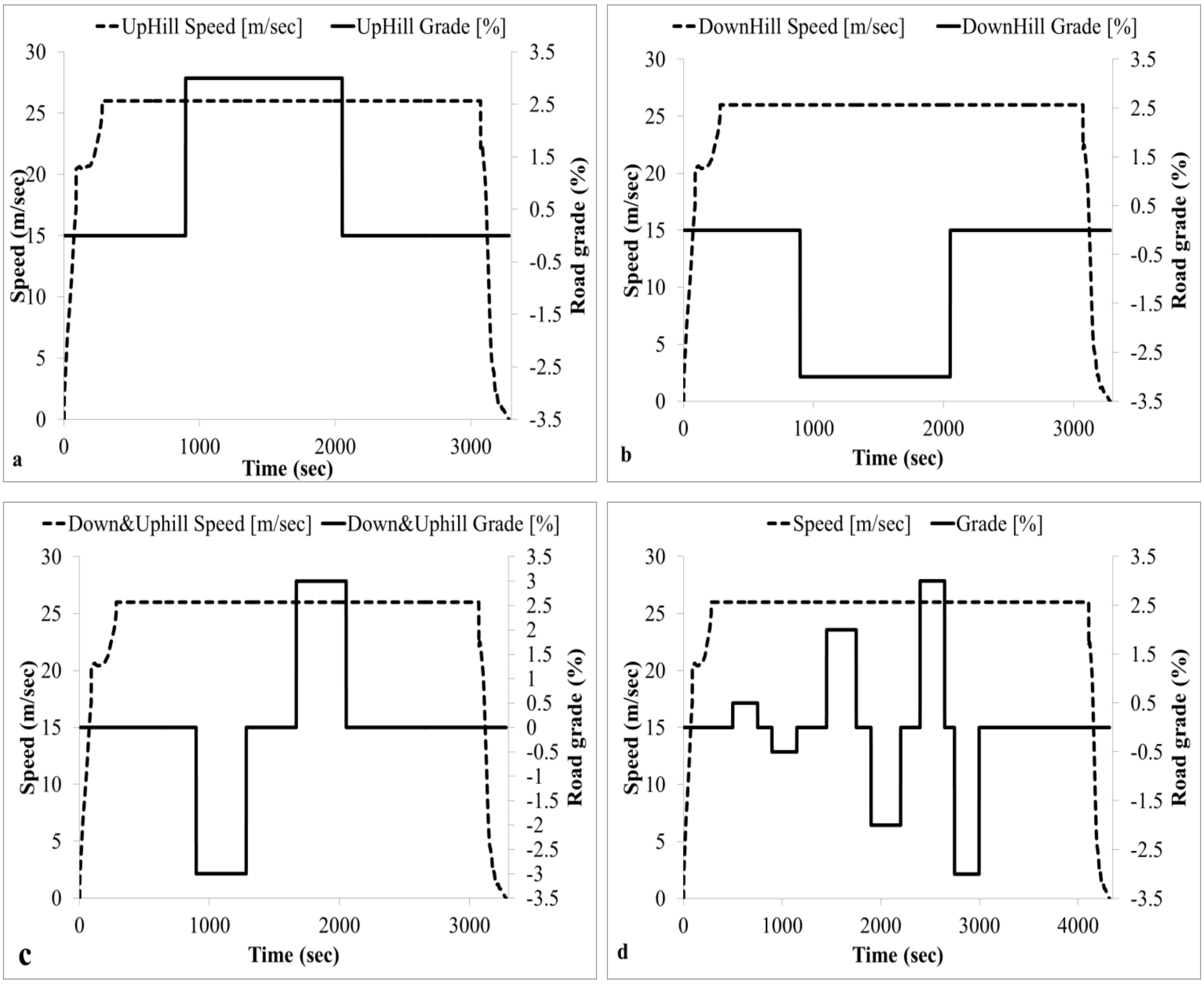

Figure 6 : constant speed driving cycles with diffirent terain types

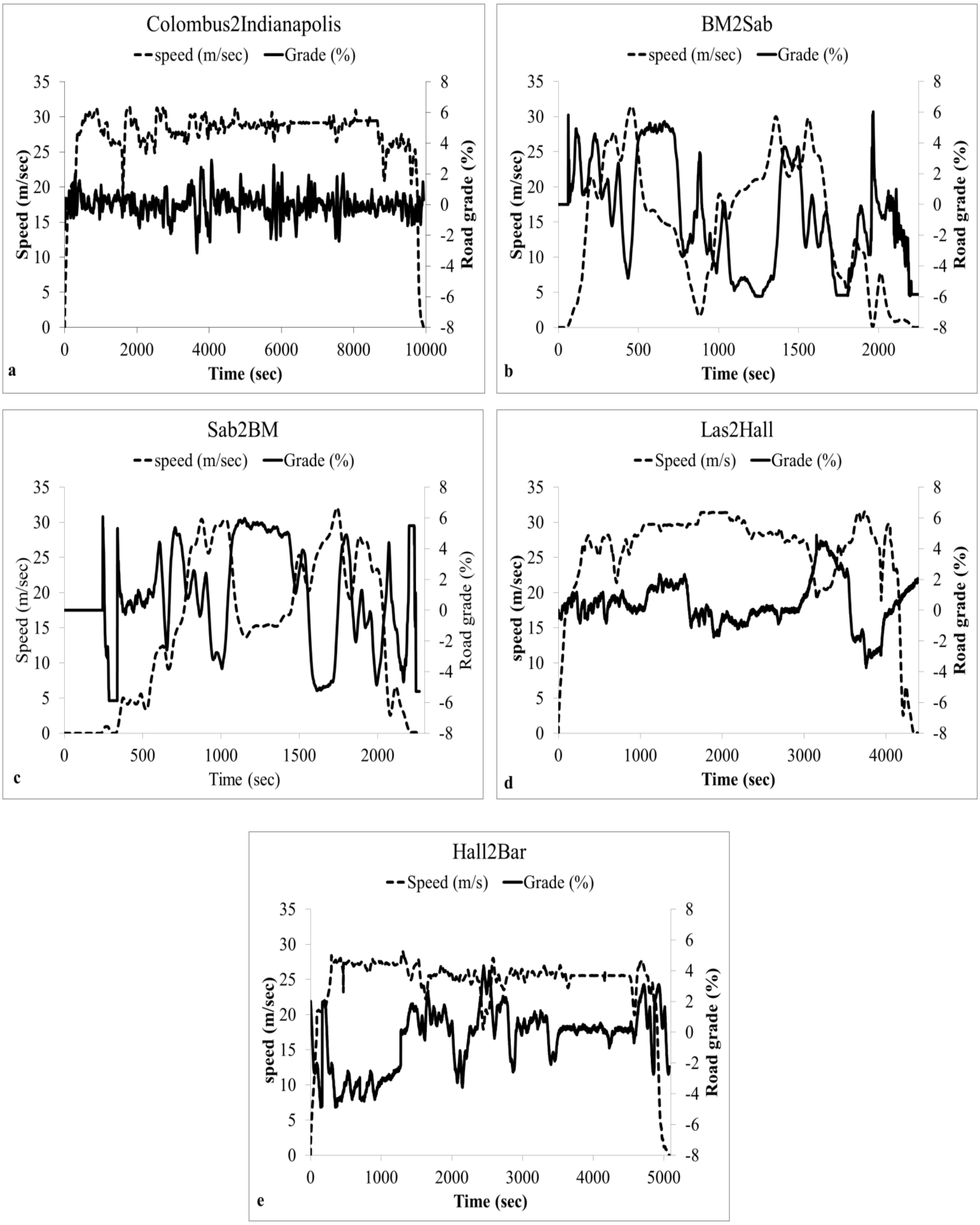

Figure 7: different real world driving cycles

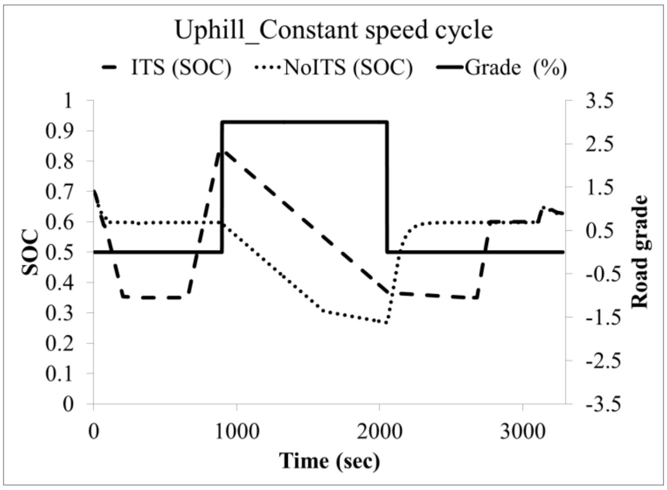

Figure 8: looking-ahead strtategy performance over ascending hill driving cycle

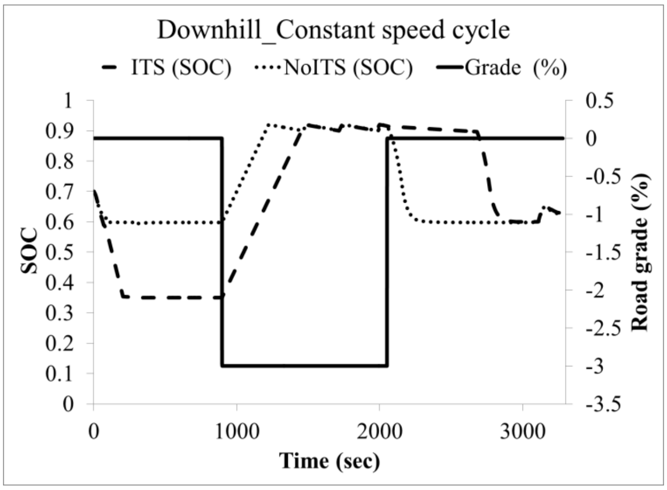

Figure 9: looking-ahead strtategy performance over ascending hill driving cycle

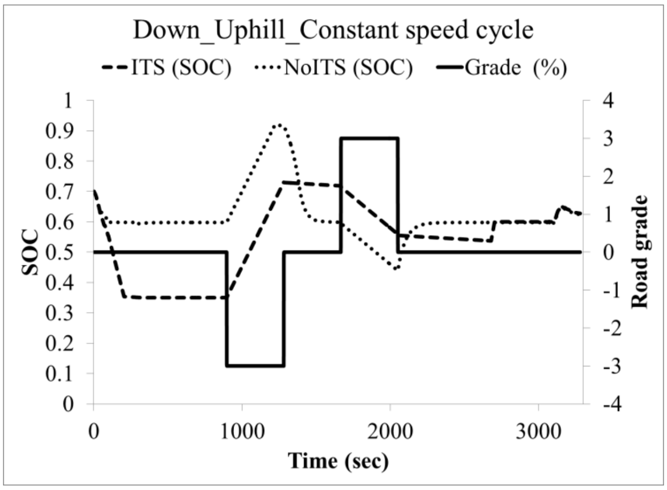

Figure 10: looking-ahead strtategy performance over descending/ascending hill driving cycle

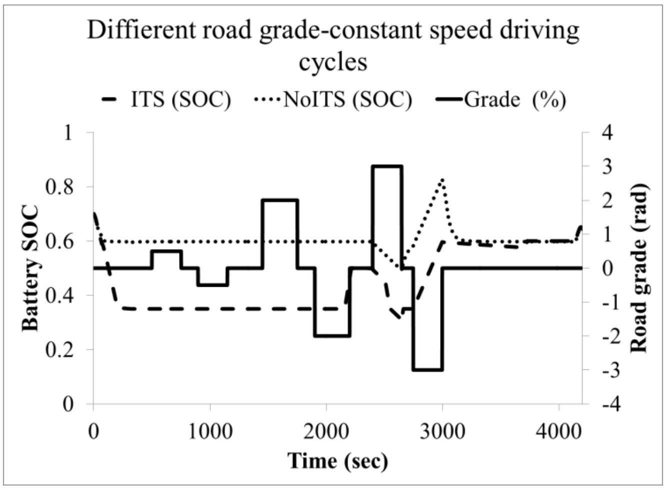

Figure 11: looking-ahead strtategy performance over descending hill driving cycle

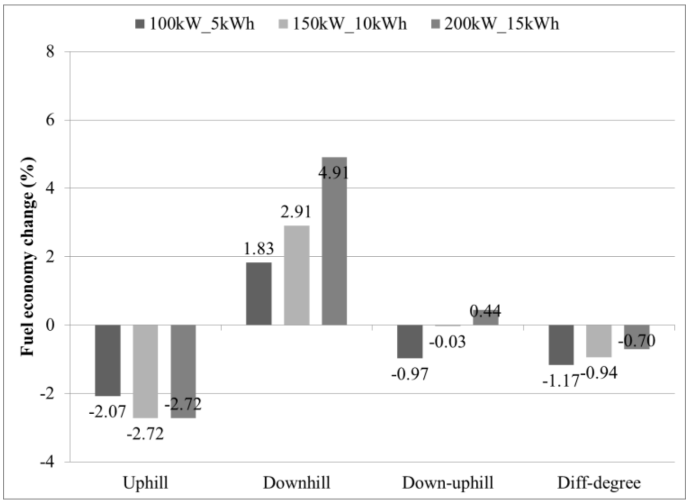

Figure 12: looking-ahead strtategy performance over descending/ascending hill driving cycle

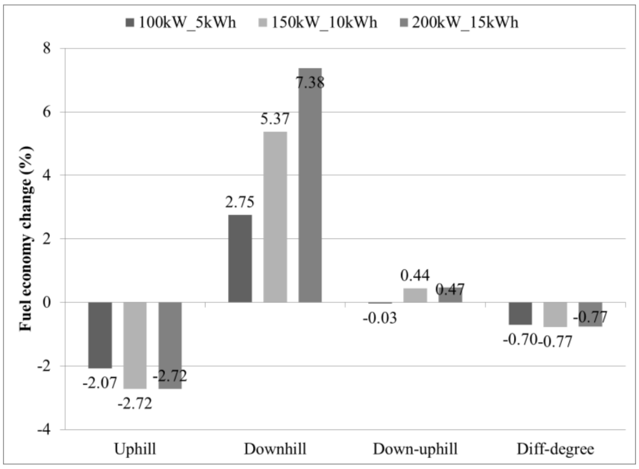

Figure 13: looking-ahead strtategy performance over ascending/descending hill driving cycle

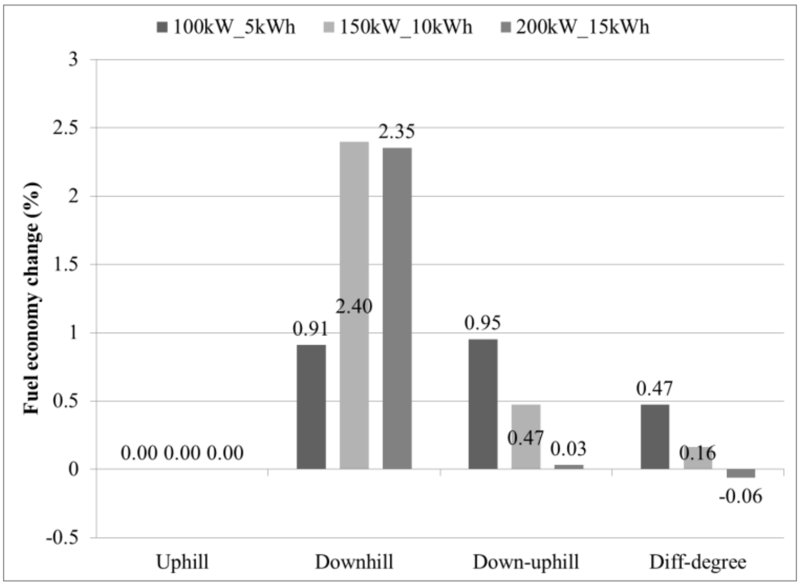

Figure 14: fuel economy change for parallel HEV comparing to conventional vehicle models

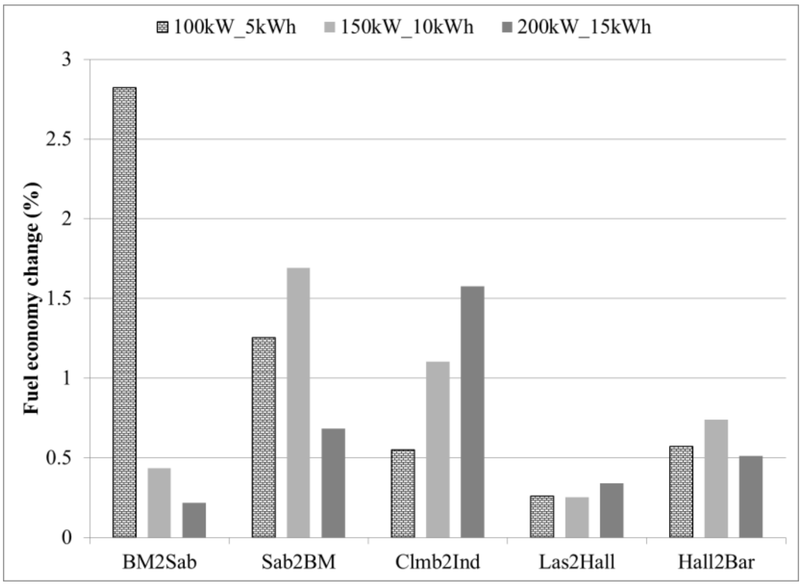

Figure 15: fuel economy change for parallel HEV (with looking-ahead control staretegy) comparing to conventional vehicle models