Converting an electric all-terrain vehicle into a hybrid vehicle with range extender

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Abstract. In this paper a full electric all-terrain vehicle (ATV) owned by the automotive laboratory of Universiti Teknologi Malaysia is converted into a series hybrid electric vehicle (HEV) with a range extender. Before the transformation, it is required to predetermine the amount of power that should be used to extend the autonomy of the battery. Experiments are conducted to define the vehicle parameters and characteristics for the development of the simulation model. By using the developed model, simulations are conducted by considering NEDC cycle for a work-commuter who wants to use a vehicle 5 hours per week (30 min one way) without having to charge the battery. It is assumed that the battery is charged at the beginning of the week and must not be discharged under 0.2 state of charge (SOC) for safety reasons. Two control strategies are considered to obtain this objective; the always on engine and the delayed use of the engine. After simulation both controls use the same amount of fuel. As conclusion, the addition of the engine is proven to be effective in prolonging the distance range of the vehicle.

1. Introduction
Fossil fuel shortage problem and environmental issues linked to automotive emissions required us to urgently develop the use of alternative powertrain. One of the promising powertrain is the hybrid electric vehicles (HEVs). The renewable energy used in such powertrain has the potential to meet the vast majority of our energy needs and to minimize air pollution [1]. HEVs release less greenhouse gases and are a good alternative choice over classic powertrain architecture regarding the fuel efficiency and other environmental benefits [2], [3]. An all-electric mode of HEV can reach an energy efficiency around 90% and it has many benefits for both the economy and the environment [4], [5], [6]. However, HEVs operating modes depend on its power sources capacities and suitable mode can be determined through simulations [7], [8], [9].

Lithium ion battery is considered to be the best power sources in hybrid electric vehicles (HEVs) application because of its higher energy density, power density and it has no memory effect compared to other type of batteries [10]. Lithium ion battery offers fast acceleration and charging capability, lucrative features such as lightweight and long driving range that makes them very suitable for HEVs.
application [11]. This work aims at assisting transformations of an ATV into a real hybrid car, by providing justifications on why the initial battery must be changed and the determination of the capacity of the engine capacity as range extender by considering the minimum amount of power required by the generator. The objective of this transformation is to attain five hours autonomy by following the New European Driving Cycle (NEDC). Simulation model of the vehicle is developed based on data obtained from experiment and the vehicle parameters. Then, modifications will be tested through simulation to determine efficient power rate so that SOC will not drop below 0.2 after 5 hours utilization. Results will be compared to analyze the compatibility of the system before conclusion and further suggestion can be made.

2. Simulation of all-terrain vehicle

The all-terrain vehicle is originally an all-electric vehicle. In this study the original battery of capacity 40 Ah with 24 cells as shown in figure 1 is used. The ATV is modeled into a hybrid vehicle by adding an internal combustion engine (ICE) which will provide energy to the battery and recharge it to extend the autonomy. It is done to know how much power the ICE should provide so that the SOC will sustain and only drop to 20% charge after 5 hours. The ICE power should be as low as possible in order to limit fuel consumption. Therefore, two simulations are ran; one where the ICE is always on all the time, and the second one where the ICE is used when the SOC reach less than 60% (half of the capacity) and then the ICE will be off as soon as the SOC reach 90%.

![Figure 1. The original battery pack of the ATV before hybridization with a capacity 40 Ah.](image)

2.1. Simulation set-up

The simulation is conducted for a work-commuter to use this vehicle 5 hours per week (30 min one way) without having to charge its battery. It is assumed that the battery is charged at the beginning of the week and must not be discharged under SOC 0.2 for safety reasons.

2.2. Performances of the battery pre-hybridization

In order to understand why it is worth trying to modify the structure of the ATV, several simulations are run and the SOC of the battery are analyzed. The battery used is a Lithium ion battery made of cells (Type: 205110135) that have a typical capacity of 10 Ah. The maximum allowed current is 100 A during discharge and 50 A during recharge. Each cell has a weight of 1.17 kg and a nominal voltage of 3.7 V. The choice of this type of cell is based on the consideration that the cell’s specifications are suitable to be used in both electric vehicles (EVs) and hybrid electric vehicles (HEVs). The electric motor is
powered by two batteries set in parallel. Figure 1 shows how the manufacturer has connected the cells: two cells of 10 Ah are set in parallel and then put in series with 23 other groups of two cells. So, each battery has a capacity of 20 Ah and a nominal voltage of 87 V. The parallel association of these batteries is equivalent to 40 Ah, 87 V of nominal voltage, composed by 24 cells in series. Figure 2 shows the model of the electric vehicle in Matlab Simulink. It is considered that the block motor-generator is a unitary gain. The driving cycle used is the NEDC. Figure 3 presents the evolution of the state of charge (SOC) after three cycles of simulation.

The results reveal that in 1hr 4mins the SOC has reached its limit value of 0.2 which is far under the expected performance of 5 hours. Therefore, it is decided to:

i. Change the battery output voltage by adding new cells

ii. Change the vehicle architecture into a hybrid car

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**Figure 2.** Model of the electric vehicle in Matlab/Simulink.

**Figure 3.** State of charge of the battery versus time for three NEDC cycles.
2.3. Change the battery output voltage by adding new cells

To augment the autonomy, the output voltage is increased by adding new cells in the model based on principle that:

\[
\text{Energy stored} = \text{Capacity} \times \text{Mean Voltage}\]

So, the simulation are ran and recorded several times by increasing each time the number of cells 40 Ah until it reach the 5 hours autonomy. Figure 4 represents the autonomy of the battery pack in function of the number of cells. As a deduction from the graph, 164 cells would be needed to attain the stated objectives of 5 hours (18000 s). In the previous setup the results are recorded after changing the number of cells. But, to multiply the number of initial cells is not the best option and it is more efficient to use cells with higher capacity. However, considering the existing electric vehicles on the market like Tesla Model S and Renault Zoé, it appears that our objective of attaining 5 hours of autonomy by following the NEDC is not ambitious. These two brands display in average 400 km of autonomy with the NEDC, which represents around twelve hours of full autonomy.

![Figure 4. Autonomy of battery in function of number of battery cells.](image)

![Figure 5. Model of the hybrid electric vehicle with ICE as the range extender.](image)
2.4. Change of the structure into a hybrid car

The ATV is modeled into a hybrid vehicle by adding an internal combustion engine (ICE) which will provide energy to the battery and will recharge it, in order to extend the autonomy. The model is as shown in figure 5. In this study the original battery (40 Ah, 24 cells) is used. It is to know the amount of ICE power to provide so that SOC reach 0.2 after 5 hours utilization. That power should be as low as possible in order to limit fuel consumption. Therefore, two simulations are conducted; one where the ICE is always on and the second one is where the ICE is used only when the SOC < 60% (half of the capacity) and stopped as soon as SOC reach 90%. The results are as shown in figure 6, 7, and 8.

2.4.1. ICE always on. Under this strategy, ICE will supply constant power whenever the vehicle started will only stop giving power if the battery reaches 0.9 SOC. In reality, there will be ICE transient state for every start-up with higher fuel consumption, but it is assumed this state to be brief and small compared to the totality of the cycle, so it can be ignored for this simulation. Figure 6 shows the SOC evolution for different ICE power and it can be seen that the ICE power has to be raised until 1920 W to make sure it is enough to extend the autonomy until 5 hours utilisation. The power supplied is below 2 kW and this corresponds to 0.7 litre/100km fuel consumption.

![Battery SOC evolution if ICE always on.](image)

2.4.2. ICE on when SOC under 60%. In this simulation, the SOC is initially 0.9 and the engine is kept off until SOC drop to 0.6, the engine will be on and is kept this way until the SOC increase to 0.9. However, figure 7 shows depleting trend of SOC for all three ICE power values with ICE supplied power of 2180 W will make sure the SOC will not go below 0.2. Based on the simulation, 2172 W power provided by ICE is enough to extend the autonomy to 5 hours with the same fuel consumption of 0.7 litre/100km. This proves that the battery spent and recovered the same amount of energy for the same final SOC of 0.2 for both cases.
3. Analysis and discussion

In both cases, it can be clearly seen the decreasing tendency of the SOC and this means that the battery spends more energy than it saves. Also, it is realized that a permanent use of the ICE whenever the SOC < 0.9 is less power-consuming than a delayed use of ICE power to recharge it if only SOC < 0.6. But then, it turns out the fuel consumption is the same for both cases. Table 1 shows the results comparison between before and after the modification, and a hybrid system with ICE as range extender. The autonomy and distance for the latter cases are significantly increased five times than the original battery capacity. These results are relevant because they clearly revealed the role of the ICE as range extender from only 31.46 km to 160.7 km for the new hybrid architecture.

Figure 7. Battery SOC evolution if ICE is on when only SOC reach below 0.6.

Figure 8 shows the simulation where the SOC remain constant between 0.5 and 0.6 with ICE power supplied of 2430 W, which means that the battery has spent and saved the same amount of energy throughout one cycle of NEDC. It is the method that widely used for a series hybrid electric vehicle. In a more advanced control strategy, the ICE generates a varied power rate depending on the power demand, vehicle velocity, or the remaining distance which are tested offline with the global optimal energy management using dynamic programming. This can be done once all the exact parameter of this system is determined, but for the moment, this part of research analysis has to be completed first.

Figure 8. Battery SOC evolution if ICE generates 2430 W for the system.
Through simulations, optimum power rate can be determined for different architecture and operating modes of the system. In real application, the system will not only has to go through one type of driving cycles or driving styles but it can be million possibilities. By using this model, driving cycles and driving styles can be simulated and analyzed so that an efficient energy management can be obtained for this system.

| Parameters                          | Electric Vehicle Battery (Initial) | Electric Vehicle Battery (Modified) | Hybrid Electric Vehicle |
|-------------------------------------|-----------------------------------|-----------------------------------|------------------------|
| Number of cells of 40Ah             | 24                                | 164                               | 24                     |
| Autonomy                            | 1 hour                            | 5 hours                           | 5 hours 2 min          |
| Distance reach (km)                 | 31.46                             | 160                               | 160.7                  |

**4. Conclusion**

As a conclusion, in both case it can be clearly seen the decreasing tendency of the SOC, which means that the battery spends more energy than it saves. It is realized that a permanent use of the ICE whenever the SOC drop to 0.9 is less power consuming than a delayed use of ICE power to recharge if only SOC has drop below 0.6. The distance that can be reached by the HEV is longer with 160.7 km compared to 31.46 km of the original architecture, thus clearly revealed the role of the ICE as range extender. In this preliminary research, only two control strategies are tested to determine the suitable battery capacity of the all-terrain vehicle. In the future, more researches have to be conducted to determine the efficient engine and optimal energy management for this hybrid vehicle.

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