DYNAMIC SIMULATION MODEL OF A HYBRID ELECTRIC ATV

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ABSTRACT

Electric vehicles have disadvantages of limited capacity of the battery, and this influence the mileage range it can covered. A hybrid electric All-Terrain-Vehicle (HEATV) equipped with gasoline-powered engine and electric generator can extend the range covered by an electric ATV. In order to determine the effectiveness of the hybrid configuration, a dynamic simulation model is developed by using Energetic Macroscopic Representation Method (EMR) to analyse the performance of the ATV. The EMR method involve the causal ordering graph and action-reaction principle together with Inversion-based Control to develop a control structure of the HEATV. The simulation test was run on the original and modifications of the ATV where the original one only depends on electric motor (EM) and battery to drive the vehicle whereas the modified vehicle include the internal combustion engine (ICE) and electric generator for charging process. The simulation results of the original ATV show the decreasing trend in terms of battery state-of-charge. However, after modifications of the simulation model, the battery state-of-charge show an increasing trend and thus, extend the range of mileage covered by the ATV.

KEYWORDS

ATV, Battery, EMR Method, Hybrid Electric, State-Of-Charge

INTRODUCTION

The application of battery in electric vehicles has its own disadvantages which can influence the critical performance of the vehicles due to its limited capacity that play a major role in the range of mileage covered. In a conventional car, a vehicle can move in range of 538 km by using 35 litres gasoline instead of battery-powered car that can only move in an average range of 160 km for a single full battery charge [1]. Besides that, the surrounding temperature can also affect electric vehicle performances, where the energy delivered by Lithium-ion battery is drastically reduced at lower temperature [2]. The limited range of mileage has made the electric vehicle only usable in urban and residencies as both can provide the charging stations. The application of electric ATV especially by off-road use is less practical when no charging station is available [2].

Hence, a hybrid electric ATV is a best solution as the addition of a gasoline-powered engine and an electric generator can extend the range covered by an electric ATV. In order to determine the effectiveness of the hybrid configuration, a dynamic simulation model is developed to analyse the performance of the ATV in terms of battery state-of-charge and fuel consumption based on New European Driving Cycle (NEDC) standard by using Energetic Macroscopic Representation (EMR) method by using different sets of parameters.

The main problem with Hybrid Electric Vehicle (HEV) is the charge-sustaining mode of the battery only depend on the regenerative braking and gasoline by a fraction of its efficiency [3]. There are several potential solutions to solve the issue which are the use of solar energy for continuous charging and the ultracapacitor for higher rate charge or discharge by the efficiency cycle around 90 percent from 80 percent [4]. A control board, fuel tank, Internal Combustion Engine (ICE), converter, battery, and electric motor (EM) Among the critical components in HEV are as shown in Figure 1 [5]. As for our study, the series hybrid configuration is selected to be included in the simulation model. Only a small ICE or generator is needed to develop the series hybrid drivetrain.

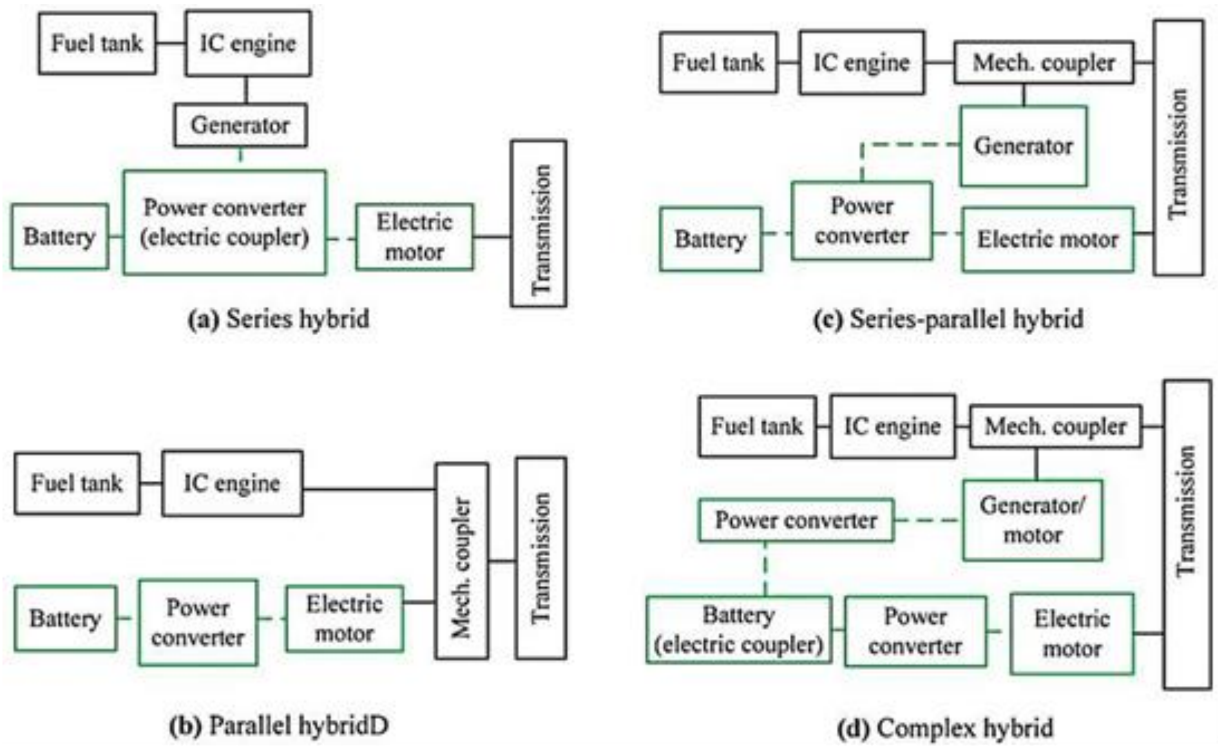

Figure 1: Various architecture of an HEV

The advantage of series hybrid drivetrain is the ICE can operate at its narrow optimal region because of no connection between ICE and the driven wheels. It also simplifies the speed control by torque-speed characteristics of EM where it prevents multi-gear transmission [6]. The energy storage system (ESS) such as battery and ultra-capacitor are important and it depends on parameters such as energy density, charging speed, life expectancy, cost, weight and size [7]. The advantages of the battery are it is low cost per watt hour, and it has high energy density, but it has weakness such as short cycle life and low specific power. Meanwhile, the ultracapacitor has the long cycle life and can maintain high peak power but has high cost per hour and low energy density [8]. It can manage the surges during the battery operation and maintain the DC-bus voltage and at the same time maintains the SOC of the ultra-capacitor.

EMR method is a synthetic graphical tool that describe the causal ordering graphs or transfer function inside of a present component and the action and reaction relationship among all connected elements [10]. Only the integral causality is considered by the causality principle in EMR. Hence, the outputs are integral functions of inputs in the accumulation elements by using the time-dependent relationship between their variables [9]. In this paper, the modelling of the HEATV is presented along with the original configuration of the electric ATV. The SOC and fuel consumption were compared between the electric ATV and HEATV by using NEDC cycle.

2.0 ATV MODEL AND SIMULATION MODEL

In the original electric ATV, the system initially depends only on the electric motor to drive the vehicle with Lithium-ion battery as its power source. In the modified version, an internal combustion engine and electric generator will be added to the vehicle in series with the electric ATV. The role of the engine is to aid the operation of the vehicle during high load cycle and recharge the battery if the SOC reach a minimum value. The ATV is available at the Automotive Laboratory in Universiti Teknologi Malaysia with its parameter as shown in Table 1.

Table 1: ATV Parameter

Curb Weight (kg)	Front Surface (m^2)	Drag Coefficient	Rolling Resistance	Wheel Radius (m)	Lithium-ion Battery	Gear Ratio	Speed Limit (km/h)
420	2.08692	0.35	0.8	0.3175	20.1 km/l	6.2	70

The electric motor used in the ATV is a brushless DC motor where it receives the power source from the Lithium-ion battery and transmit the power to the ATV drivetrain by the transmission gear for the torque amplification. The electric motor parameters are provided in Table 2.

The data given are before the ATV is modified into a series hybrid electric ATV, which will be containing an ICE and an electric generator. Including the weight of the electric generator, electric motor and ICE to the vehicle, the total curb weight is 553 kg for the HEATV.

Table 2: Electric Motor Parameter

Voltages, V	Rated P, kw	Peak P, kw	Speed, RPM	Rated T, Nm	Peak T, Nm
72-120	20-25	50	32000-5000	80	160

The EMR model in Figure 1 is developed after the list of formulas that show the connection among all the components are obtained mathematically based on the configuration of Hybrid Electric ATV. The vehicle block consists of the environment, chassis, wheel, and transmission. The engine and electric generator are attached to the battery for the power source, and the electric motor to the transmission to drive the vehicle.

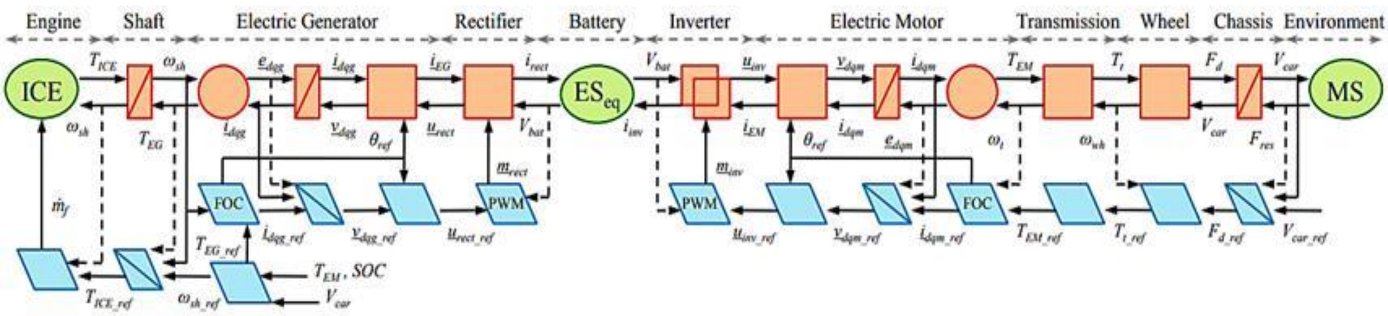

Figure 1: EMR and control structure of Hybrid Electric ATV

The EMR with control structure model is transformed into an overall simulation model where the proper input applied based on the reference velocity of ATV. The Charge Management element is responsible for the charging process of the battery by considering the needed electric motor torque, its angular velocity, and the current value of SOC. The overall simulation model is as shown in Figure 2.

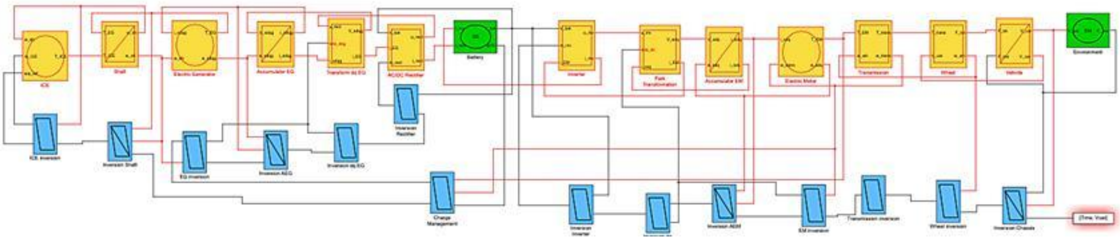

Figure 2: Overall simulation system model in MATLAB-Simulink

3.0 CHARGE MANAGEMENT

In HEATV configuration, there is only one source of power to drive the vehicle which is the Lithium-ion battery. The internal combustion engine and electric generator are used to charge the battery whenever necessary.

With the appropriate charge management or strategy, the condition can be arranged to allow the charging process taking place. For a simplification purpose, the velocity of the vehicle will be the control variable in the charge management and thus, the charging process takes place when the ATV velocity reach 20 km/h and above.

The charge management of the HEATV configuration drivetrain is implemented in the MATLAB-Simulink, specifically at the Charge Management block. The parameters of the ATV and other parts used for HEATV system is inserted into the model in order to run the simulation model shown in Figure 2. The NEDC cycle used for the reference velocity is as shown in Figure 3. It is repeated six times to reach the average time of an ATV utilisation time. The maximum velocity is 50 km/h which is suitable for the ATV real utilisation.

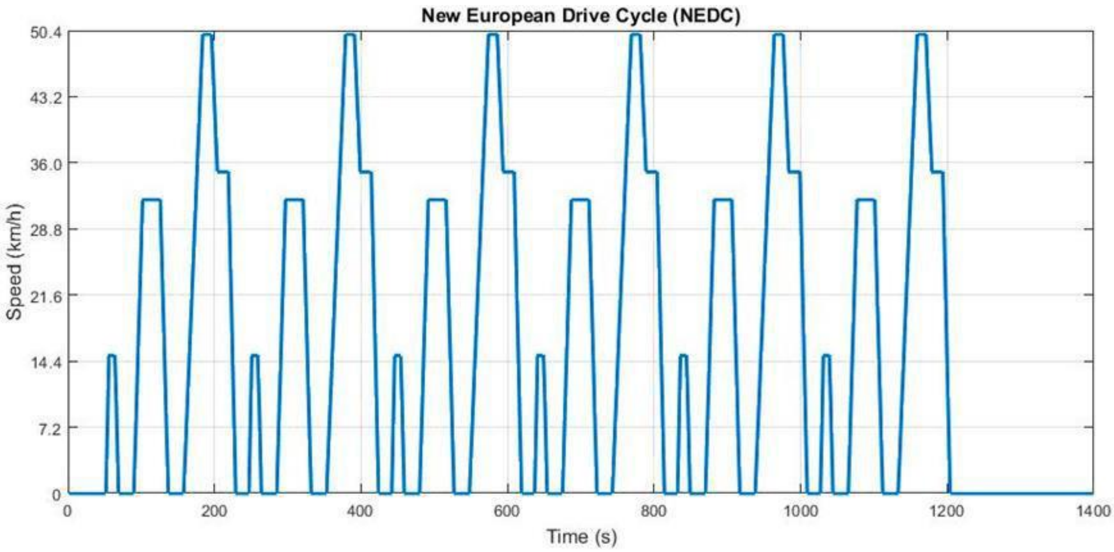

Figure 3: NEDC cycle implemented

4.0 RESULTS AND DISCUSSION

By the step size of 0.01 s, the simulation is done for the period of 20 minutes and 20 second. The result is as shown in Figure 4. The battery state-of-charge began with initial value of 0.5 SOC. At the end of the simulation, the value decreased drastically by 50.9 percent at 0.2452 SOC. The decreasing trend of SOC indicates the battery was working in discharging mode. As the battery optimum SOC range for operation is between 0.9 to 0.2, the range the electric ATV can cover will only be 16.5 km with one full charge.

However, after the ATV modified into a hybrid electric ATV (HEATV) by adding ICE and electric generator, the value increased significantly by 12.74 percent at 0.5637 SOC from initial value of 0.5 SOC. The increasing trend of SOC indicates the battery was working in charging mode. It is because the charge management block allowed the charging process to take place when the ATV velocity reach 20 km/h and above. Hence, the range of the ATV mileage can be extended for longer use. Based on the charge management, from the initial 0.5 SOC, the HEATV will be fully charged to 0.9 SOC after 40 km of this driving cycle. That means, one cycle of recharging from 0.2 SOC and discharging the battery back to 0.2 SOC will give 82.4 km of autonomy.

The fuel consumption is 0.143 litre for the driving cycle, increased from 0.365 litre to 0.508 litre. The increasing fuel consumption indicates the battery was working in charging mode. This consumption occurred for the 5.022 km trip during the whole simulation period. Thus, the rate of fuel consumption over distance travelled when compared to NEDC standard are satisfying as the fuel consumption exceeds the NEDC standard of 20.1 km/l by 74.7 percent at 35.12 km/l. This occurred because the charging process will operate at the most efficient point of the engine. And since the lower minimum value of velocity needed to allow the charging process to take place are above 20 km/h, most of the time the engine will be operating and recharge the battery. Considering the utilisation for one complete cycle of charging discharging, the rated fuel consumption is equal to 52.4 km/l for this driving cycle with 1.573 litre fuel for the 82.4 km range. It can be concluded that the HEATV can significantly increased the autonomy range with efficient fuel consumption compared to the original electric ATV that can only have 16.5 km range with a full charge battery.

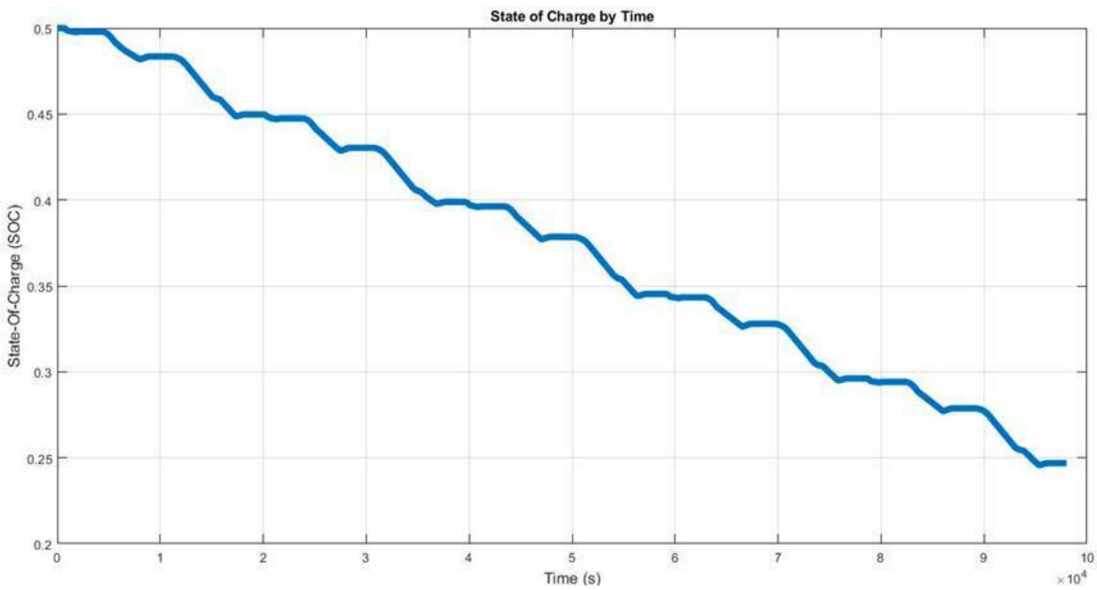

Figure 4: State-of-Charge graph of Lithium-ion battery in original ATV

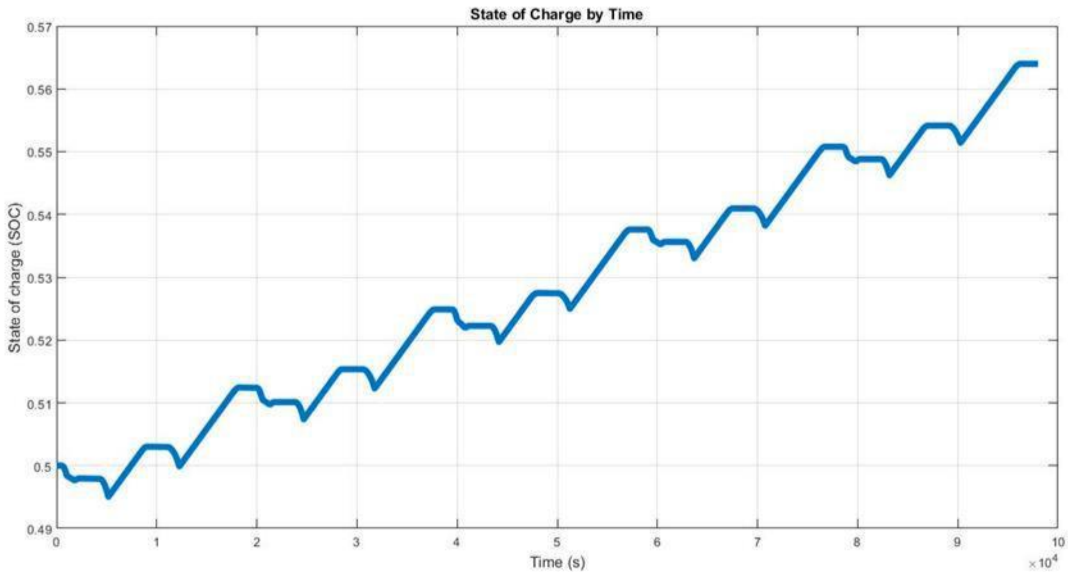

Figure 5: Battery state-of-charge in HEATV model

5.0 CONCLUSION

In conclusion, the objective of this study has been achieved. The dynamic simulation model of the hybrid electric ATV was developed and can be run smoothly according to the NEDC cycle. Through simulations, the range of the electric ATV and hybrid electric ATV were compared for the same driving cycle. The electric ATV can only reach a maximum of 16.5 km autonomy range if the vehicle to be operated from full charge of 0.9 SOC to 0.2 SOC. Considering the same SOC range, the HEATV can reach up to 82.4 km autonomy for one cycle of recharging and discharging the battery. This is five times more of the original ATV autonomy. Considering fuel consumption of the engine, the HEATV 52.4 km/l fuel consumption is efficient compared to the standard fuel consumption of 20.1 km/l for NEDC cycle. The simulation considers efficiencies of the transmitted power from the ICE to the electrical generator.

As for recommendation, the charge management need more study to determine the optimum level of the velocity to have a comparable fuel and battery charge consumption. More and real driving cycles should be considered in order to have an efficient hybrid vehicle system. In future, a system with other architecture or different types of components should also be considered in order to find the optimal design of the hybrid ATV.

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CONCLUSION

This research has introducing three approaches in deriving surrogate model. The models are called as RB model, VB model, and PB model. Among these three models, the PB model is the most unreliable model. The main flaw on PB model is the changing of parameter could lead to unrealistic behaviour of suspension system in even though the gap between surrogate model and HF model is close as indicated in Figure 6. MAE, RMSE, and R^2 were three key performance indicators (KPIs) used in evaluating the variance performance of surrogate model relative to HF model. Based on KPIs values and graph visualisation, the RB and VB models were considered as two useful surrogate models. Moreover, the VB model gave slightly more satisfy as surrogate model than the RB model. As a conclusion, the attempt to conduct a feasibility study of surrogate model for vehicle suspension system has successfully achieved.

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