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Modelling The Performance of Auxiliary Power Unit for Reevs

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Abstract:
The article “Modelling the Performance of Auxiliary Power Unit for Range-Extended Electric Vehicles (REEVs)” is devoted to the study of energy efficiency, optimization, and technical possibilities of integrating auxiliary power units (APUs) into the structure of modern electric vehicles. In today’s context, when the global automotive industry is moving towards sustainable energy and the electrification of transport, the development of range-extending technologies becomes an urgent task. The research highlights the role of APUs as a key component in REEVs, which not only ensures extended driving distance but also improves the stability and reliability of energy supply for traction batteries. The annotation outlines the main objectives of the study, which include: analyzing different types of APUs (internal combustion engines, fuel cells, microturbines), comparing their energy efficiency and environmental performance, and creating a mathematical model to evaluate system behavior under various load and driving conditions. The article also emphasizes the significance of simulation modelling, which allows predicting fuel consumption, emission levels, thermal management, and the overall balance between performance and sustainability. Furthermore, the work discusses the methodological basis of modelling, which relies on MATLAB/Simulink and other digital simulation tools. Special attention is given to optimization parameters such as fuel efficiency, cost-effectiveness, noise reduction, and compactness of design. The study underlines that in REEVs, the auxiliary power unit does not operate continuously, but rather in a strategically optimized mode, depending on the state of charge of the main battery and real-time driving demands. This approach significantly reduces fuel consumption compared to conventional vehicles and enhances the environmental benefits of electric mobility. The research findings demonstrate that the integration of APUs in REEVs offers a balance between the advantages of battery electric vehicles (zero direct emissions during electric drive) and the reliability of hybrid solutions (longer driving range). The proposed model serves as a practical tool for automotive engineers, energy system designers, and policymakers interested in accelerating the adoption of REEV technology.

Keywords: engine efficiency map, optimal operating line, auxiliary power unit, REEV

1. Introduction

While battery electric vehicles (BEV) provide substantial environmental advantages through reduced harmful emissions and improved energy efficiency, their widespread adoption is limited by the relatively short driving range achievable on a single charge. This limitation often results in "range anxiety", a concern among drivers regarding the adequacy of battery capacity for long trips. To address this challenge, the integration of an onboard power source, commonly referred as an auxiliary power unit, has emerged as an effective approach to increase the driving distance. The APU includes an internal combustion engine coupled with an electric generator [1]. However, alternative technologies such as fuel cells [2], micro gas turbines [3], wind turbines [4] and photovoltaic cells can also be employed instead of the conventional engine [5]. Today, the ICE technologies are the most mature ones therefore they are widely used in the conventional vehicles as well as REEVs [6]. Hence, the studies devoted to development of the ICE based range extenders are vast.

In the work the performance of REEV powertrain is studied using AVL Cruise software by incorporating an engine and generator model into pure BEV model. The total driving range of REEV is increased by 14.24% and 21.93% on NEDC and Japan transient Cycle 08 driving cycles, respectively. Furthermore, the thermal energy from the REEV's internal combustion engine can be used to heat the battery and cabin, reducing the amount of electricity used for these tasks. Li et al. has investigated the possibility of using range extender unit to power the electric bus. Their objective was to optimise the overall cost of the bus, mainly acting on the cost of the traction battery[6].

Previous studies primarily focus on the general architecture and feasibility of the system. However, the detailed performance characteristics of APUs such as efficiency, fuel consumption behaviour, and their influence on overall vehicle energy management have not been extensively addressed. This gap highlights the need for further research on APU modelling and optimization to enhance the efficiency of REEVs. To address this gap, the present study investigates the modelling of the APU and examines its optimal operating line (OOL)[7].

2. Materials and Methods

The construction of the APU model is based on the technical specifications of the BMW i3 REX 2014 which are summarized in Table 1.

Table 1. The main technical indicators of the APU.

Parameter	Unit	Value
	Engine	
Engine type/Cylinders/Valves	-	In line /2/4
Capacity	cm^3	647
Engine power / at rpm	kW	25/ 4800
Engine torque	Nm	55/4800
	Generator	
Power/ at rpm	kW	23.5/ 4800
Torque / at rpm	Nm	55/ 4800

Engine characteristics

The mathematical model of the internal combustion engine is established using a fuel consumption map as a lookup table or by analytically solving polynomial equations. Experimental data are employed to evaluate the required engine output torque, angular speed, and fuel mass flow rate for both approaches[8]. The engine model of BMW i3 REX 2014 is developed by re-scaling the engine model of *Toyota Camry* which is already built based on analysis of publicly available experimental data, as referenced in [9]. The engine characteristics are rescaled to a designated maximum power via a two-step process [10]. Initially, the original characteristics of the engine are normalized relative to its maximum power point **P** $(\omega_{ICE.Pmax.Camry}, T_{ICE.Pmax.Camry})$ (Figure1.b).

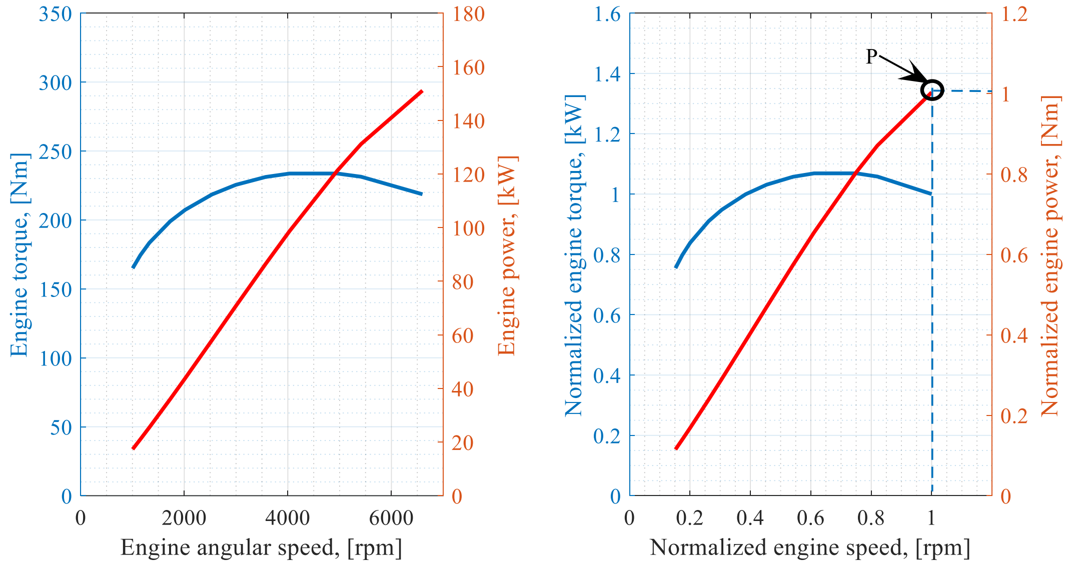


Figure 1. Power and torque characteristics of engine: a) original (Toyota Camry); b) normalized; Subsequently, normalized coordinates are multiplying by the coordinates $\omega_{ICE.Pmax.BMW}, T_{ICE.Pmax.BMW}$ of the BMW i3 REX 2014, so that engine's torque-speed characteristics are updated to new torque - speed data (Figure 2.a).

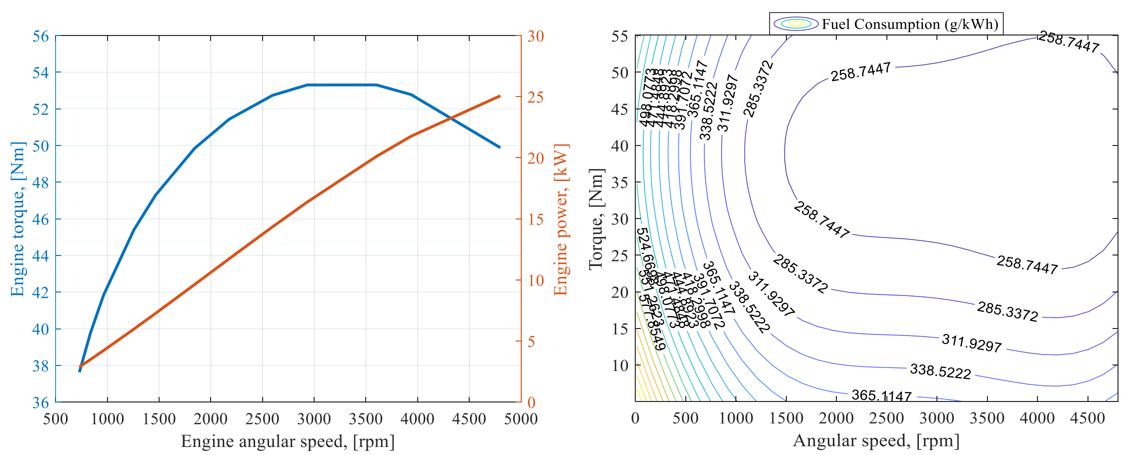


Figure 2. Engine characteristics: a) power and torque characteristics; b) engine fuel consumption contour map

Figure 2.b shows the map that describes the specific fuel consumption in terms of engine speed and torque, and is commonly utilized to evaluate the operating efficiency of the APU. The engine output power is obtained from the torque – speed relationship, given by Equation 2.

$$\dot{m}_{fuel} = f(\omega_{engine}, P_{engine}) \tag{1}$$

$$P_{engine} = \omega_{engine} \cdot T_{engine} \tag{2}$$

where $\dot{m}_{fuel}$ - engine fuel consumption rate in (g/kWh); ω_{engine} – angular speed of the engine in

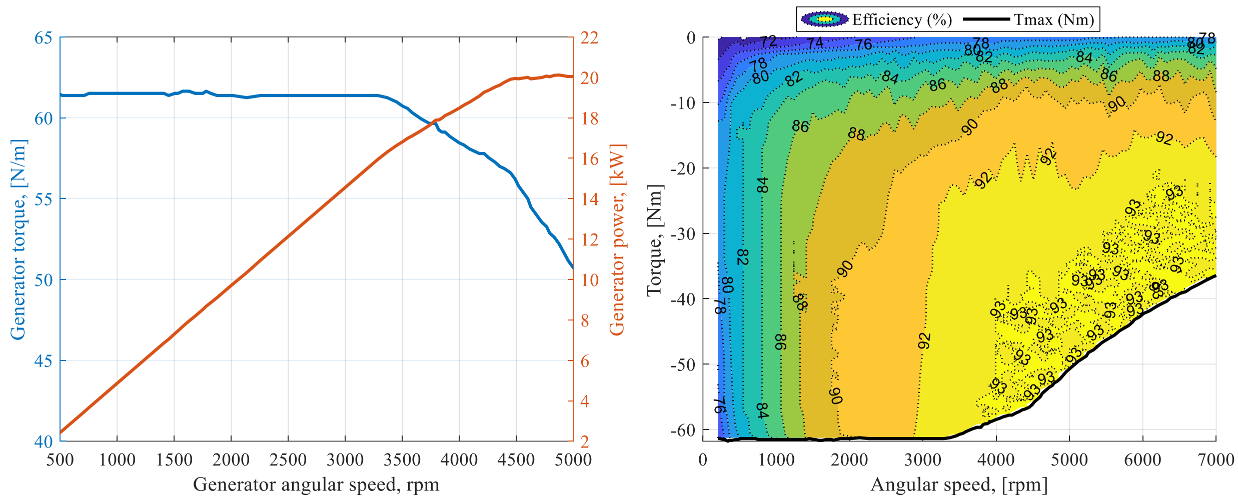
(rad/s); T_{engine} - engine torque, (N/m);

Generator characteristics

The model of generator converts mechanical power of engine into electrical energy demands of electric machine via its efficiency map. The generator efficiency (η_{gen}) can be described in terms of generator angular speed (ω_{gen}) and torque (T_{gen}).

$$\eta_{gen} = f(\omega_{gen}, T_{gen}) \quad (3)$$

Figure 3.a demonstrates the torque–power characteristics of the generator, while Figure 3b



presents its efficiency map.

Figure 3. Generator characteristics: a) power and torque characteristics; b) efficiency contour map

Fuel consumption optimization

Since the APU and wheels are not mechanically linked in a REEV, the engine can run at any operating condition [11]. The optimal operating line (OOL) of the APU is defined as the set of operating points that minimize fuel per unit of delivered electric power. Unlike the minimum fuel consumption line of the engine in terms of mechanical power output, the APU OOL accounts for generator efficiency. For the APU, the delivered electric power is expressed as Equation 4[12].

$$P_{APU} = \eta_{gen} \cdot P_{engine} \quad (4)$$

where P_{APU} - output power of APU, $[kW]$;

The sequence of calculating minimal fuel consumption for each unit of APU power is shown in Figure 4.

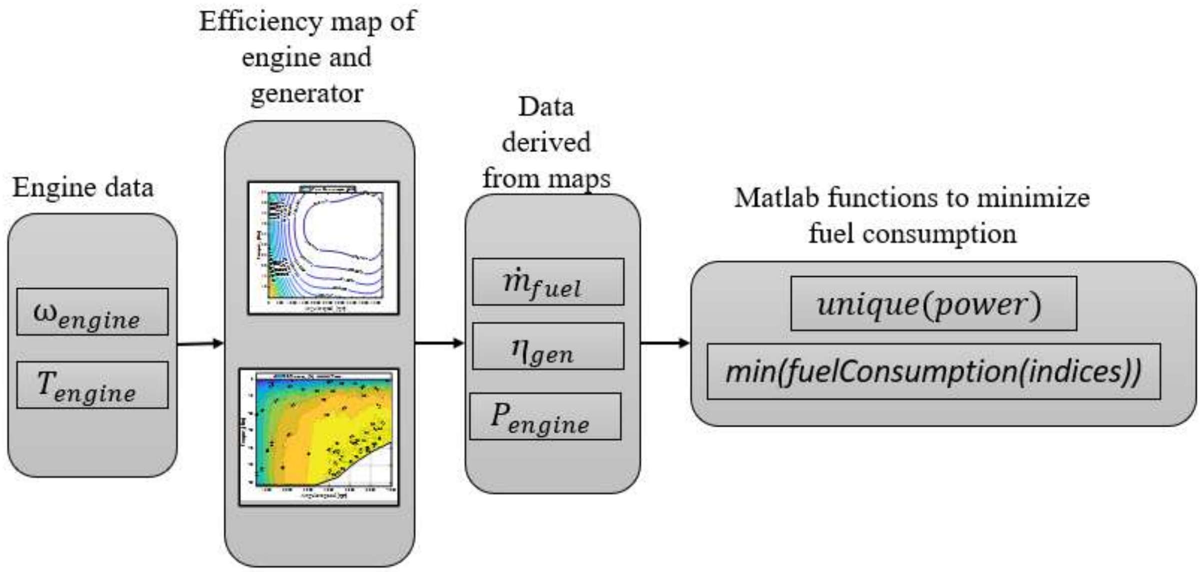
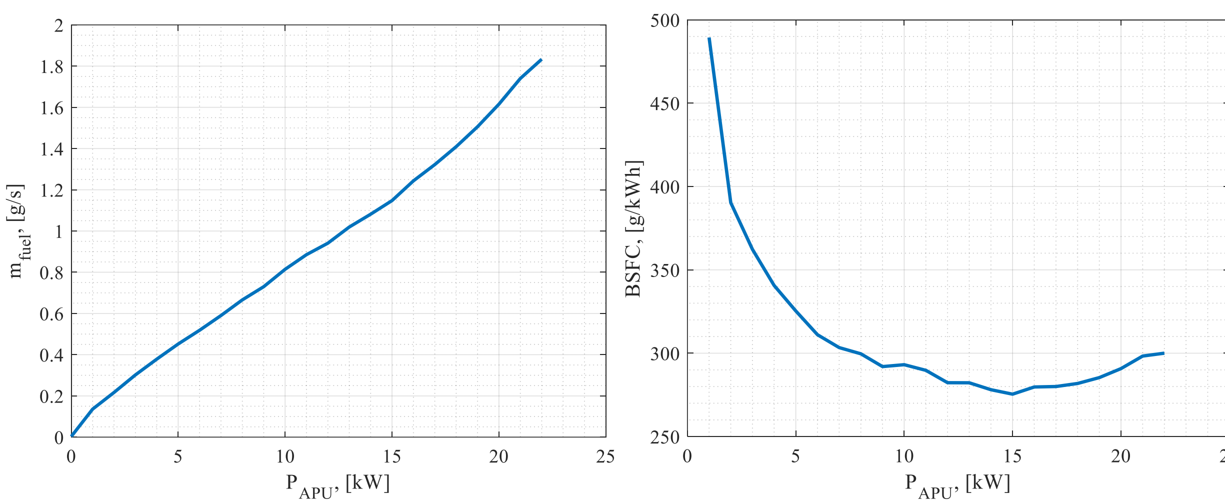


Figure 4. The sequence of calculating minimum fuel consumption for each unit power of APU.

3. Results

To determine the optimal specific fuel consumption for each unit of APU power, the vehicle data summarized in Table 1 were incorporated into the MATLAB/Simulink environment [13]. By performing the sequence of calculating minimum fuel consumption which is shown in Figure 4,

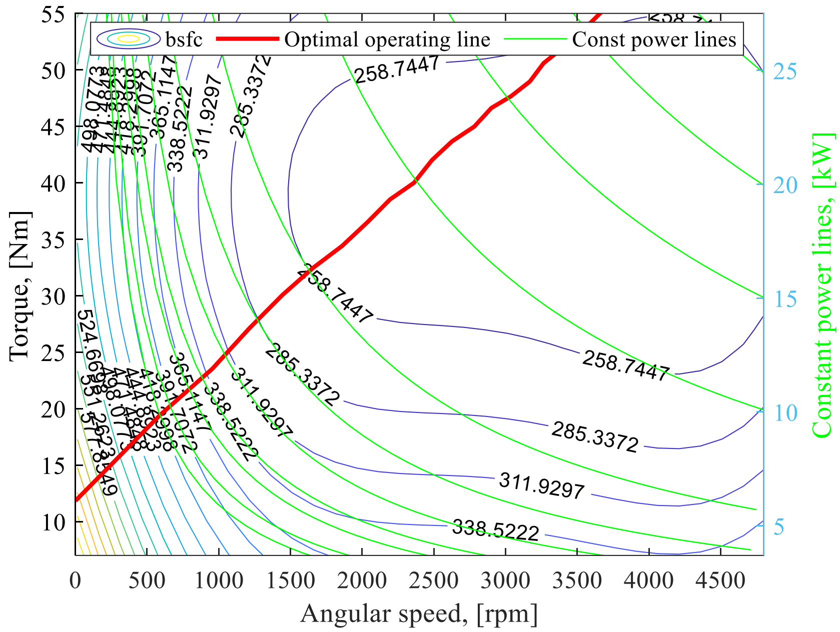


the optimal fuel consumption line as function of output power of APU is obtained in Figure 5 [14].

a) b)

Figure 5. The optimal specific fuel consumption for each unit of APU power: a) the fuel consumption in [g/s] b) the fuel consumption in [g/kWh]

The optimal operating line (OOL) is obtained by identifying the torque – speed points at which the engine achieves minimum fuel consumption for each power level. By connecting these optimal points, the OOL is formed which represents the most efficient operating region of the APU[15]. Figure 6 shows the OOL was obtained at the tangency points between the constant power lines



and the specific fuel consumption contours [16].

Figure 6. Optimal operating line of the APU on the engine BSFC map with constant power lines.

4. Conclusion

In this study, the auxiliary power unit (APU) is modeled as an internal combustion engine-based subsystem for range-extended electric vehicles (REEVs). Additionally, an optimal specific fuel consumption line is derived for each APU output power. The empirical relationship for the fuel mass flow rate will serve as a foundational component for the implementation of the Equivalent Consumption Minimization Strategy (ECMS) in future work.

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