MENZİL ARTTIRICILI ELEKTRİKLİ ARAÇLAR İÇİN 1B MİKRO GAZ TÜRBİNİ MODELLENMESİ

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ÖZET

Elektrikli araçlarda batarya kapasiteleri menzil sınırlamalarının ve uzun şarj sürelerinde devam etmesi nedenli ile Menzil Arttırıcılı Elektrikli Araçlara (REEV) olan ilgi artarak devam etmektedir. Bu araçlarda batarya durumu belirli bir seviyenin altına düştüğünde menzil artırıcı (İçten Yanmalı Motor, Yakıt Hücresi, Mikro Gaz Türbini) devreye girerek bataryayı şarj eder; elektrik araç sürüş menzilini arttırır. Yüksek güç yoğunluğu ve düşük emisyon özellikleri nedeniyle Mikro Gaz Türbinlerinin (MGT) menzil uzatıcı olarak kullanımı giderek daha fazla ilgi görmektedir. MGT sistem tasarımında istenilen performansların elde edilmesi için 1B modelleme tekniği sıkça kullanılmaktadır. Bu çalışmada 182 kW kapasiteli bir mikro gaz türbini Siemens Amesim program kullanılarak modellenmiştir. Sistem kompresör, yanma odası, türbin bileşenlerinden oluşmaktadır. Kompresör ve türbin haritaları Siemens Amesim üzerinden ölçekleme yöntemi ile oluşturulmuştur. Mikro gaz türbinin tasarım parametreleri şaft dönme hızı 90 000 rpm, basınç oranı 5, hava debisi ise 0.85 kg/s olarak belirlenmiştir. Kompresör ve türbin verimleri sırasıyla 0.786 ve 0.879 olarak belirlenmiştir. Yakıt olarak Metan kullanılmıştır. Modelleme sonucunda kompresör ve türbin performanslıları incelenmiştir. Türbin Giriş Sıcaklığının (TIT) sistemin termal verimliliği üzerinde etkisi basınç oranına bağlı olarak gösterilmiştir. TIT arttıkça termal verimin arttığı belirli bir basınç oranından sonra düştüğü gözlemlenmiştir. Çalışma sonucunda Mikro gaz türbinlerinin elektrikli araçlar için verimli, sürdürülebilir ve kompakt bir menzil uzatıcı çözüm olduğunu gösterilmiştir.

Anahtar Kelimeler: REEV, Mikro gaz türbini, Elektrikli araçlar, Siemens Amesim

MODELLING OF 1D MICRO GAS TURBINE FOR RANGE EXTENDER ELECTRIC VEHICLES

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ABSTRACT

Interest in Range-Extended Electric Vehicles (REEVs) continues to grow due to the range limitations imposed by battery capacities in electric vehicles and persistent long charging times. In these vehicles, when the battery level drops below a certain threshold, a range extender (Internal Combustion Engine, Fuel Cell, or Micro Gas Turbine) activates to charge the battery, thereby extending the electric vehicle's driving range. The utilization of Micro Gas Turbines (MGT) as range extenders is gaining increasing attention due to their high-power density and low emission characteristics. 1D modeling techniques are frequently employed in MGT system design to achieve desired performance outcomes. In this study, a 182-kW micro gas turbine was modeled using the Siemens Amesim software. The system consists of a compressor, combustion chamber, and turbine components. Compressor and turbine maps were generated using the scaling method within Siemens Amesim. The design parameters of the micro gas turbine were determined as a shaft rotational speed of 90 000 rpm, a pressure ratio of 5, and an air mass flow rate of 0.85 kg/s. Compressor and turbine efficiencies were defined as 0.786 and 0.879, respectively. Methane was utilized as fuel. As a result of the modeling, compressor and turbine performances were examined. The effect of Turbine Inlet Temperature (TIT) on the system's thermal efficiency was demonstrated as a function of the pressure ratio. It was observed that thermal efficiency increases with rising TIT but declines after a certain pressure ratio. The study concludes that micro gas turbines represent an efficient, sustainable, and compact range extender solution for electric vehicles.

Keywords: REEV, Micro Gaz Turbine, Electric vehicle, Siemens Amesim

1. INTRODUCTION

The automotive industry is rapidly transitioning toward electric powertrains in order to reduce fossil fuel consumption and harmful emissions. The widespread adoption of Electric Vehicles (EVs) is constrained by challenges such as limited driving range due to the low energy density of lithium-ion batteries, long charging times, and insufficient charging infrastructure, particularly in developing countries (Ji et al. 2020). Because of these limitations, Range-Extended Electric Vehicles (REEVs) have emerged as a promising solution. REEVs incorporate an onboard Auxiliary Power Unit (APU) or engine to charge the battery and extend the driving range; this unit does not directly drive the wheels but operates solely as a generator to produce electricity (Weerakoon et al. 2023). This configuration enables the extension of the battery's daily driving range while maintaining the battery state of charge (SOC). Since the range extender unit is mechanically decoupled from the vehicle drivetrain, it becomes possible to employ alternative engine types beyond conventional reciprocating internal combustion engines (Karvountzis-Kontakiotis et al. 2018). In this context, Micro Gas Turbines (MGTs) stand out as a promising technology for portable power generation applications and hybrid propulsion systems. Micro gas turbines are small-scale turbomachines, typically with power outputs below 500 kW. The main advantages of using MGT technology in REEVs include multi-fuel capability (such as natural gas, LPG, diesel, hydrogen, etc.), low emission levels, reduced maintenance requirements, and a high power-to-weight ratio. Moreover, MGTs have fewer moving parts compared to internal combustion engines and generate lower vibration and noise during operation (Li et al. 2023). When compared to conventional diesel engine-based range extenders (ICERE), MGT-based range extenders (MGTRE) exhibit a higher power-to-weight ratio in the range of 0.48–0.8 kW/kg. Additionally, MGTs produce lower raw exhaust emissions (HC, CO, and NOx) than internal combustion engines and are lighter than an equivalent ICE (Wei et al 2023).

In this study, one-dimensional (1D) modelling of a micro gas turbine was carried out using Siemens Amesim. Thermodynamic system analyses were performed, and the effects of different turbine inlet temperatures on thermal efficiency, net power output, and specific fuel consumption were investigated.

2. MATERIAL AND METHODS

The main components of a micro gas turbine system consist of a compressor, a combustion chamber, and a turbine. Air drawn from the atmosphere is first compressed in the compressor; the air, with increased pressure and temperature, is then directed into the combustion chamber, where it is combusted together with the fuel. The high-pressure and high-temperature combustion products generated after the combustion process are expanded in the turbine to produce mechanical work. This cycle operates based on the simple Brayton cycle. Figure 1 presents the schematic representation of the simple Brayton cycle along with its temperature–entropy (T–s) diagram.

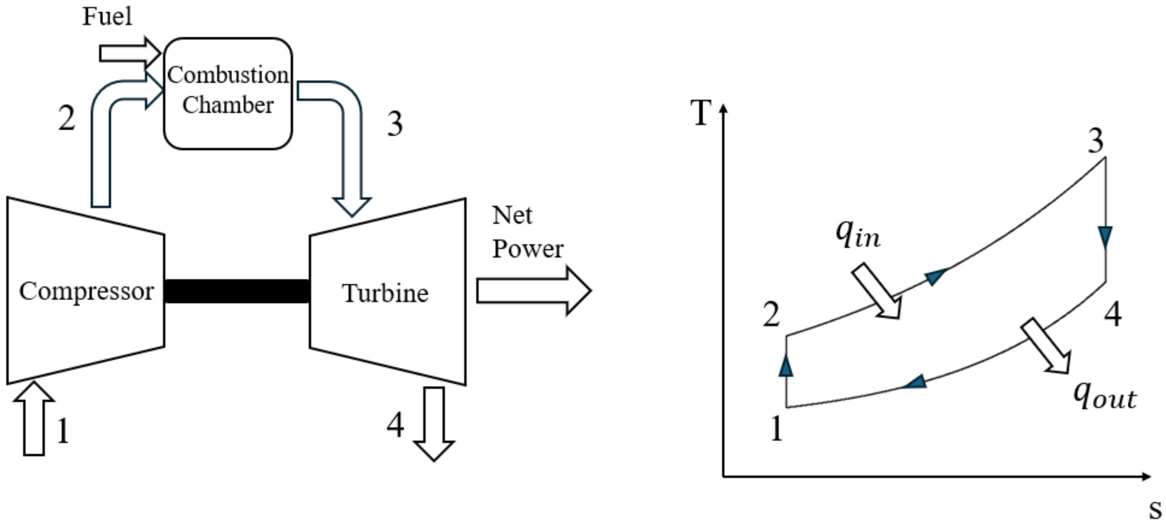

Fig. 1. Schematic of simple Brayton cycle and T-s diagram.

Siemens Amesim was used for the one-dimensional (1D) modeling of the system. As an initial step, the gaseous species present in air, the fuel, and the combustion products were defined within the software environment. Oxygen, argon, and nitrogen were specified as the constituent gases of air; methane (CH_4) was selected as the fuel; and carbon dioxide (CO_2) and water vapor (H_2O) were considered as the combustion products. In total, six different species were defined in Amesim, and their thermodynamic properties were implemented using the NASA polynomial format. Subsequently, the combustion reaction equation governing the reaction process in the combustion chamber was defined. The air composition and the combustion reaction equation are presented below.

Air Composition: $0.78109\ N_2 + 0.20954 O_2 + 0.00937 Ar$

Combustion Equation: $2O_2 + CH_4 \rightarrow CO_2 + 2H_2O$

For the development of the one-dimensional (1D) model of the system, the main components, namely the compressor, volume, combustion chamber, and turbine—were employed. The operating parameters of the micro gas turbine are presented in Table 1.

Table 1. Design parameters of micro gas turbine

	Unit	Value
Air flow	kg/s	0.85
Design point of shaft	rpm	90 000
Net Power	kW	182
Compressor efficiency	-	0.786
Turbine efficiency	-	0.879
Pressure ratio	-	5
Turbine Inlet Temperature (TIT)	K	1275
Specific fuel consumption (SFC)	kg/kWh	0.318
Ambient Pressure	barA	1.013
Ambient Temperature	K	288.15

The performance maps of the centrifugal compressor and the single-stage radial turbine, which were generated based on the design parameters of the micro gas turbine, are respectively illustrated in Figure 2.

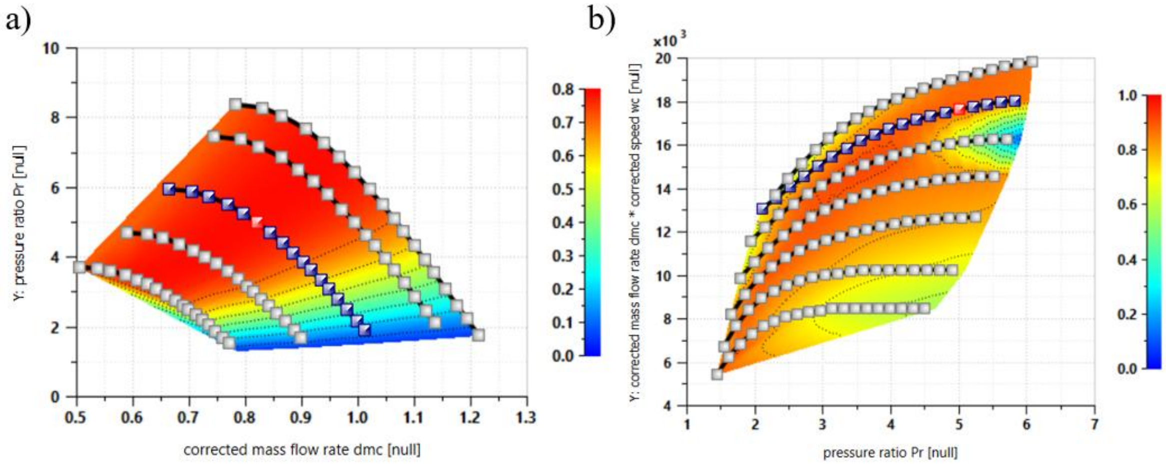

Fig. 2. Performance maps of compressor (a) and turbine (b).

To generate the performance map of the micro gas turbine, the system was operated in Speed Control Mode. A PID controller acting on the shaft initially functioned as a starter motor at low rotational speeds to drive the system. Once the engine exceeded its self-sustaining speed, the same unit operated as a generator (load), absorbing the net power produced by the turbine. In this manner, quasi-steady-state operating data were obtained across the entire operational range between 20,000 rpm and 110,000 rpm. For the parametric analysis, the Turbine Inlet Temperature (TIT) was maintained at distinct setpoints of 900 K, 1000 K, 1100 K, and 1275 K, respectively, utilizing a closed-loop PID control algorithm. The output of the fuel flow controller was saturated between a lower limit of 0 kg/s and an upper limit of 0.05 kg/s to represent the physical constraints of the fuel injector. The maximum TIT limit was established at 1275 K, considering the metallurgical thermal limits of typical uncooled radial turbine blade materials. The one-dimensional (1D) model of the micro gas turbine developed in Siemens Amesim is presented in Figure 3.

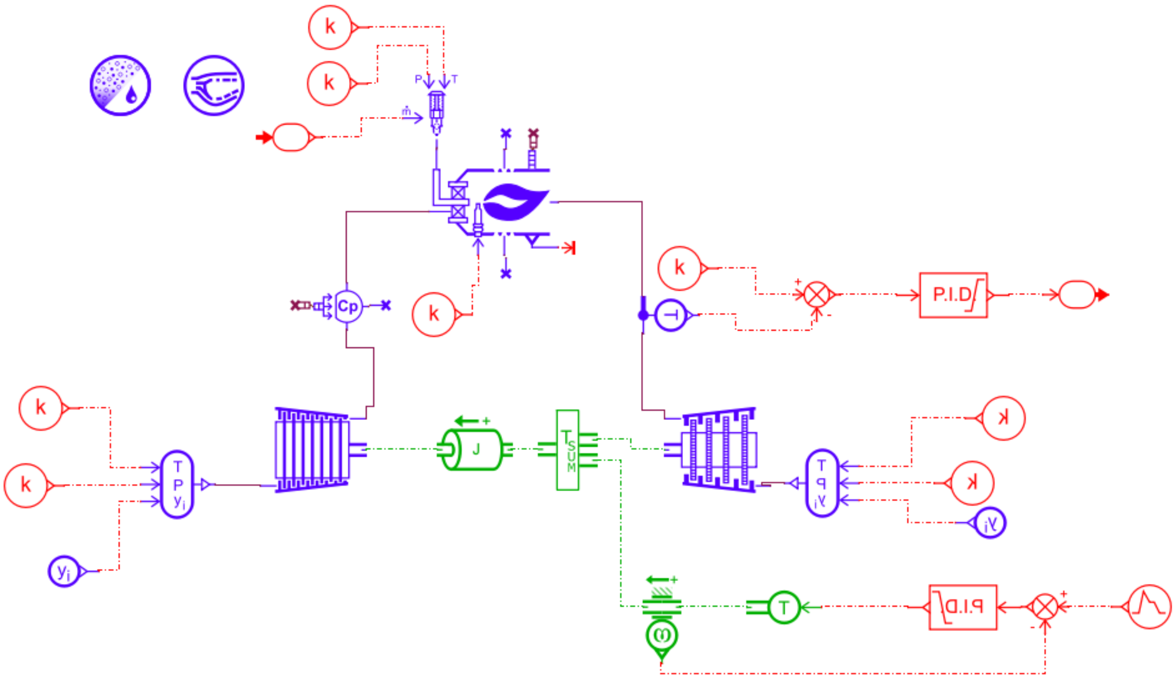

Fig. 3. 1D Model of the micro gas turbine

3. RESULTS AND DISCUSSION

Each simulation was conducted at turbine inlet temperatures of 900 K, 1000 K, 1100 K, and 1275 K. Based on the results obtained from each simulation, the net power output, thermal efficiency, and specific fuel consumption were calculated using the formulations given below. Here, P_{net}, denotes the net power output; T_t represents the turbine torque; T_c denotes the compressor torque; ω is the angular speed (rad/s); LHV refers to the lower heating value of the fuel; $\dot{m}_f$ is the fuel mass flow rate; Q denotes the fuel consumption heat rate; and SFC represents the specific fuel consumption.

$$P_{net} = (T_t - T_c).\omega \tag{1}$$

$$Q = \dot{m}_f.LHV \tag{2}$$

$$\eta_t = \frac{P_{net}}{Q} \tag{3}$$

$$SFC = \frac{\dot{m}_f}{P_{net}} \tag{4}$$

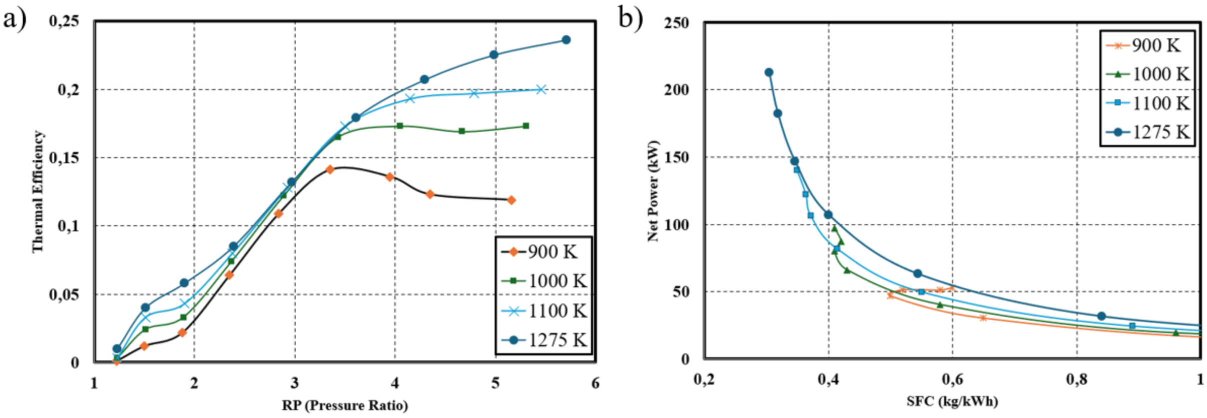

Fig. 4. Thermal efficiency–pressure ratio (a) and Net power-SFC (b)

Figure 4 presents the thermal efficiency–pressure ratio and net power–specific fuel consumption (SFC) curves obtained from the simulation results for four different turbine inlet temperature (TIT) levels. As shown in Figure 4a, the thermal efficiency increases with increasing TIT; however, beyond a certain pressure ratio, a decline in thermal efficiency is observed. Higher TIT values result in overall improved efficiency. In addition, thermal efficiency increases with increasing pressure ratio. Nevertheless, the compressor design pressure ratio was specified as 5; although higher pressure ratios may further enhance efficiency, they would require a compressor capable of delivering a higher mass flow rate, which would not be economically feasible. At a pressure ratio of 5, the thermal efficiency was found to be approximately 0.22. Figure 4b illustrates the net power output as a function of specific fuel consumption for different TIT levels. As observed, increasing the TIT leads to a reduction in SFC and a corresponding increase in net power output. Accordingly, increasing the TIT within the allowable limits of turbine blade materials results in both enhanced power output and reduced fuel consumption.

CONCLUSIONS

In this study, a one-dimensional (1D) model of a micro gas turbine aimed for use in range-extender electric vehicles was developed using Siemens Amesim. At the design operating point, the modelled micro gas turbine produces 182 kW of power at 90,000 rpm with a thermal efficiency of 0.22. The thermal efficiency of the micro gas turbine can be significantly improved by integrating a recuperator at the turbine exhaust. As part of future work, the modelling of a recuperated micro gas turbine will be carried out in Siemens Amesim. If thermal efficiency levels in the range of 30–35% can be achieved, micro gas turbines are expected to become competitive with internal combustion engines (ICEs) as range extenders for electric vehicles.

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REFERENCES

Ji, F., Zhang, X., Du, F., Ding, S., Zhao, Y., Xu, Z., Wang, Y., Zhou, Y. (2020). Experimental and numerical investigation on micro gas turbine as a range extender for electric vehicle. Applied Thermal Engineering 173, 115236.

Karvountzis-Kontakiotis, A., Andwari, A. M., Pesyridis, A., Russo, S., Tuccillo, R., Esfahanian, V. (2018). Application of Micro Gas Turbine in Range-Extended Electric Vehicles. Energy 147, 351-361.

Li, J., Li, Y. (2023). Micro gas turbine: Developments, applications, and key technologies on components. Propulsion and Power Research 12(1),1-43.

Weerakoon, A. H. S., Mohsen Assadi, M. (2023). Trends and advances in micro gas turbine technology for sustainable energy solutions: A detailed review. Energy Conversion and Management: X 20, 100483.

Wei, Z., Duan, W., Gao, H., Wei, C., Ren, G., Gan X. Preliminary design and key components validation of modular recuperated micro gas turbine for small unmanned systems. Case Studies in Thermal Engineering 73, 106547.