Study on a CHP plant using SOFC-ICE integrated system: Analysis, modeling and control

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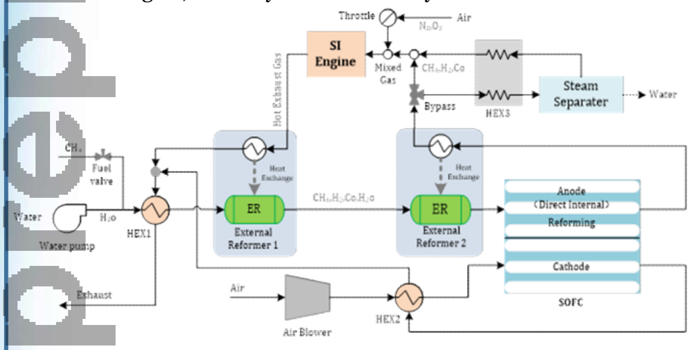
Introduction

Combined heat and power (CHP) system has been demonstrated to be an efficient cogeneration energy system, however, how to optimize the system efficiency, maximize the flexibility of system are not clear yet. Aiming to improve fuel efficiency, this research studies controller design of this system using operation point optimization theory for electricity generation, and the performances are validated by simulation.

System structure and modeling

The structure of the SOFC-ICE system studied in this work shows below. The main components of this system are external reformers, heat exchangers, SOFC system and ICE system.



- The dynamics of heat exchanger can be modelled as linear parameter varying (LPV) system.
- Considering chemical dynamics in external reformer, the reaction ratio can be calculated by the curve fitting of experimental data.
- Referring to the SOFC Voltage-current Intensity (V-I) curve at 1023 K, the desired flow rate of hydrogen consumption can be obtained, corresponding to a certain output power requirement.
- The caloric value of mix gas from the anode of SOFC can be calculated. Therefore, given the output power requirement of engine, the desired flow rate of gas can be obtained as well.

Controller design

The simulation environment is setup in the Simulink@Matlab. The controller is designed to distribute the power requirement from consumer to SOFC and SI engine, by minimizing gas consumption.

$$\min_{P_{SOFC}\in\Omega} \frac{P_{req}-P_{SOFC}+285.8\times\frac{P_{SOFC}}{237.2\times\eta_{SOFC}}\times\eta_{SI}}{H_{gas}\times\eta_{SI}}$$

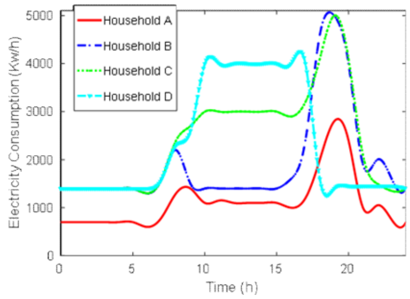
Subject to

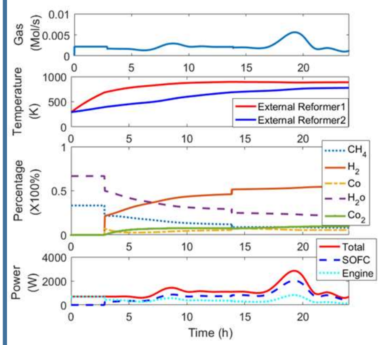
$$\frac{P_{SOFC}}{237.2\times\eta_{SOFC}\times Frac_{H_2}} < \frac{P_{req}-P_{SOFC}+285.8\times\frac{P_{SOFC}}{237.2\times\eta_{SOFC}}\times\eta_{SI}}{H_{gas}\times\eta_{SI}}$$

where, P_{req}, P_{SOFC}, are the requirement power from consumer, output power of SOFC. The $Frac_{H_2}$, H_{gas} are the percentage of H_2, caloric value of the gas entering SOFC. The η_{SI}, η_{SOFC} are the SI engine power efficiency and the SOFC power efficiency.

Simulation validation

There are four kinds of the daily electricity consumption curves for families used in the study. The table shows the system efficiency for a weekly consumption. The efficiency is around 100-110 g/kwh, corresponding to 66.7%-69.5% thermal efficiency.





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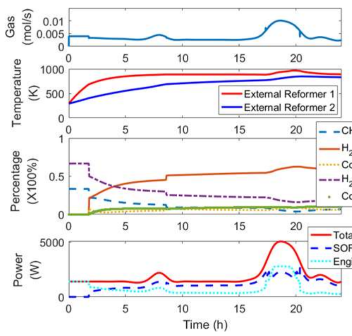

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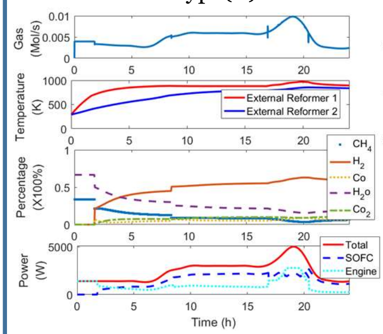

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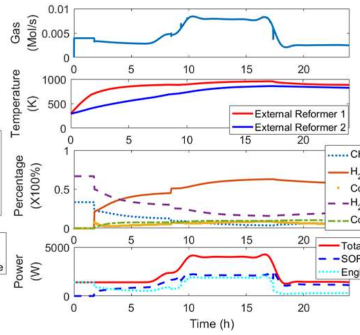

Type(D)

Mode	Electricity Consumption	CH_4 Consumption	System Efficiency
Householder A	189.7 kwh	19869 g	104.74 g/kwh
Householder B	325 kwh	34880 g	107.32 g/kwh
Householder C	410.4 kwh	45248 g	110.25 g/kwh
Householder D	399.8 kwh	43600 g	109.05 g/kwh

Conclusion

An optimal power distribution strategy is designed to minimize the consumption of natural gas and meet the power requirement.

As the validation, four different type of families are employed to demonstrate the effectiveness of the proposed power distribution method. This kind of CHP system is capable of applying the power to a family with much higher system and thermal efficiency.

Further study will focus on transient control of this CHP system.