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Multi-Stack Fuel Cell System Stacks Allocation Optimization Based on Genetic Algorithms

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Abstract

High-powered and modularity is the trend for fuel cell systems. Similar to the evolution from single-cylinder to multi-cylinder in conventional internal combustion engines, fuel cell systems shall also follow this developing process. Compared to single-stack fuel cell systems, multi-stack fuel cell systems (MFCS) can enhance the system maximum output power and improve the system performance. To achieve modular design and improve the performance of high-powered MFCS, a MFCS stacks allocation optimization algorithm based on genetic algorithms is proposed in this paper. First, remaining useful life (RUL) and efficiency are choosing as an integrated optimization index, the decision model for MFCS stacks allocation is developed. Then, a heavy-duty commercial vehicle was used as an example to match the vehicle power train parameters. The genetic algorithm is used to solve the global optimal stacks allocation scheme for the vehicle in a specific application scenario. The individual fitness values in the genetic algorithm are solved by the SQP algorithm. The optimized results are analyzed and beneficial conclusions are obtained. Weights of efficiency and RUL and the number of stacks has impacts on the determination of optimal stacks allocation scheme. The overall system efficiency will increase with the efficiency factor weight increase, and the overall RUL will decrease with the efficiency factor weight increase. If the focus is on improving the overall economy of the MFCS, the efficiency/RUL weights shall be taken as 1/0. Finally, the impact of different stacks allocation schemes on the efficiency and RUL of the MFCS is compared.

Introduction

Proton exchange membrane fuel cell (PEMFC) as a kind of electrochemical reaction device could convert the chemical energy in hydrogen into electrical energy quietly and efficiently. With the fuel cell system's maximum power demand increasing, the multi-stack fuel cell system (MFCS) has been investigated and developed. A MFCS could provide a higher power output compared to a single-stack fuel cell system (SFCS). Appropriate control strategies could enhance the performance of the MFCS. MFCS is already applied in the fields of rail transport [1], ships [2], power plants et al. [3].

In recent years, the possibilities of MFCS applications and the special problems of MFCS applications have been studied in various ways. Palma et al. [4] described the disadvantages of increasing the system power by increasing the number of single cells. A modular design approach for the fuel cell system is proposed and an example design of a 150kW MFCS and corresponding DC/DC converter is given. Dépature et al. [5] built a simulation model of MFCS and verified the simulation results through experiments. The results showed that MFCS can improve the system reliability than SFCS. Assabumrungrat et al. [6] investigated the effect of the topology of multi-stack solid oxide fuel cell (SOFC) stacks on the system and found that a multi-stack SOFC tandem topology could improve the performance of the system. Bernardinis et al. [7] proposed a fault-tolerant structure for the MFCS with an anti-parallel bypass diode, which allows current to pass through the bypass when a fault occurs in one of the stacks, ensuring that the system continues to operate. Cardenas et al. [8] studied the degradation mode of the MFCS when a stack is failed. The change in energy management strategy and the impact on the overall system efficiency during different stack failures was also investigated. Zhou et al. [9] studied the stacks allocation schemes for an application with a maximum demand power of 30kW shows that the objective values corresponding to scheme 2 (120kW, 100kW, 10kW, 10kW) are better in the low power range than those of scheme 1 (120kW, 100kW, 20kW). When the demand power reaches a certain Power, the objective values of the two schemes are equal, and when the demand power is higher, the objective value of the scheme 2 is higher than that the scheme 1. Therefore, it can be concluded that when the fuel cell system often operates in the middle power range, the effect of the number of stacks on the RUL and efficiency of the fuel cell is not significant, and when it often operates in the low power and high power range, increasing the number of stacks will help to improve the system performance index.

Conclusions

High-powered systems is one of the development trends of fuel cell systems. SFCS has disadvantages such as poor single-unit consistency, poor maintainability, and limited efficiency, which limit the application of fuel cell systems in high-powered scenarios. MFCS has the advantages of modular design, high-powered, fault tolerance, and increases the freedom of parameter matching and control strategy design. In this work, the MFCS stacks allocation optimization algorithm are proposed with specific application scenarios by considering efficiency and RUL as the integrated optimization index, and the optimization problem is solved by genetic algorithms, and some beneficial results are obtained. The main conclusions of this paper are shown below:

1. Based on efficiency and RUL integration optimization index and objective constraints, a mathematical model can be established for the MFCS stacks allocation problem, and the optimal stacks allocation scheme can be determined using the genetic algorithm and SQP algorithm.
2. The stacks allocation optimization can help to improve the MFCS fuel economy and system durability.
3. The optimal MFCS stacks allocation scheme is related to the efficiency and RUL weights, number of stacks etc. The optimal MFCS stacks allocation scheme for this application scenario can be determined by considering these influencing factors.

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Definitions/Abbreviations

MFCS - multi-stack fuel cell system
SFCS - single-stack fuel cell system
ICE - internal combustion engine
PEMFC - proton exchange membrane fuel cell
C-WTVC - China heavy-duty commercial test cycle
WTVC - World Transient Vehicle Cycle
RUL - remaining useful life

Symbols

α weight of efficiency
β weight of RUL
η the efficiency of the MFCS, %
δ the RUL factor of the MFCS, %
Δ denotes change in quantity

Subscripts and Superscripts

d demand
max maximum
min minimum
out output
a auxiliary plant
m motor

Nomenclature

P - power demand, kW
N - window size
k - scale factor
J - optimization index
n - number of stacks
L - number of different P_i^d