Solid Oxide Fuel Cells (SOFCs) are considered suitable for alternative energy solutions due to advantages such as high efficiency, fuel flexibility, tolerance to impurities, and potential for combined cycle operations. One of the main operating constraints of SOFCs is fuel starvation, which can occur under fluctuating power demands. It leads to voltage loss and detrimental effects on cell integrity and longevity. In addition, reformer based SOFCs require sufficient steam for fuel reforming to avoid carbon deposition and catalyst degradation. Steam to carbon ratio (STCR) is an index indicating availability of the steam in the reformer. This work takes a holistic approach to address the aforementioned concerns in SOFCs, in an attempt to enhance applicability and adaptability of such systems. To this end, we revisit prior investigation on the invariant properties of SOFC systems, that led to prediction of fuel utilization U and STCR in the absence of intrusive and expensive sensing. This work provides further insight into the reasons behind certain SOFC variables being invariant with respect to operating conditions. The work extends the idea of invariant properties to different fuel and reformer types.

In SOFCs, transient control is essential for U, especially if the fuel cell is to be operated in a dynamic load-following mode at high fuel utilization. In this research, we formulate a generalized abstraction of this transient control problem. We show that a multi-variable systems approach can be adopted to address this issue in both time and frequency domains, which leads to input shaping. Simulations show the effectiveness of the approach through good disturbance rejection. The work further integrates the aforementioned transient control research with system level control design for SOFC systems hybridized with storage elements. As opposed to earlier works where centralized robust controllers were of interest, here, separate controllers for the fuel cell and storage have been the primary emphasis. Thus, the proposed approach acts as a bridge between existing centralized controls for single fuel cells to decentralized control for power networks consisting of multiple elements. As a first attempt, decentralized control is demonstrated in a SOFC ultra-capacitor hybrid system. The challenge of this approach lies in the absence of direct and explicit communication between individual controllers. The controllers are designed based on a simple, yet effective principle of conservation of energy. Simulations as well as experimental results are presented to demonstrate the validity of these designs.

Approved for distribution by Dr. Tuhin Das, Committee Chair, on October 8, 2014.

The public is welcome to attend.