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A framework for the optimization of integrated energy systems

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HIGHLIGHTS

► We introduce an exergy-based framework for steady-state optimization and control of integrated energy systems.
► Exergy destruction describes irreversibilities across multiple energy domains making it an apt efficiency metric for IESs.
► Minimization of the objective function generates feedforward (FF) control input signal to achieve optimal setpoints.
► Robustness of the control signals to model uncertainty is demonstrated through a case study using validated system models.
► The physical significance of an exergy-based objective function makes it easily generalizable to complex IESs.

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ABSTRACT

This paper introduces an exergy-based objective function for the steady-state optimization and control of integrated energy systems (IESs). The use of exergy destruction as the metric for minimization enables the objective function to be scalable with respect to (1) subsystem configuration and (2) subsystem capacity, thereby rendering the approach generalizable to a wide class of IESs. More specifically, exergy destruction can be used to characterize irreversibilities across multiple energy domains (chemical, electrical, mechanical, thermal) which makes it very suitable for the types of energy subsystems which comprise IESs. The approach presented in this paper couples the exergy-based optimization with a feedforward control framework which uses static models to estimate the control inputs required to achieve the optimal setpoints. It is shown that the physical significance obtained using an objective function derived from first-principles makes the objective modular and therefore easily generalizable to complex IESs.

1. Introduction and motivation

Integrated energy systems (IESs) combine prime-mover technologies, such as internal combustion (IC) engines, and/or fuel cells, with other technologies which directly utilize the power produced by the prime-mover and/or utilize the thermal energy otherwise wasted in the production of power. IESs can be thought of as complex systems comprised of many interconnected heterogenous subsystems such as the prime-movers listed above, thermally-activated heating systems, desiccant dehumidifiers, vapor-compression refrigeration systems, and/or energy storage systems [1]. A key feature of the IES heterogeneity is that it typically spans multiple energy domains – chemical, electrical, mechanical, and thermal – as evidenced by the examples of subsystems which comprise IESs.

IESs are becoming more prevalent because of their environmental, reliability, economic, and efficiency benefits [1–3]. Many researchers have conducted thermodynamic analyses of IESs to optimize design parameters and production costs in these systems. Specifically, exergy-based analysis has been widely used to evaluate and optimize IESs at the design stage because of its ability to accurately capture the effect of irreversibilities and produce results which respect the physical limitations imposed by both the first and second laws of thermodynamics [4–7]. However, to fully realize the benefits of IESs, effective control of these systems is required. Through online optimization and control, systems can effectively respond to disturbances such as weather or varying loads that cannot be accounted for at the design stage [8–12].

The critical component of any optimization problem is the definition of the objective function. A common minimization metric for IESs is operational cost (in dollars) [12–15]; however, this metric does not explicitly consider the efficiency of the IES which is heavily dependent on the level of irreversibility in the system (which in turn also has environmental implications). Moreover, economic metrics do not accurately capture the underlying physics which govern the behavior of the system, particularly because these metrics are typically empirically-derived. In [9], the

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