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Reliability and availability modelling of combined heat and power (CHP) systems

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ABSTRACT

Many subsystems are involved in the reliability modeling of combined heat and power (CHP) systems, but in most studies these subsystems have not been classified and in many cases have been considered separately. Furthermore, calculating the reliability from the generation point to the consumer has not yet been studied. Herein, we classify combined heat and power subsystems and model their reliability, availability and mean-time-to-failure indices based on interactions between subsystems from the generation site to consumer delivery. The proposed CHP reliability and availability model is based on the state space and the continuous Markov method with electricity-generation, fuel-distribution and heat-generation subsystems. The effects of fuel- and water-distribution networks at the CHP site and the hot-water-distribution network on the consumer-utility reliability of CHP systems were fully assessed in an applicable case study. Additionally, we present a sensitivity analysis for island, standby and parallel operational modes of CHP systems. The results from the case study prove that improving the gas-distribution network, the network delivering hot water to the consumers and the water-delivery network to the CHP, in addition to optimizing the failure and repair rates of CHP systems, have considerable effects on the reliability improvement of the complete integrated system and have major roles in technical and economic feasibility studies of CHP systems.

1. Introduction

Currently, implementing distributed generation and combined heat and power (CHP) systems in factories, buildings and houses has an essential role in providing improved energy efficiency and demand-side growth management. A CHP system simultaneously produces electrical and thermal energy from a single fuel [1]. Typically, CHPs are classified according to the technology used as the prime mover [2]. It is evident that a common gas-powered generation system typically has a heat efficiency of about 30–37% along with an energy loss of almost 40–50% as waste heat [2,3]. Cogeneration systems are able to reduce this huge loss of energy. In general, reliability is an innate characteristic of a system or product. Thus, an assessment of the effects of design parameters on reliability should be performed as an integral part of a design process [4].

Calculating the reliability of combined heat and power systems plays an essential role in economic and technical feasibility studies, operating expenses and optimal maintenance scheduling of these systems. The concept of combined heat and power reliability denotes the probability of satisfactorily operating a cogeneration system under operational conditions encountered in a specific period of time. Satisfactory operation of CHP systems is defined as generating electricity and heat (hot water or steam). Here, we modeled three CHP subsystems: Electricity-generation subsystem, Fuel-distribution subsystem and Heat-generation subsystem.

An electricity-generation subsystem includes a prime mover such as a natural gas or diesel engine or a gas turbine coupled with an alternator or other prime mover technologies such as micro turbines.

Fuel-distribution subsystem here means a gas-delivery network for a CHP system using gas-based technologies such as gas engines cogeneration system or other fuel-delivery system for technologies not using gas as a fuel. Urbina and Zuyi [5] presented the gas-delivery system model. Generally, a gas-delivery network operates radially.

A heat-generation subsystem in a CHP system generally includes heat exchangers such as exhaust or engine-heat exchangers, boilers and other heat-recovery facilities.

For a more comprehensive reliability modeling, we considered two other systems that affect system reliability in several major CHP technologies. The water-delivery system to a CHP site in technologies that require water for cooling, such as gas and diesel engines or gas turbines, and the hot-water-delivery network to the consumer were fully assessed in this paper. Heat-recovery output could be steam or hot water that is delivered by the hot-water or steam-delivery network to the end users.

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