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Optimal nuclear trigeneration system considering life cycle costing

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ABSTRACT

A nuclear reactor can generate a large amount of high-temperature waste heat, which can be recovered to produce simultaneous electricity, heating and cooling, known as a trigeneration system. Trigeneration System Cascade Analysis is a methodology based on Pinch Analysis to optimise a centralised trigeneration system in various energy ratings in demands. However, the previous study does not consider a complete life cycle costing in the Trigeneration System Cascade Analysis. The methodology consists of three main parts, which are data extraction, development of Trigeneration System Cascade Analysis, and calculations of the life cycle costing. In this analysis, a centralised Pressurised Water Reactor, which is the most commonly used nuclear reactor in the world, is applied in a trigeneration mode in three different industrial plants. Based on the results of the case study, an optimal Pressurised Water Reactor trigeneration system is obtained where the total thermal energy required is 1,102.25 MW or translated into 26.5 GWh/d. The Equivalent Annual Cost for the case study, on the other hand, showed the centralised Pressurised Water Reactor trigeneration system requires 1.89×10^{11} USD/y for maintaining, operating, constructing, and disposing of the overall Pressurised Water Reactor trigeneration system. The maintenance cost is the highest percentage which constitutes 51.3% of the overall cost. Comparisons between normal conditions, and planned and unplanned shutdowns are also conducted, and the results show that Equivalent Annual Costs of planned and unplanned shutdowns required an additional 1.4 MUSD and 0.5 MUSD to support the deficit energy during shutdowns. The implementation of the full life cycle costing during the normal conditions planned and unplanned shutdowns of the Pressurized Water Reactor trigeneration system gives a proper projection of the cash flows that can create an economic model that reflects all the project realisation conditions.

1. Introduction

Renewables and conventional power plants such as nuclear reactors typically have not fully utilised their potential to generate electricity. Around 30–40% of the total thermal energy are used to generate electricity, and the rest of it is dissipated into the surrounding (Wu and Wang, 2006). Many countries, including Malaysia, have taken actions to improve the efficiency of their renewables and conventional power plants. The Malaysian government, for instance, has taken the initiative to propose a comprehensive Energy Efficiency and Conservation Act to promote the effective utilisation of energy (Zulkifli, 2021). Cogeneration and trigeneration development are among the newest sectors that received special incentives from the government of Malaysia through the Green Technology Master Plan (GTMP) (Zailan et al., 2021). Implementation of a trigeneration system for renewables and conventional power plants can improve thermal efficiency by up to 90%. The trigeneration system is defined as a technology that can simultaneously generate power, heating, and cooling to improve thermal efficiency and help reduce the dependency on fossil fuels and mitigate climate change. As stated by Birol (2021), energy demands in the European Union are estimated to increase from 120 GW in 2019 to 270 GW in 2050 due to the increase in the deployment of heat pumps and air conditioners.

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