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Analysis of a multiple generation system based on geothermal energy by simultaneously using two organic Rankine cycles, a compressed air storage source, and an absorption chiller in different regions

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Extended Abstract

Introduction

The global energy sector is still heavily dependent on fossil fuels, particularly in residential, industrial, and power generation sectors. Industrial energy consumption, as a key production input, has intensified concerns regarding efficiency, sustainability, and environmental impacts. The adverse consequences of fossil fuel utilization—including greenhouse gas emissions, environmental degradation, and energy insecurity—have accelerated the transition toward renewable energy systems. Among renewable sources, geothermal energy stands out due to its reliability, high capacity factor, and independence from climatic intermittency.

Despite extensive research on renewable-based power generation systems, fully geothermal-driven multigeneration systems remain underexplored, particularly those capable of simultaneously producing electricity, heating, and cooling. Furthermore, integrating energy storage technologies such as compressed air energy storage (CAES) can significantly enhance system flexibility, peak shaving capability, and overall efficiency. Therefore, developing a geothermal-based multigeneration system combined with advanced energy storage and optimization techniques is of critical importance, especially for regions with high geothermal potential such as Iran.

This study proposes a novel geothermal-driven multigeneration energy system designed to produce clean electricity, heating, and cooling without reliance on fossil fuels. The system is comprehensively evaluated from thermodynamic, exergetic, economic, environmental, and regional feasibility perspectives.

Methodology

A novel multigeneration system integrating geothermal wells, dual Organic Rankine Cycles (ORC), a single-effect absorption chiller, and a compressed air energy storage (CAES) unit is proposed. The geothermal heat source supplies thermal energy to the ORCs, utilizing R123 and ammonia as working fluids to maximize performance across different temperature levels. The CAES subsystem enables load shifting and peak shaving by storing excess energy during off-peak periods and releasing it during peak demand.

The system is modeled under steady-state conditions using Engineering Equation Solver (EES). Energy and exergy balance equations are applied to all system components, considering realistic assumptions such as negligible pressure losses and isentropic efficiencies for turbines and pumps. Economic analysis is conducted by applying component cost correlations to determine the total cost rate of the system.

To optimize system performance, a multi-objective optimization framework based on Response Surface Methodology (RSM) is employed using Design-Expert software. The objective functions include maximizing round-trip exergy efficiency (ERTE) and minimizing cost rate. Eleven decision variables—including geothermal mass flow rate, turbine inlet temperatures, component efficiencies, CAES pressure, and evaporator pinch point—are considered. For site selection, climatic data for ten cities in Iran are extracted using Meteonorm software. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is applied to rank candidate locations based on technical and economic criteria. Finally, an environmental assessment is performed to quantify CO_2 emission reductions and ecological benefits.

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Results and Discussion

Validation results confirm high accuracy of the developed model, with deviations below 1% when compared to reference studies. Among ten evaluated organic fluid combinations, the R123–ammonia configuration demonstrates superior performance and is selected for further analysis. The multi-objective optimization yields an optimal round-trip exergy efficiency of **77.98%** and a minimum cost rate of **5.49 $/h**, with a desirability index of 0.955. Sensitivity analyses reveal that geothermal mass flow rate, ORC turbine efficiency, and CAES pressure are the most influential parameters affecting system performance.

The regional feasibility analysis indicates that ambient temperature significantly impacts power output and efficiency. Colder regions exhibit higher power generation and exergy efficiency, while warmer regions favor higher heating output. Based on combined technical and economic performance, **Bandar Anzali** is identified as the optimal location for system deployment. Environmental analysis shows that implementing the proposed system in Bandar Anzali can significantly reduce CO_2 emissions, equivalent to preventing approximately 0.204 tons of CO_2 per MWh of electricity generation. This reduction corresponds to an estimated environmental cost saving and contributes to the expansion of green spaces by approximately **11 hectares** annually.

Conclusion

The proposed geothermal-based multigeneration system demonstrates strong potential as a sustainable, efficient, and economically viable solution for clean energy production. By eliminating fossil fuel dependency and integrating advanced energy storage, the system enhances grid stability, reduces environmental impacts, and supports long-term energy security.

Future research should focus on dynamic modeling, uncertainty analysis, and experimental validation of the proposed configuration. Additionally, expanding the system to include hydrogen production or integrating hybrid renewable sources could further enhance its flexibility and sustainability. The findings of this study provide valuable insights for policymakers, energy planners, and researchers aiming to advance renewable-based multigeneration technologies in regions with high geothermal potential.

Keywords: Geothermal energy, multiple energy generation system, compressed air energy storage, multi-objective optimization.

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