

ABSTRAK

Indonesia berkomitmen untuk mengurangi emisi karbon melalui transisi energi, dengan target beralih dari bahan bakar fosil ke sumber energi terbarukan (EBT), yaitu mencapai 23% energi terbarukan pada tahun 2025 dan *Enhanced NDC*. Namun, sumber EBT menghadapi tantangan, seperti karakteristik intermiten dan ketergantungan pada kondisi alam, yang dapat menyebabkan risiko ketidakstabilan pasokan energi dan baseload. Oleh karena itu, optimasi integrasi pembangkit listrik berbasis energi terbarukan dengan *Energy Storage System* (ESS) sangat penting. *Battery Energy Storage System* (BESS) dapat meningkatkan efisiensi sistem tenaga listrik, sementara *Hydrogen Energy Storage System* (HESS), dengan densitas energi yang lebih tinggi dibandingkan baterai, semakin populer dan dapat menjadi opsi di masa depan. Pembangkit listrik energi terbarukan, seperti *Nuclear-Renewable Energy System* (N-RES), khususnya *Small Modular Reactor* (SMR), menawarkan keunggulan ekonomi, fleksibilitas, dan modularitas dibandingkan pembangkit listrik berbahan bakar fosil. Penelitian ini berfokus pada optimalisasi perencanaan integrasi BESS, HESS, dan N-RES untuk mencapai tiga aspek utama: keandalan sistem, total biaya sistem, dan total emisi gas rumah kaca. Setiap aspek akan dianalisis secara terpisah untuk menentukan nilai optimal sebelum menggabungkannya, dengan mempertimbangkan ketidakpastian sistem tenaga listrik Indonesia. Pada fase awal penelitian, diperoleh hasil mengenai kapasitas pembangkitan, produksi, bauran EBT, dan emisi karbon dalam skenario *Business as Usual* (BaU) dan *New Renewable Energy* (NRE). Sistem yang digunakan dalam penelitian ini mewakili 70% dari total sistem tenaga listrik Indonesia, khususnya wilayah Jawa-Bali. Temuan menunjukkan bahwa meskipun skenario NRE memiliki biaya awal pasokan listrik (LCOE) yang lebih tinggi yaitu 9 cent USD/kWh dibandingkan dengan skenario BaU sebesar 8,8 cent USD/kWh, skenario NRE secara signifikan mengurangi emisi CO₂. Pengurangan emisi CO₂ ini didorong oleh berkurangnya penggunaan batu bara dan diesel, serta meningkatnya produksi dari energi nuklir, surya, dan biomassa. Meskipun biaya awal lebih tinggi, skenario NRE menawarkan manfaat lingkungan yang substansial, menunjukkan keberlanjutannya dan keselarasan dengan target energi nasional Indonesia serta komitmen iklim global.

Kata kunci -Transisi Energi, Sistem Penyimpanan Energi, Perencanaan Pembangkit Listrik, Energi Baru Terbarukan.

ABSTRACT

Indonesia is committed to reducing carbon emissions through an energy transition, targeting a shift from fossil fuels to renewable energy sources (RES), with an objective of achieving 23% renewable energy by 2025 and meeting Enhanced NDC goals. However, renewable sources face challenges such as intermittent characteristics and dependency on natural conditions, which could pose risks to energy supply stability and baseload capability. Consequently, optimizing the integration of renewable power generation with energy storage systems (ESS) is crucial. Battery energy storage systems (BESS) can enhance the efficiency of the power system, while hydrogen energy storage systems (HESS), with their higher energy density compared to batteries, are becoming increasingly popular and could be a future option. Renewable power plants, such as nuclear-renewable energy systems (N-RES), particularly small modular reactors (SMR), offer economic advantages, flexibility, and modularity over fossil-fuel-based power plants. This research focuses on optimizing the planning integration of BESS, HESS, and N-RES to achieve three main aspects: system reliability, total system cost, and total greenhouse gas emissions. Each aspect will be analyzed separately to determine the optimal value before combining them, considering the uncertainties in Indonesia's power system. Initial research results obtained include generation capacity, production, renewable mix, and carbon emissions under Business as Usual (BaU) and New Renewable Energy (NRE) scenarios. The systems studied in this research represent 70% of Indonesia's total power system, particularly in the Java-Bali region. Findings indicate that although the NRE scenario has a higher initial electricity supply cost (LCOE) at 9 cents USD/kWh compared to the BaU scenario at 8.8 cents USD/kWh, it significantly reduces CO₂ emissions. This reduction in CO₂ emissions is driven by decreased use of coal and diesel and increased production from nuclear, solar, and biomass energies. Despite the higher initial costs, the NRE scenario offers substantial environmental benefits, demonstrating its sustainability and alignment with Indonesia's national energy targets and global climate commitments.

Keywords -Energy Transition, Energy Storage, GEP, Renewable Energy.