

INTISARI

Gas Sulfur Heksafluorida (SF₆) merupakan media isolasi dan pemadam busur listrik yang banyak digunakan pada peralatan tegangan tinggi di Gardu Induk, khususnya tipe *Gas Insulated Switchgear* (GIS) dan *Air Insulated Switchgear* (AIS) 500 kV. Meskipun unggul dari sisi teknis, SF₆ termasuk gas rumah kaca dengan potensi pemanasan global (GWP) sangat tinggi, yakni 24.300 kali dibandingkan CO₂, serta masa hidup di atmosfer yang sangat panjang, lebih dari 3.000 tahun. Penelitian ini bertujuan untuk menganalisis risiko emisi gas rumah kaca akibat pemakaian SF₆ di Gardu Induk dengan pendekatan kuantitatif berbasis simulasi Monte Carlo. Lokasi studi dilakukan di 18 Gardu Induk milik PT PLN (Persero) Transmisi Jawa Bagian Tengah, yang terdiri dari 14 AIS dan 4 GIS. Data diperoleh dari histori pengisian ulang (*top-up*) dan penggantian gas SF₆ selama masa operasional. Risiko dianalisis berdasarkan probabilitas kebocoran dan besarnya dampak emisi setara CO₂. Hasil penelitian menunjukkan bahwa emisi SF₆ meskipun volumenya relatif kecil, berdampak signifikan terhadap total emisi gas rumah kaca akibat nilai GWP yang tinggi. Simulasi Monte Carlo memberikan gambaran probabilistik atas berbagai skenario kebocoran, serta memungkinkan penyusunan peta risiko yang menggambarkan tingkat kemungkinan dan dampak secara komprehensif. Dari hasil simulasi diperoleh *best case scenario* terdapat 300 kali risiko kebocoran SF₆ dan *worst case scenario* terdapat 360 kali potensi risiko kebocoran SF₆ serta *best case scenario* masih ada dampak emisi CO₂ ek sebesar 155.133,66 ton dan *worst case scenario* sebesar 199.101,08 ton dampak emisi CO₂ ek sampai dengan tahun 2028. Analisis sensitivitas juga mengidentifikasi variabel-variabel paling berpengaruh terhadap peningkatan emisi yaitu frekuensi dan massa pengisian gas SF₆ pada peralatan di AIS/GIS. Penelitian ini memberikan kontribusi terhadap upaya pengelolaan risiko lingkungan di sektor ketenagalistrikan, khususnya dalam mendukung target Rencana Jangka Panjang (RJP) PLN 2028, *Nationally Determined Contribution* (NDC) 2030 dan *Net Zero Emission* 2060. Rekomendasi meliputi peningkatan sistem pemantauan kebocoran, optimalisasi pengelolaan gas SF₆, serta eksplorasi alternatif gas isolasi yang lebih ramah lingkungan.

Kata kunci: Utilisasi SF₆, Emisi, Gas Rumah Kaca, Simulasi Monte Carlo, Analisis Risiko.

ABSTRACT

Sulfur Hexafluoride (SF₆) is widely used as an insulating and arc-quenching medium in high-voltage equipment, particularly in Gas Insulated Switchgear (GIS) and Air Insulated Switchgear (AIS) substations operating at 500 kV. While SF₆ offers excellent technical performance due to its high dielectric strength and chemical stability, it is also one of the most potent greenhouse gases, with a global warming potential (GWP) 24,300 times greater than CO₂ and an atmospheric lifetime exceeding 3,000 years. This study aims to assess the environmental risk posed by SF₆ usage in high voltage substations through a quantitative risk analysis using Monte Carlo simulation. The research was conducted at 18 substations under the management of PT PLN (Persero) Central Java Transmission, comprising 14 Air Insulated Switchgear (AIS) and 4 Gas Insulated Switchgear (GIS) installations. Operational data, including SF₆ refill and replacement records, were collected to estimate emissions and evaluate risk based on the likelihood of gas leakage and its environmental impact in CO₂-equivalent terms. The results show that even relatively small quantities of leaked SF₆ contribute significantly to overall greenhouse gas emissions due to its exceptionally high Global Warming Potential (GWP). Monte Carlo simulation enabled the modelling of emission scenarios and the construction of risk maps that reflect both the probability and severity of potential environmental impacts. From the simulation results, it was obtained that there are 300 times the risk of SF₆ leakage and the worst case scenario there are 360 times the potential risk of SF₆ leakage and the best case scenario still has an impact on CO_{2ek} emissions of 155.133,66 tons and the worst case scenario is still 199.101,08 tons of CO_{2ek} emission impact until the end of 2028. Sensitivity analysis further identified key variables that significantly influence emission outcomes namely the frequency and mass of SF₆ gas filling in the equipment in AIS/GIS. This research supports the development of risk mitigation strategies in the electric power sector, aligning with Indonesia's commitment to achieving Long Term Plan PLN in 2028 in emission reduction, Nationally Determined Contribution (NDC) 2030 and Net Zero Emissions (NZE) by 2060. Recommendations include improving SF₆ leakage monitoring systems, enhancing gas management practices, and exploring environmentally friendly alternative insulating gases.

Keywords: SF₆ Utility, Green House Gas, Emission, Monte Carlo Simulation, Risk Analysis.