Analisis Variabel Modul PV dan Variabel Ketinggian Lahan Terhadap Kinerja Sistem Pembangkit Listrik
Tenaga Surya Skala Besar. Studi Kasus : PLTS IKN 50 MW
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INTISARI

Pemerintah Indonesia menargetkan bauran energi terbarukan sebesar 23% pada tahun 2025. Kendala teknis dan pembiayaan dilaporkan menyebabkan keterlambatan proyek Energi Baru Terbarukan (EBT). Pembangunan PLTS IKN 50 MW di Kalimantan Timur merupakan proyek strategis negara dengan target selesai ditahun 2025. Perubahan spesifikasi komponen utama (modul PV) dan kondisi topografi-geologi lahan terjadi saat fase perencanaan dan desain melalui *Basic Engineering Design* (BED) sampai fase *Engineering Procurement Contruction* (EPC) melalui *Detail Engineering Design* (DED). Penelitian bertujuan menganalisis dampak variabel perubahan modul PV dan deviasi topografi-geologi lahan terhadap kinerja PLTS dan kerugian teknis. Melalui 6 varian skenario alternatif dilakukan perancangan dan simulasi. Metodologi penelitian menerapkan pendekatan deskriptif kuantitatif yang mengombinasikan data sekunder pengukuran topografi/geologi lahan, pemrosesan data meteorologi, serta pemodelan simulasi 3D dan parameter kelistrikan berbasis perangkat lunak PVsyst 8.1.4. Variabel independen modul PV dengan 4 varian spesifikasi modul PV *monocrystaline* berteknologi : *p-type monofacial* PERC 550 Wp (BED) dan *n-type bifacial* (DED) terdiri SMBB 625 Wp, HPDC 620 Wp, i-TOPCon 625 Wp. Parameter independen lahan dengan 3 varian deviasi lahan yaitu *before land clearing based* BED, *after land clearing based* DED, dan setelah *land development based final* DED. Parameter dependen adalah kinerja PLTS mencakup produksi energi tahunan, produksi spesifik, *performance ratio*, DC/AC *ratio*, kerugian *array*, kerugian *system* dan diagram kerugian teknis. Hasil penelitian menunjukkan bahwa perubahan modul PV pada Skenario 1 (78HL4-BDV) memiliki keunggulan diantara varian modul pada lahan BED, dengan DC/AC ratio sebesar 1,35, produksi energi tahunan 17.435 MWh/tahun dan nilai PR 81,2%. Modul dengan tegangan kerja (V_{mpp}) lebih tinggi terbukti menekan arus (I_{mpp}) sehingga menurunkan rugi-rugi resistif kabel (I^2R) dan mengoptimalkan kerugian sistem (Ls) sebesar 0,23 kWh/kWp/hari. Pada variabel perubahan lahan, Skenario 6 (paska land development-DED) melalui rekayasa lahan (*land development*/*land treatment*) mampu mengoptimalkan nilai Final *Grade Level*/FGL dan pelebaran pitch dari 6 m menjadi 7,38 m mampu menurukan nilai *Ground Coverage Ratio*/GCR dari 82,5% menjadi 67,1% memitigasi kerugian naungan dekat. Kombinasi Skenario 6 (modul "A" dan *land development* DED) menghasilkan kinerja PLTS tertinggi secara keseluruhan, dengan energi sistem tahunan 17.852 MWh/tahun, PR sebesar 83,1%, produksi spesifik 1.322 kWh/kWp/tahun, daya *DC nominal* 13.500 kWp, Lc sebesar 0,47 kWh/kWp/hari, dan Ls sebesar 0,26 kWh/kWp/hari, yang secara signifikan memenuhi seluruh kriteria prasyarat penerimaan proyek. Penelitian ini mengonfirmasi bahwa alternatif teknologi modul PV dan rekayasa topografi dan geologi lahan secara simultan terbukti berdampak positif pada peningkatan nilai kinerja PLTS dan menurunkan kerugian teknis pada PLTS skala besar di area tropis.

Kata Kunci: PLTS Skala Besar, Simulasi Kinerja PLTS, Simulasi PVsyst, *Performance Ratio*, DC/AC *Ratio*, Kerugian Teknis PLTS, Deviasi Topografi-geologi Lahan PLTS, Teknologi Modul PV, PLTS.

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ABSTRACT

The Indonesian government targets a renewable energy mix of 23% by 2025. Technical and financing constraints have reportedly caused delays in New and Renewable Energy (EBT) projects. The construction of the 50 MW IKN Large-Scale Solar Power Plant (PLTS IKN) in East Kalimantan is a strategic national project with a target completion in 2025. Changes in the specifications of the main components (PV modules) and the topographic-geological conditions of the land occurred during the planning and design phase through Basic Engineering Design (BED) to the Engineering Procurement Construction (EPC) phase through Detailed Engineering Design (DED). The study aims to analyze the impact of variables of changes in PV modules and deviations in topographic-geological land on solar PV plant performance and technical losses. Through 6 alternative scenario variants, design and simulation were carried out. The research methodology applies a quantitative descriptive approach that combines secondary data from topographic/geological measurements of the land, meteorological data processing, and 3D simulation modeling and electrical parameters based on PVsyst 8.1.4 software. Independent variables of PV modules with 4 variants of monocrystalline PV module specifications with technology: p-type monofacial PERC 550 Wp (BED) and n-type bifacial (DED) consisting of SMBB 625 Wp, HPDC 620 Wp, i-TOPCon 625 Wp. Independent parameters of land with 3 variants of land deviation: before land clearing based on BED, after land clearing based on DED, and after land development based on final DED. The dependent parameters are solar PV plant performance including annual energy production, specific production, performance ratio, DC/AC ratio, array losses, system losses and technical loss diagrams. The results show that changes in PV modules in Scenario 1 (78HL4-BDV) have advantages among module variants on land BED based, with a DC/AC ratio of 1.35, annual energy production of 17,435 MWh/year and a PR value of 81.2%. Modules with higher working voltage (Vmpp) are proven to suppress current (Impp) thereby reducing cable resistive losses (I2R) and optimizing system losses (Ls) by 0.23 kWh/kWp/day. In the land change variable, Scenario 6 (post-land development-DED) through land engineering (land development/land treatment) is able to optimize the Final Grade Level/FGL value and widening the pitch from 6 m to 7.38 m is able to reduce the Ground Coverage Ratio/GCR value from 82.5% to 67.1% mitigating near-shading losses. The combination of Scenario 6 (module "A" and land development DED) yielded the highest overall solar PV plant performance, with an annual system energy of 17,852 MWh/year, PR of 83.1%, specific production of 1,322 kWh/kWp/year, power nominal dc of 13,500 kWp, Lc of 0.47 kWh/kWp/day, and Ls of 0.26 kWh/kWp/day, significantly meet all project acceptance criteria. This study confirms that alternative PV module technologies and land topography and geology engineering simultaneously have a positive impact on improving solar PV plant performance and reducing technical losses in large-scale solar PV plants in tropical areas.

Keywords: Large-Scale Solar PV Plant, Solar PV Plant Performance Simulation, PVsyst Simulation, Performance Ratio, DC/AC Ratio, Solar PV Plant Technical Losses, Topographic-Geological Deviation of Solar PV Land, PV Module Technology, Solar PV Plant.