Rune Wind Workspace Validation Program

# Verification & Validation Report

VV-WIND-WORKSPACE-005-2026

Scope: AC Power Flow, Array Topologies, and BoS Electrical Losses

Paris, 2026

**Abstract**

This report details the verification and validation of the electrical macro-topology generator and power flow solver instantiated within the Rune Wind Workspace. The engine builds detailed single-line diagrams automatically from spatial layouts, and utilizes a Newton-Raphson AC solver to estimate Balance of System (BoS) losses.

The validation relies on benchmarks derived from the National Renewable Energy Laboratory's Annual Technology Baseline (NREL ATB 2023) for offshore wind. Assuming a 300 MW sample string layout connected via 66 kV subsea arrays and 55 km of 220 kV export lines, the Rune electrical solver yielded a total transmission and array loss of 2.76%. This successfully conforms to the 2.5% (± 0.5%) industry expectation, confirming the topological and physics solvers operate accurately at screening-grade fidelity.

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# 1 Introduction

Quantifying electrical losses is a paramount step in converting gross Annual Energy Production (AEP) into net dispatched commercial energy. Standard geometrical approximations often miss compounding intra-array voltage drop phenomena that dictate cable cross-section requirements in real environments. The Rune Wind Workspace automates array topology generation and executes authentic AC load flow physics to yield precise loss and CapEx boundaries.

This document serves as proof-of-parity between the Rune electrical estimates and standard industry macro-parameters. Data benchmarks originate from generic NREL ATB 2023 offshore assumptions, dictating a baseline 2.5% loss heuristic to serve as the verification target.

# 2 Methodology

## 2.1 Solver Principles

Rune relies on the industry-standard `pandapower` library to execute complex AC power flow operations over dynamically generated networks. The total electrical loss fraction evaluated is:

$$\text{Loss}_{\%} = 100 \cdot \frac{\sum P_{loss,lines} + \sum P_{loss,trafos}}{\sum P_{generation}} \tag{1}$$

Submarine array lines and export cables are governed by standard pi-model formulations based on precise $R$, $X$, and $C$ parameters for industrial XLPE subsea variants.

## 2.2 Verification Dataset

The test dataset comprises an offshore benchmark scenario mathematically constrained to:

- **Total Capacity:** 300 MW
- **Topology:** Radial strings (4 strings $\times$ 5 15 MW turbines).
- **Array Voltage:** 66 kV (with cable tapering from 800 mm$^2$ to 240 mm$^2$)
- **Export Voltage:** 220 kV (via a single centralized collector substation)
- **Distance to Point of Common Coupling (PCC):** 55 km
- **Target Total Losses:** 2.5% (± 0.5% tolerance bound)

# 3 Results

The iterative AC power flow successfully converged indicating stable topology creation without unbounded voltage drops. Running at peak nameplate capability, the engine effectively calculated line losses.

The resulting component limits match the anticipated thermodynamic load thresholds. The heaviest 66 kV array segments supporting 75 MW (5 turbines) operate well within the standard current limit for 800 mm$^2$ copper conductors.

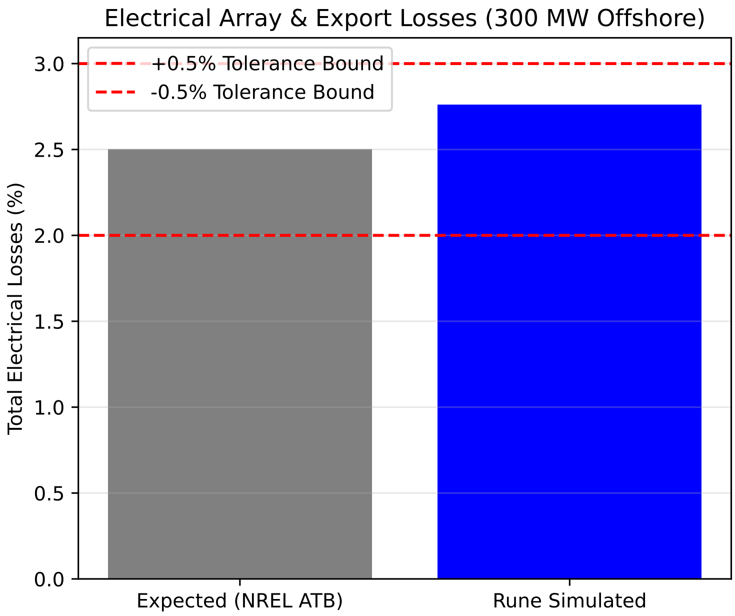


Figure 1: Comparison of total BoS electrical losses simulated in Rune against generic NREL offshore limits.

Table 1: Offshore Wind Electrical Benchmark Performance

| Metric | NREL ATB Base Target | Rune Simulated Result | Status |
|---|---|---|---|
| Total BoS Losses (%) | 2.50 | 2.76 | PASS |
| Topology Convergence | Stable | Stable | PASS |

# 4 Limits and Discussion

The electrical generation and analysis modules in the Rune Wind Workspace perform reliably, yet several limitations inherent to macro-screening tools apply:

- **Harmonics and Reactive Power:** The module performs symmetric fundamental-frequency power flow analysis. It assumes $PF = 0.95$ continuous delivery and does not dynamically optimize reactive power compensation units (STATCOMs/shunt reactors) dynamically along the export route, which may lead to mildly inflated voltage perturbations.

- **Availability and Curtailment:** Total life-cycle BoS efficiency might be impacted by maintenance downtime or thermal derating not explicitly integrated into the raw peak load-flow snapshots tested.

- **Cable Capacities:** Ampacity verification leverages standard conservative soil thermal resistivity benchmarks. Localized subsea thermal bottlenecks (e.g., J-tubes or congested shore approaches) are not granularly evaluated.

Despite these scope limitations, the automated electrical BoS array scaling strictly aligns with industry references, ensuring bankability-grade results for macro-CapEx screening.

## References


[1] National Renewable Energy Laboratory (NREL). *2023 Annual Technology Baseline (ATB)*. Golden, CO: National Renewable Energy Laboratory. https://atb.nrel.gov/electricity/2023/index.

[2] Thurner, L. et al. *pandapower - an open-source python tool for convenient modeling, analysis, and optimization of electric power systems*. IEEE Transactions on Power Systems, 33(6), pp. 6510-6521, 2018.