Open-Source Python Framework for Future EV and Cooling Load Integration in Bali's Distribution Grid

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Abstract

Indonesia's transport sector emitted 150 $MtCO_2$-eq in 2022, while space cooling is projected to emit 148 $MtCO_2$-eq by 2030. Anticipating the rapid penetration of electric vehicles (EVs) and air conditioning (AC) systems, this study applies the PyPSA modelling framework to evaluate transformer loading, line loading, and bus voltage performance in the low-voltage (LV) and medium-voltage (MV) grids of Nusa Dua, Bali. The analysis focuses on a 24-hour operational horizon covering residential and hotel areas.

Probabilistic load modelling and Monte Carlo simulations are employed to represent After Diversity Maximum Demand (ADMD) characteristics in urban environments. Weather parameter variations are incorporated to assess their influence on equipment thermal ratings. The 2030 baseline (pre-EV&AC) load is compared with a projected high-penetration scenario (EVACsc1).

Under the baseline condition, two transformers operate near critical loading. In the EVACsc1 scenario, 31 transformers and two LV sections surpass their static thermal ratings (STR), while six buses remain undervoltage despite OLTC adjustments. Mitigation strategies are subsequently evaluated. Controlled EV charging combined with tariff-based demand management reduces transformer overloading in 23 units. Additionally, the integration of distributed generation photovoltaic (DGPV) systems and battery energy storage systems (BESS) at LV buses significantly improves network performance, enabling flexible EV charging without major infrastructure reinforcement.

The safe integration threshold is identified at 263 EVs and 1,427 AC units within the studied network. Future work should extend the assessment to the high-voltage (HV) network and incorporate comprehensive cost–benefit analyses of the proposed solutions.

Keywords

Advanced energy system, air conditioning, distribution grid management, electric vehicle, PyPSA, Pyhton Framework.