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RISK ASSESSMENT FRAMEWORKS FOR INTEGRATING RENEWABLE ENERGY TECHNOLOGIES INTO EXISTING INFRASTRUCTURE: A STRUCTURED REVIEW

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Abstract – The rapid expansion of inverter-based renewables is transforming power, industrial and building infrastructures that were designed around centralized synchronous plants, creating new and interconnected risk profiles. This review synthesizes 2019–2025 academic and institutional literature to (i) classify the main technical, economic, operational and institutional risks associated with integrating renewables into existing infrastructure and (ii) evaluate quantitative and qualitative methods used to assess them. The synthesis shows that deterministic planning tools are inadequate under high renewable penetration. Probabilistic methods (Monte Carlo and probabilistic power flow) more accurately capture frequency, voltage and congestion risk distributions and can significantly reduce expected loss-of-load and energy-not-served metrics when embedded in planning studies. Multi-criteria decision analysis, particularly AHP- and TOPSIS-based approaches with fuzzy extensions, provides transparent ranking of technologies and integration strategies under conflicting technical, economic, environmental and social criteria, though results are sensitive to method choice and weighting. FMEA and fuzzy-FMEA effectively prioritize component-level failure modes in wind, PV and storage projects but are rarely linked to system-wide analyses. Emerging hybrid frameworks that couple probabilistic simulation, MCDA and (fuzzy) FMEA and align with ISO 31000 principles offer the most comprehensive coverage of the identified risk categories, yet their practical uptake is limited by data, modeling and governance gaps, especially for cybersecurity, climate resilience and social equity. The paper proposes an integrated risk taxonomy and outlines priorities for embedding such hybrid approaches into utility planning, project appraisal and energy-transition governance.

Keywords – *Decision-support methods; Failure Mode and Effects Analysis (FMEA); Multi-Criteria Decision Analysis (MCDA); power-system resilience; probabilistic reliability modelling; uncertainty quantification*