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WASTE HEAT UTILISATION FOR THERMAL MANAGEMENT OF OUTDOOR BATTERY ENERGY STORAGE IN COLD-CLIMATE MICRO-PV SYSTEMS

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Abstract – In Estonia, a micro-producer is defined by the distribution system operator *Elektrilevi* as an electricity producer operating a three-phase generating unit with a maximum installed capacity of up to 15 kW. Over recent years Estonia has experienced rapid growth in photovoltaic (PV) generation connected to the distribution network, accompanied by a substantial increase in installed solar capacity. By the end of 2024, cumulative PV capacity connected to the Estonian power system had exceeded by approximately 1.3 GW, following a record annual addition of around 513 MW during the same year. In parallel, the number of electricity producers connected to the *Elektrilevi* distribution network had risen to over 22 800 by 2025, the vast majority of which are PV-based installations. Concurrently, electricity market conditions have evolved, so that periods of high solar generation increasingly coincide with low or even negative wholesale electricity prices. This development has incentivised producers to seek solutions for temporal shifting of electricity exports to more favourable price periods, most commonly through the deployment of battery energy storage systems. However, many Estonian micro-producers face significant barriers to battery adoption, as PV installations are frequently located away from buildings and most commercially available battery systems are not recommended for outdoor operation under sub-zero temperature conditions, thereby complicating year-round use in cold climates. This study investigates the hypothesis that internally generated waste heat – arising from inverter (DC/AC) conversion losses and battery charge–discharge inefficiencies could be sufficient to maintain the thermal conditions required for an outdoor battery facility located adjacent to a PV installation. The objective is to assess whether such a passive or semi-passive thermal management approach is technically feasible and economically viable for micro-producers operating under Estonian climatic conditions

Keywords – Distributed generation; electricity price volatility; heat dissipation; passive heating; sub-zero operation