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Keywords Kolmogorov-arnold networks, Critical event prediction, Proximal policy optimization, Chernoff–Hoeffding bound, Alarm significance, Info-gap decision theory

Highlights

- Probabilistic forecasting of transformer overload alarms under LV grid stress.
- KAN, ANN, and KAN + ANN estimate load together with epistemic and aleatoric uncertainty.
- PPO selects best prediction model at each time step reducing error and uncertainty.
- Chernoff–Hoeffding bound quantifies the predicted overload significance.
- IGDT evaluates the robustness of alarm states under uncertainty enlargement.

Abstract

The increasing electricity demand and rapid adoption of Electric Vehicle (EV) charging stations are intensifying transformer loading and uncertainty in electrical grids operating near their capacity limits. This paper presents a probabilistic framework for overload alarm forecasting using real residential load data augmented with synthetically generated EV charging demand. Epistemic and aleatoric uncertainties are modeled through Monte Carlo dropout and a probabilistic output distribution, respectively. Three prediction models are considered, namely the Kolmogorov-Arnold Network (KAN), an Artificial Neural Network (ANN), and a hybrid KAN + ANN model. To dynamically select the most suitable model at each time step, the Proximal Policy Optimization (PPO) algorithm is employed with three reward functions targeting prediction accuracy, uncertainty reduction, and a trade-off between the two. Unlike conventional threshold-based alarm triggering, the proposed method evaluates the significance of predicted overload intervals using a discrete Chernoff–Hoeffding bound formulation applied to the uncertainty-aware predicted load trajectory. The resulting alarm significance is classified into green, yellow, and red states, while Info-Gap Decision Theory (IGDT) is used to assess the robustness of each alarm class under uncertainty enlargement. The proposed framework is evaluated as a proof of concept using hourly aggregated load data from two Danish residential transformers under EV-augmented loading scenarios. Within this study setting, the framework identifies the analyzed overload patterns, assigns alarm-significance levels, and provides robustness information beyond simple threshold crossing. The comparison with DDQN indicates broadly comparable alarm-horizon results, with only modest numerical differences observed in one borderline yellow interval.

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