Risk-Based Dynamic Thermal Rating in Distribution Transformers via Probabilistic Forecasting

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By 2050 electricity demand is expected to increase 50–100% [1]. Current LV distribution transformer planning and protection philosophies are static and conservative, often constraining capacity unnecessarily. To meet future demand requirements DNOs need to be able to overload assets with controllable risk levels. This work uses day-ahead, probabilistic forecasting, to demonstrate potential capacity gains with quantifiable hotspot risk levels ahead of time.

Methodology:

Adaptive protection devices can allow some degree of overloading via an adjustable scale factor which controls the current at which the device trips [2]. We propose using these devices to enable Dynamic Thermal Rating (DTR) in distribution networks. We employ a dataset of 644 LV transformers with five months of load data to examine the applicability of this approach at scale.

Retrospectively, we calculate the optimal scale factor which would cause the protection device to trip when the loading and ambient temperature are sufficient to generate a hotspot temperature of 140°C in the transformer. We use a probabilistic forecasting model to predict the next day's optimal scale factor with a quantified level of certainty that it will offer sufficient protection from excessive hotspot development (> 140°C).

Forecasting Accuracy:

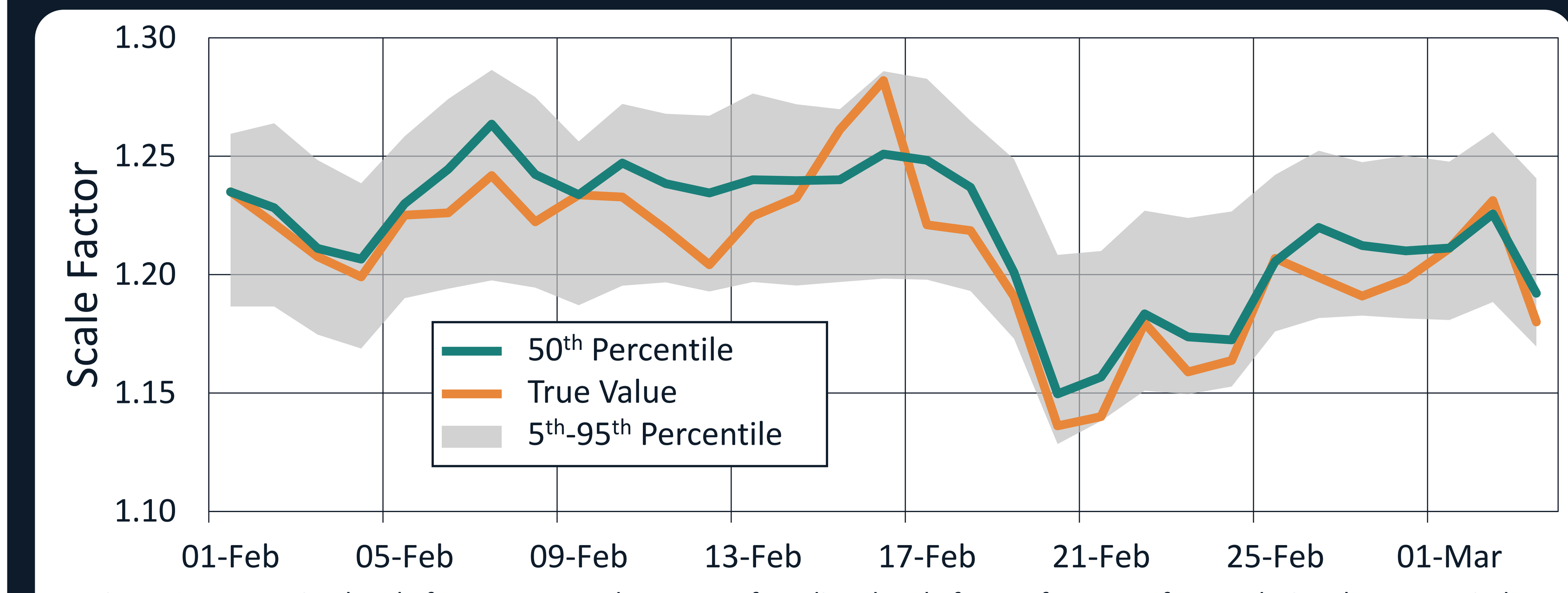

Figure 1: True optimal scale factor compared to range of predicted scale factors for a transformer during the test period.

Figure 1 shows how the calibration accuracy of the predicted percentiles can be determined. The true optimal scale factor falls within the 5th and 95th prediction percentiles over 90% of the time across the fleet.

When multi-stage load forecasting-based approaches are used, this collapses to 17%, due to the compounding of errors.

Choosing the *p*th percentile maps to *p%* overheating vulnerability.

A 2% vulnerability to overheating can unlock >10% extra capacity compared to static protection.

Direct prediction of protection settings outperforms multi-stage load forecasting-based approaches.

Results:

Figure 2 shows the consistent mapping between the prediction percentile and the vulnerability to excessive hotspot temperatures (> 140°C). By directly predicting the optimal scale factors, DNOs control the risk vs capacity gain trade-off. Using a conservative 2nd percentile allowed >10% more loading across the transformer fleet.

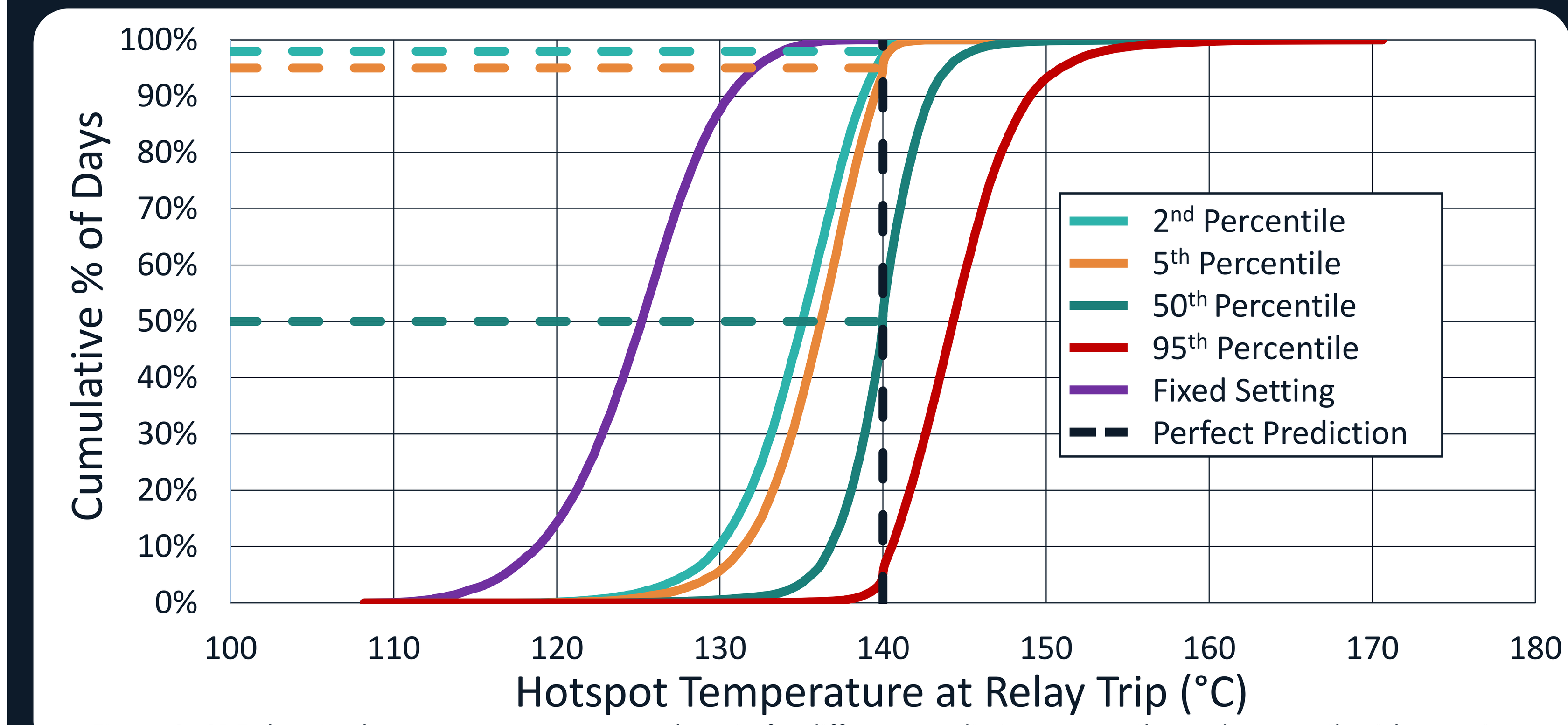

Figure 2: CDF showing hotspot temperature at relay trip for different prediction percentiles and percentile-risk mapping.

Implications:

The need for complex load and temperature correlation analysis is removed through the direct forecasting of protection settings as it has been shown to outperform load forecasting-based approaches.

The simple percentile-risk mapping provides a clear, interpretable basis for DNOs to set protection policy in line with their risk appetite and capacity requirements. Probabilistic forecasting also allows operators to absorb other uncertainties such as weather into the selected percentile of predicted scale factor.

This approach enables scalable, automated deployment of risk-aware DTR in LV transformers, unlocking significant capacity increases whilst still ensuring transformers are sufficiently protected from excessive hotspot development. Future work will look at how the tripping signal from these devices can be used to mitigate overload in future active LV distribution grids.

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[Online]. Available: https://www.spenergynetworks.co.uk/userfiles/file/DFES_SP_Distribution_2023.pdf

[2] GE Grid Solutions, "Relay Technical Manual," 2022
[Online]. Available: https://www.gevernova.com/grid-solutions/products/manuals/p40aenh-tm-en-3.pdf

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