Autonomous AI-Driven Grid Protection: Sub-Cycle Fault Response via NPU-Optimized Neural Networks

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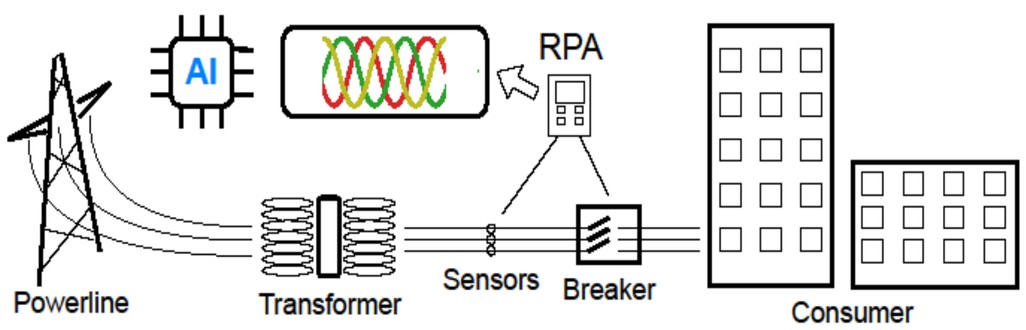
Motivation

Relay Protection and Automation (RPA) devices are essential for detecting and isolating faults and maintaining the stability of the power system. Conventional RPA systems rely on static and manually tuned thresholds, which do not always adapt to dynamic grid environments, particularly with renewable energy integration.



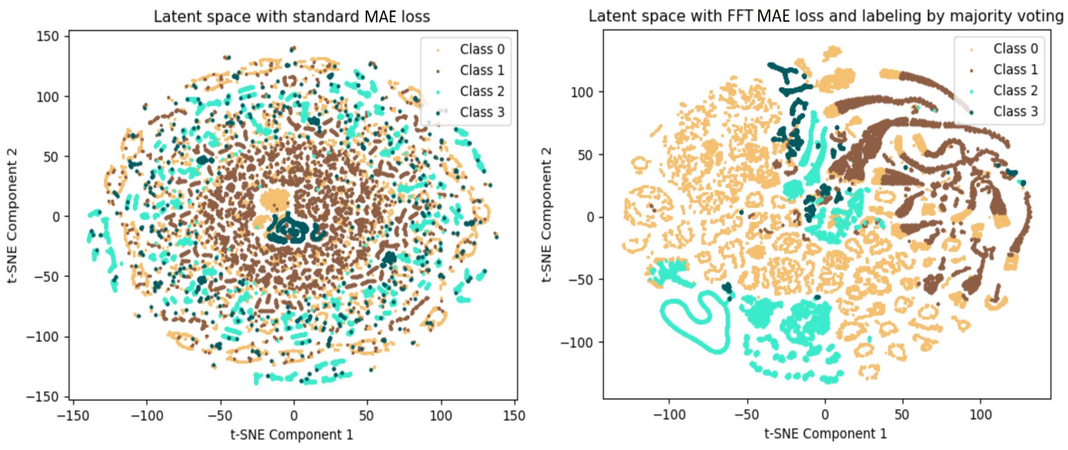
Relay Protection and Automation (RPA) devices are installed between the power supplier and the consumer. They monitor the power quality and, under certain triggering conditions, send a request to switch power lines. The built-in AI can enhance their performance by improving response time and reliability.

Baseline

Static threshold for the first harmonics of line voltages:

$$100 \times \sqrt{2} \times 0.85 \text{ (V)}$$

Neural Networks



The best scores were obtained by the CNN based autoencoder. Fast Fourier Transform (FFT) was used in reconstruction loss:

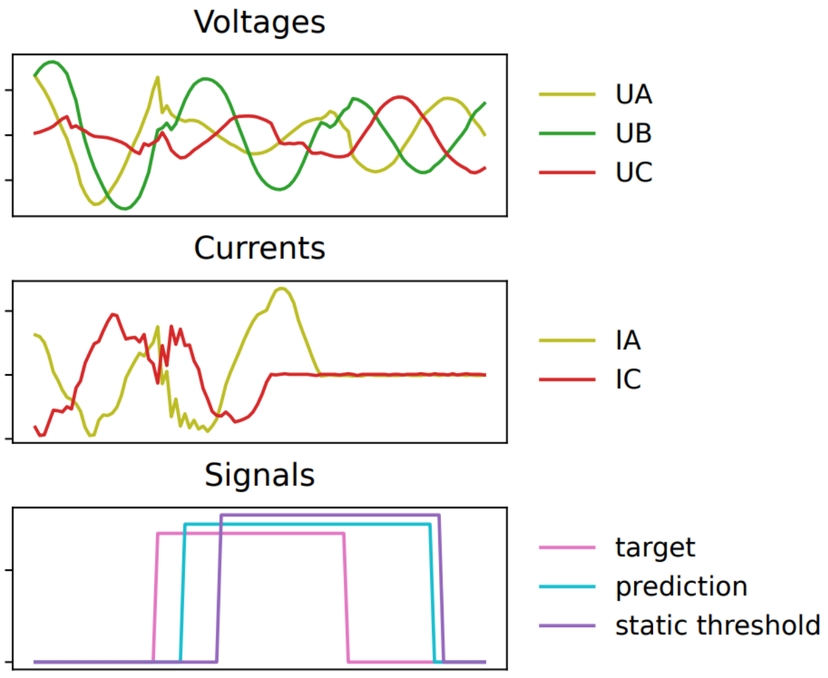
$$MSE_{FFT} = \frac{1}{N}\sum(FFT(x) - FFT(\hat{x}))^2$$

NPU implementation

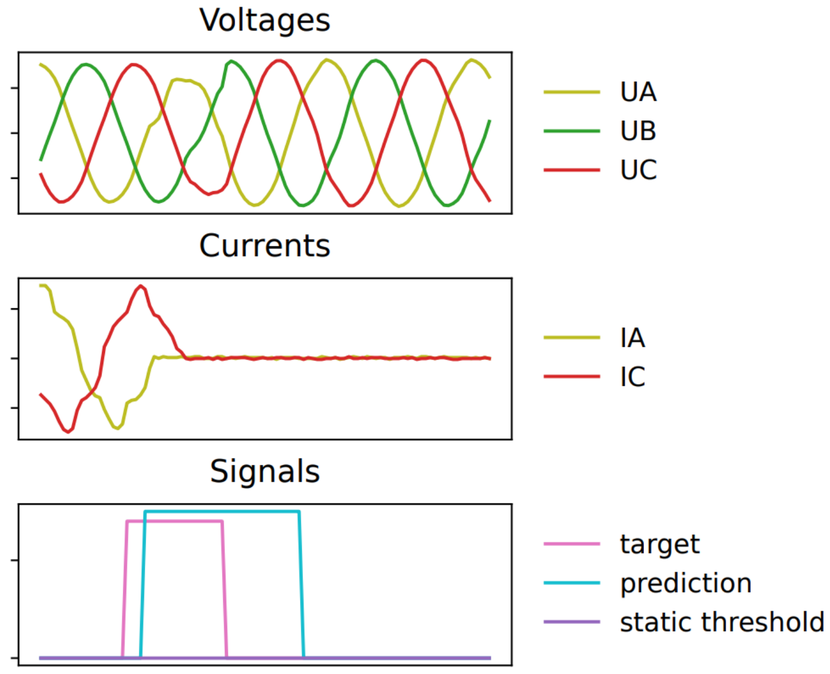
Models (MLP, GRU, CNN) were deployed on an embedded platform featuring the Rockchip RK3588 SoC with NPU. All architectures were implemented without quantization, retaining native 16-bit floating-point operations.

F1-score: 0.89Inference time: 0.2 ms (in 20ms cycle)

Comparison with static threshold



A case where the CNN operates faster than the static threshold.



Fault detected by CNN but missed by the static threshold.