

Comparison of IR, EKF, and NARX Estimators for Battery SOC and Voltage Prediction Across EV Pack Sizes

- Data-Driven and Physics-Based Approaches for Multi-Scale Battery Packs -

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Accurate state-of-charge (SOC) and terminal-voltage estimation are important for battery management systems in electric commercial vehicles. This study compares an Internal Resistance (IR) model, an Extended Kalman Filter (EKF), and a Nonlinear Autoregressive with Exogenous Inputs (NARX) model across S, M, and L battery configurations containing one, two, and three parallel battery-pack units, respectively. Their nominal energies are approximately 41, 83, and 124 kWh. The experimental setup includes battery climatic chambers and a charge/discharge simulator, as shown in Fig. 1.

The IR model calculates SOC by current integration and terminal voltage from SOC-dependent OCV and resistance relations. The EKF applies a bounded SOC correction while retaining the same underlying IR voltage relation. The NARX model estimates SOC and terminal voltage using delayed battery operating information. Architecture screening selected Levenberg–Marquardt training, hidden layers of 15 and 10 neurons, purelin transfer functions, 300 maximum epochs, and a delay range corresponding to approximately 10 s of preceding battery behavior.

On regular-temperature JE05 logger data, the IR and EKF models produced nearly identical results, with a mean voltage RMSE of 2.82 V. NARX reproduced the complete SOC and voltage trajectories more closely, achieving mean (R^2) values of 0.9997 for SOC and 0.9626 for voltage, with a mean voltage RMSE of 0.53 V. The corresponding NARX trajectories are shown in Fig. 2. These full-run results represent whole-cycle reproduction rather than independent prediction.

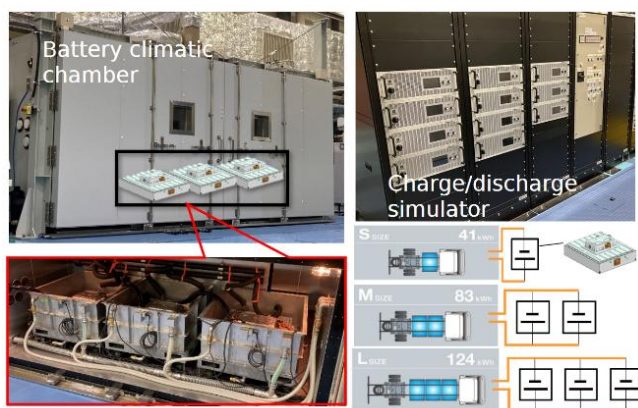


Fig. 1 Powertrain testing facility

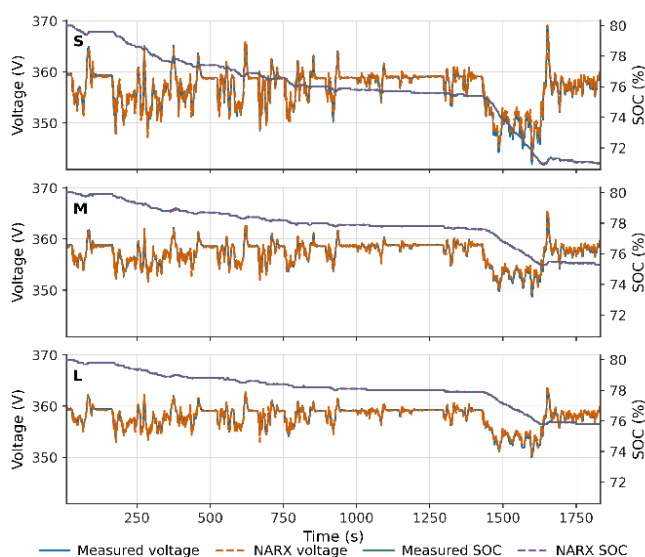


Fig. 2 Regular-temperature JE05 full-run NARX estimates for S, M, and L.

Predictive performance was therefore evaluated separately using blocked and forward holdout tests. The controlled voltage predictor used ten previous current samples, ten previous measured-voltage samples, and three S/M/L configuration indicators, without using present-sample SOC, current, voltage, or future information. Relative to a previous-sample voltage baseline, the delayed model reduced RMSE by 16.8–22.6% in the blocked holdout and 17.8–20.8% in the forward holdout for every battery configuration.

Additional cold-condition tests using a separately fitted model gave voltage (R^2) values of 0.9899 for 50 km/h at -25°C , 0.9960 for 80 km/h at -15°C , and 0.7571 for JE05 at -25°C . Overall, the results show that recent operating history provides useful predictive information for terminal-voltage estimation across the evaluated S, M, and L battery configurations.