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Dynamic state estimation using ESN+NARX in ESP-operated oil wells

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ABSTRACT

The Echo State Network (ESN) is a type of recurrent artificial neural network (RNN) within the reservoir computing paradigm. Originally introduced by Jaeger (2001), the ESN model consists of three main components: an input layer, a reservoir (hidden) layer, and a readout (output) layer. Its training procedure is relatively simple and computationally efficient compared to other recurrent architectures, such as Long Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU) networks. In the offshore oil and gas industry, where phenomenological models often exhibit uncertainties due to parameter variations under real field operating conditions, ESNs emerge as a promising alternative. Their performance becomes even more effective when combined with a Nonlinear AutoRegressive with Exogenous Input (NARX) structure, enabling the use of historical data to infer variables that are difficult to measure. This study proposes an extension of the ESN model presented by Abreu et al. (2025) by introducing an ESN+NARX architecture to estimate difficult-to-measure variables in an artificial lift system equipped with an Electrical Submersible Pump (ESP). The estimated variables are annulus level (La), choke pressure (pwh), production flow rate (qm), fluid viscosity (μ), and productivity index (PI), which are important for production monitoring and control (Takacs, 2018). The ESN+NARX model was trained using datasets obtained from a state estimator presented in the work of Abreu et al. (2022) at the pilot plant of the Artificial Elevation Laboratory (LEA) of the Federal University of Bahia. The hyperparameters were systematically tuned through a grid-search approach, considering reservoir sizes ranging from 50 to 900 neurons, leakage rates between 0.1 and 0.2, and spectral radii from 0.90 to 0.99. The proposed methodology was implemented using the open-source CasADi framework. The validation procedure compared the conventional ESN with the proposed ESN+NARX architecture using datasets not included in the training phase. The results demonstrate that the ESN+NARX model outperforms the conventional ESN in estimating the analyzed variables. The close agreement between the predicted and experimental data, associated with lower Mean Absolute Percentage Error (MAPE) values, highlights the robustness and accuracy of the ESN+NARX model, demonstrating its potential for reliable monitoring of offshore oil and gas production systems.

Keywords: Electrical submersible pump, State estimation, Echo State Network

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