Dynamic Simulation and Control of a Wind Powered Chlor-Alkali Electrolysis System

R.B.G.D.N. Rajapaksha*, N. Fernando

Faculty of Engineering, University of Peradeniya, Peradeniya, 20400, Sri Lanka
**e20311@eng.pdn.ac.lk*

The chlor-alkali membrane electrolysis process is one of the most electricity intensive operations in the chemical industry, producing chlorine, sodium hydroxide, and hydrogen for numerous industrial applications. Replacing fossil fuel-based electricity with renewable energy sources such as wind power offers significant environmental benefits but introduces power fluctuations that challenge stable electrolyzer operation. This study develops a dynamic mathematical model and control strategy to investigate the feasibility of operating a membrane chlor-alkali electrolyzer under fluctuating wind power while maintaining stable product quality. The research methodology involved developing an electrochemical model based on reversible voltage, activation overpotential, ohmic losses, and the additional resistance effects caused by gas bubble formation at the electrode surfaces. Dynamic mole balance model was also developed for the anode and cathode compartments to predict concentration changes as a result of flow variations with time. The model was implemented in Scilab, while the control strategy was developed in Scilab-Xcos using two PI controllers to regulate the anode brine feed rate and cathode water feed rate. The electrolyzer was operated over an industrial current density range of 3000–6000 A m^{-2}, representative of flexible operation under variable wind power. Model predictions were validated against published literature data, showing good agreement for steady-state cell voltage and electrolyte concentration trends. Inclusion of the bubble resistance model increased the predicted cell voltage by approximately 2.0 – 2.5 V at 6000 A m^{-2}, significantly improving agreement with reported operating voltages. The PI controllers maintained the cathode outlet concentration at 32 wt.% NaOH despite rapid current density variations. Controller parameters of Kp = 0.12, Ki = 0.28 for brine flow control and Kp = 74.27, Ki = 7.42 for cathode water flow control provided stable disturbance rejection with minimum steady state error. The results demonstrate that membrane chlor-alkali electrolyzers can be operated flexibly under renewable electricity while maintaining stable product quality. Future work will focus on benchmarking the model against industrial operating data and developing a two-dimensional CFD model using OpenFOAM to capture detailed hydrodynamics, gas bubble behaviour, and species transport, thereby providing more realistic predictions of electrolyzer performance.

Keywords: chlor-alkali electrolysis, dynamic modeling, wind energy integration, process control, CFD modeling