Control of a methanol reformer system using an Adaptive NeuroFuzzy Inference System approach

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Control of a methanol reformer system using an Adaptive Neuro-Fuzzy Inference System approach


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Introduction

This work presents a stoichiometry control strategy for a reformer methanol fuel cell system, which uses a reformer to produce hydrogen for a HTPEM fuel cell. One such system is the Serenus H3-350 battery charger developed by the Danish company Serenergy® which this work is based on. Figure 1 shows a picture of the system.

To avoid starving the fuel cell of hydrogen, it is important to know how much hydrogen is produced at any given time. It is not practical to measure the hydrogen production online and the standard control system of the H3-350 system assumes full reformation. However, the degree of reformation varies with the reformer temperature and the fuel flow. The stoichiometry set point is therefore set to 1.5, which is a safe distance from the recommended minimum of 1.15. This means that more methanol than necessary is consumed in some operating points and the stoichiometry approaches the minimum limit in others. The reformed gas composition can be calculated with some accuracy if the temperature of the reformer bed is known exactly. This is, however, not the case here as the temperature measurement in the reformer is placed in the bulk material next to the bed and not in the bed itself. Figure 3 shows an illustration of this issue.

This means that as the flow is increased, the reformer bed is cooled, the temperature gradient between the burner and the reformer bed becomes steeper, and the temperature measurement becomes unreliable.

Modeling

This work proposes a method which uses Adaptive Neuro-Fuzzy Inference Systems, ANFIS, trained on experimental data to predict the reformed gas composition. ANFIS is a neuro-fuzzy modeling approach which uses linguistic variables and parameters which are trained using a neural network to mimic the behavior of a physical system. Arbitrary precision can be achieved by increasing the complexity of the models. The ANFIS function in MATLAB is used to train the ANFIS models in this work. Figure 4 shows the ANFIS structure.

The ANFIS model shows good correlation with the measurements and the model is therefore deemed to be valid. Figure 6 shows the stoichiometry calculated using full reformation and the ANFIS model during a series of load changes.

The actual stoichiometry is very different from the one which is assumed using full reformation and approaches the lower stoichiometry at higher currents.

Conclusion

In this work the problem of controlling the stoichiometry of a Reformed Methanol Fuel Cell system is presented and a solution based on an ANFIS model is proposed. The ANFIS models are trained using experimental data obtained using a gas analyzer. The method has been tested experimentally in a Serenus H3-350 module. The method is capable of controlling the fuel cell anode stoichiometry both in steady state and during transients. The efficiency at the lower operating points is higher using the ANFIS fuel predictor but it is lower at the high operating point because of the higher constant stoichiometry.

Future Work

The ANFIS models can be improved by performing long term gas measurements and including reformer catalyst degradation as an input. Models of the mass flow of CO2, CO and the methanol which passes unreacted through the reformer have also been developed and used in a dynamic model of the Serenus H3-350 module. These models could also be incorporated in a diagnostic system in connection with a fuel cell model to catch incipient faults before the system is harmed.

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References

Figure 1: The Serenus H3-350 Reforming Methanol Fuel Cell system produced by Serenergy®

Figure 2: Diagram of the Serenus H3-350 Reforming Methanol Fuel Cell system produced by Serenergy®

Figure 3: Concept drawing of the reformer and burner of the Serenus H3-350

Figure 4: ANFIS model structure with two membership functions, T marks the use of a T-norm and H marks the normalisation of the firing levels.

Figure 5: Output of the ANFIS model for the hydrogen content in the reformed gas. Inputs are reformer temperature, the fuel flow and the fuel temperature.

Figure 6: Observed fuel cell stoichiometry during a series of load changes.

If a fuel cell is starved of hydrogen, the voltage will drop. There is no sign of this happening in this case. The efficiency from the higher heating value system efficiency is plotted in Table 1.

The efficiency is higher at both 10 and 14 [A] using the ANFIS predictor. This is because the fuel flow is lower at these operating points using the ANFIS predictors than with the standard controller. The opposite is the case at 16 [A] but here the stoichiometry using the standard control is dropping towards the lower stoichiometry limit.

Table 1: Higher heating value to electrolysis efficiency at different fuel cell currents

<table>
<thead>
<tr>
<th>Current [A]</th>
<th>Relative change %</th>
</tr>
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<tbody>
<tr>
<td>10</td>
<td>+20.2</td>
</tr>
<tr>
<td>14</td>
<td>+7.1</td>
</tr>
<tr>
<td>16</td>
<td>-5.8</td>
</tr>
</tbody>
</table>

The stoichiometry shown in figure 8 is calculated using an ANFIS model which is based on the same data as the predictor. This is a general problem in this kind of system. To give another indication of the validity of the method, the fuel cell voltage during a load change is plotted in Figure 9.