Proceedings of EFC2019
European Fuel Cell Technology & Applications Conference - Piero Lunghi Conference
December 9-11, 2019, Naples, Italy

EFC19152

DIAGNOSIS OF ELECTROCATALYST DEGRADATION IN POLYMER ELECTROLYTE FUEL CELLS UNDER AUTOMOTIVE CONDITIONS

D. Low*, L.M.Jackson*, and S.J.Dunnett*
*Department of Aeronautical and Automotive Engineering,
Loughborough University, Loughborough, (*United Kingdom*)

Abstract **– This paper presents a fuzzy inference system approach for diagnosis of electrocatalyst degradation in polymer electrolyte fuel cells (PEFC's) under automotive conditions. The fuzzy inference system enables diagnosis of electrocatalyst degradation based on fuel cell operating conditions. The method incorporates classification of selected input parameters on a scale of membership to fuzzy sets or categories and provides connection to any consequential degradation through a database of diagnostic rules. Experimental procedures involved drive cycle durability testing including the world harmonized light-duty vehicle test procedure (WLTP) and start/stop cycling. The observed results support the validation of the proposed membership functions within the fuzzy inference system and the database of diagnostic rules. This approach can provide a fast and effective diagnosis of electrocatalyst degradation in PEFC's and enable proactive decision support for planning operation and maintenance strategies for improved fuel cell reliability, availability and durability.**

Index Terms **– Diagnosis, electrocatalyst degradation, polymer electrolyte fuel cells, transportation application.**

I. INTRODUCTION

With the transport sector transitioning to low carbon technologies to reduce emissions and environmental impact, the application of fuel cells has become increasingly important. However, for commercialisation and consumer adoption to grow, attaining lifetime targets of up to 5,000hrs for automotive applications is required [1][2]. In order to achieve this, the reliability and durability aspects of fuel cells needs to be improved. Diagnosing the impact of operating conditions on fuel cell performance and lifetime is crucial to the advancement. An effective, low complexity diagnostic approach can provide the necessary improvement in health management and decision support for fuel cells in transport applications. This paper presents a diagnostic fuzzy inference system approach for electrocatalyst degradation in polymer electrolyte fuel cells (PEFC's) operated under automotive conditions. Automotive conditions for fuel cells include start/stop cycles and load cycling. It was estimated that the proportion of fuel cell degradation caused by these dynamic operating modes was 44% and 28% respectively [3]. Therefore, these operating modes were selected as input parameters for the diagnostic fuzzy inference system (FIS). Electrocatalyst degradation was identified to significantly impact the performance and lifetime of fuel cells and is known to be strongly influenced by automotive conditions [1][2]. Hence, this approach provides an effective diagnosis of electrocatalyst degradation for fuel cells under automotive conditions.

II. METHODOLOGY

The diagnostic fuzzy inference system approach incorporates fuzzification of selected indicators, a database of diagnostic rules, and defuzzification. The fuzzification process classifies the input data into broad categories based on severity. The classification is then compared to the database of diagnostic rules to identify the occurrence of any subsequent degradation. Defuzzification converts the broad classification into a numeric output for interpretation. The fuzzification of the input parameters and database of diagnostic rules were developed from a literature review and validated through experimental testing. Table 1 outlines the diagnostic rules for electrocatalyst degradation.

Table 1 Diagnostic rules for electrocatalyst degradation.

Rule	If	Then	References
1	Start/stop cycle number is high AND cell voltage cycle number is high	Electrocatalyst degradation is certain	[1][2][4][5]
2	Start/stop cycle number is high OR cell voltage cycle number is high	Electrocatalyst degradation is evidenced	[1][6][7] [8][9][10]
3	Start/stop cycle number is low OR cell voltage cycle number is moderate	Electrocatalyst degradation is none	[1][2]

III. Experimental

Experimental testing involved 145hrs of start/stop cycles and 145hrs of WLTP drive cycles on a $5cm^2$ cell and $25cm^2$ cell respectively. MEA's consisted of a 50-micron membrane and integrated carbon cloth GDL, with a $0.5mg/cm^2$ platinum loading anode and cathode (an/ca). Start/stop cycles included 30mins operation at steady state and 30 mins off (with nitrogen purge). Steady state conditions included 0.6V, 70ºC, 80% RH (an/ca), 1.5 and 2.0 stoichiometries (an/ca), $1e^{-6}$ and $3e^{-6}$ m^3/s flow rates (an/ca), 1 bar pressure.

IV. Results

Polarisation curves (IV curves) were used to analyse fuel cell performance and compare OCV differences which indicate electrocatalyst degradation. Figure 1 shows the beginning of life (BoL) and post test IV curves for start/stop cycle testing.

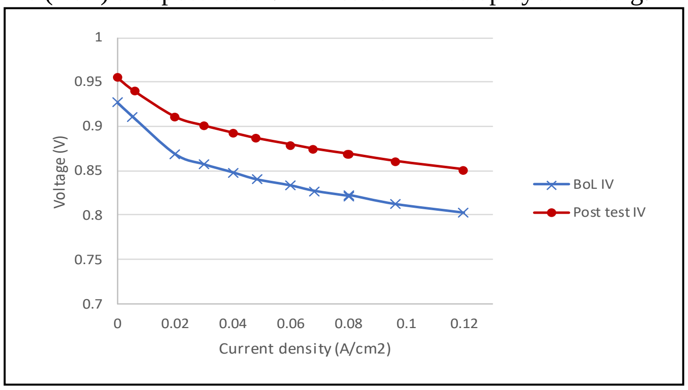

Fig. 1. Polarisation change curve after start/stop cycle testing

In Figure 1, the post test OCV increased by 28mV and overall performance improved. This confirms electrocatalyst degradation does not occur if start/stop cycles are low validating rule 3 outlined in table 1. Figure 2 shows the IV curves before and after WLTP drive cycle testing.

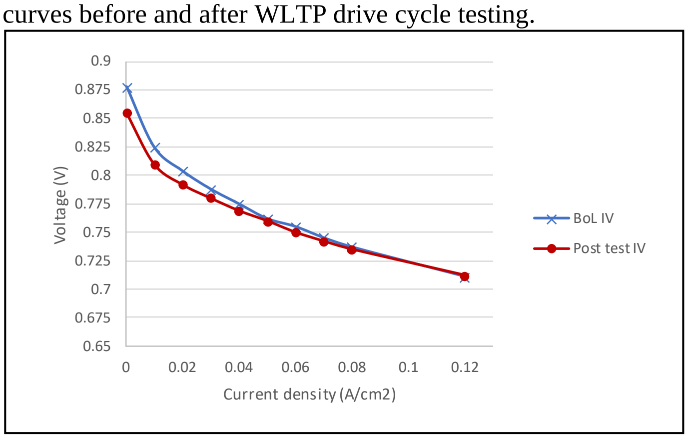

Fig. 2. Results from WLTP drive cycle testing

In Figure 2, the post test OCV decreased by 25mV confirming that if the voltage cycle number is high then electrocatalyst degradation is evident. Results show that start/stop cycles and voltage cycles can be effective indicators and support the diagnostic rules for electrocatalyst degradation.

V. Conclusion

Electrocatalyst degradation was not evident after the start/stop cycle test as OCV increased. The OCV decreased after the WLTP drive cycle test indicating that electrocatalyst degradation was evident. These results validate the diagnostic rules developed and show the diagnostic FIS can be utilised as an effective method for diagnosing electrocatalyst degradation in PEFC's under automotive conditions. Further work includes remaining useful life estimation based on degradation rates.

References

[1] Y. Yu, H. Li, H. Wang, X. Yuan, G. Wang, and M. Pan, "A review on performance degradation of proton exchange membrane fuel cells during startup and shutdown processes : Causes , consequences , and mitigation strategies," vol. 205, pp. 10–23, 2012.

[2] M.M Mench; E.C Kumbar; T.N Veziroglu, *Polymer Electrolyte Fuel Cell Degradation*. 2012.

[3] R. Shimoi, T. Aoyama, and A. Iiyama, "Development of Fuel Cell Stack Durability based on Actual Vehicle Test Data : Current Status and Future Work," *SAE Int. J. Engines*, vol. 2, no. 1, pp. 960–970, 2009.

[4] J. H. Kim, E. A. Cho, J. H. Jang, H. J. Kim, T. H. Lim, I. H. Oh, J. J. Ko, and S. C. Oh, "Effects of cathode inlet relative humidity on PEMFC durability during startup-shutdown cycling: I. Electrochemical study," *J. Electrochem. Soc.*, vol. 157, no. 1, pp. 104–112, 2010.

[5] J. H. Kim, Y. Yeon Jo, E. A. Cho, J. H. Jang, H. J. Kim, T. H. Lim, I. H. Oh, J. J. Ko, and I. J. Son, "Effects of cathode inlet relative humidity on PEMFC durability during startup-shutdown cycling: II. Diagnostic study," *J. Electrochem. Soc.*, vol. 157, no. 5, pp. 633–642, 2010.

[6] R. L. Borup, J. R. Davey, F. H. Garzon, D. L. Wood, and M. A. Inbody, "PEM fuel cell electrocatalyst durability measurements," vol. 163, pp. 76–81, 2006.

[7] V. Dam and F. de Bruijn, "The Stability of PEMFC Electrodes," pp. 494–499, 2007.

[8] W. Bi, Q. Sun, Y. Deng, and T. F. Fuller, "The effect of humidity and oxygen partial pressure on degradation of Pt / C catalyst in PEM fuel cell," *Electrochim. Acta*, vol. 54, pp. 1826–1833, 2009.

[9] S. J. Bae, S. J. Kim, J. I. Park, C. W. Park, J. H. Lee, I. Song, N. Lee, K. B. Kim, and J. Y. Park, "Lifetime prediction of a polymer electrolyte membrane fuel cell via an accelerated startup-shutdown cycle test," *Int. J. Hydrogen Energy*, vol. 37, no. 12, pp. 9775–9781, 2012.

[10] Y. S. Suk Joo Bae, Seong-Joon Kim, Jin-Hwa Lee, Inseob Song, Nam-In Kim and J.-Y. P. Ki Buem Kim, Naesung Lee, "Degradation pattern prediction of a polymer electrolyte membrane fuel cell stack with series reliability structure via durability data of single cells," *Appl. Energy*, vol. 131, pp. 48–55, 2014.