An Efficient Optimization Algorithm for Fuel Cell Stack Operation

Ganesh Sankaran
Software Developer
Gyan Data Private Limited
Chennai-600113 India
ganeshsankaran@gyandata.com

About the Client

Naval Materials Research Laboratory (N.M.R.L) is one of the oldest Laboratories of Defence Research and Development Organization under the Ministry of Defence, situated at Ambernath in Maharashtra state with proven record of excellence in scientific achievement.The lab has been particularly focusing their attention on the technological requirements of the Indian Navy with regard to marine materials and corrosion protection.

Motivation

India's reliance on foreign players for her defence needs has always been a matter of concern for national defence agencies.The self-reliance index for the defence industry has hovered around 40% to 50% for the last half of the decade [1]. There has been an increasing push from the government to develop indigenous technologies which would work symbiotically with armaments procured from abroad. This call for action has been met withN.M.R.L developing custom fuel cell stacks for use in Air Independent Propulsion (A.I.P) systems in submarines. In order to maintain battlefield supremacy through increased sortie times and reduced payload, these fuel cell stacks have to be operated optimally.

Problem

The operation of the fuel cell stacks can be posed as a constrained optimization problem, with the objective being minimization of the current drawn from the fuel cell stacks. The constraints were posed as the power generation from the stacks meeting the requested power and the potential across each of the fuel cell stacks and the current drawn from each of the fuel cell stacks being above a threshold.

Our early approach to solving the problem was conventional. Commercially available optimizers were used to solve the problem. The optimizers were able to converge to a solution when the requested power was within what was capable of the fuel cell stacks, but quickly failed with convergence issues for edge case scenarios. Additionally, the computational requirement for these optimizers were also steep, immediately making them unsuitable for use in embedded systems. We had to resort to other means to meet the requirements of robustness and low computational footprint.

Solution

We had expertise in fuel cell systems and used it to our advantage. Instead of concentrating our efforts in modifying the existing optimizers to suit our needs, we realized that a more fundamental understanding of the I-V characteristics of the fuel cell stacks was required. This decision led us to identify exploitable structures in the functional form of the I-V curve.

A purely geometrically derived interpretation to the entire optimization process was arrived at through this effort, with each step of the algorithm being explainable in terms of physical interactions among the fuel cell stacks. This not only allowed us to arrive at the optimal solution but also enabled us to provide suggestions on the manner in which the fuel cell stacks had to be connected to each other.

The computational requirement of this algorithm was also lower, with its highest level of mathematical complexity being reduced to solving a polynomial with closed form solutions. The algorithm was also robust, as it identified edge cases at the outset, allowing the supporting advisory power management systems to instantly take over and follow fail-safe protocols.

With the core in place, an intelligent I-V characteristic model updater was implemented on top of the algorithm for seamless integration into the power management systems for real-time usage. This was tested offline at the N.M.R.L facility on their land based prototype with excellent results.

Gyan Data is currently working closely with a third-party and N.M.R.L to integrate the algorithm into their P.L.Cs.

Acknowledgements

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References

[1] Behera, L. K. Indian defence industry issues of self-reliance. IDSA Monograph Series, 21 (2013), 52.