**Proceedings of the 18th UK Heat Transfer Conference**

**9-11 September 2024, Birmingham**

**UKHTC2024-068**

# MULTI-OBJECTIVE ROBUST OPERATION-OPTIMIZATION OF GAS TURBINE SYSTEM INSTALLED IN INDUSTRIAL COMBINED CYCLE GAS POWER PLANT

Waqar Muhammad Ashraf[1*], Muhammad Ahmad Jamil[2], Syed Muhammad Arafat[3], Akhtar Muhammad[4], Ghulam Moeen Uddin[4], Muhammad Wakil Shahzad[2], Vivek Dua[1*]

[1] The Sargent Centre for Process Systems Engineering, Department of Chemical Engineering, University College London, Torrington Place, London WC1E 7JE, UK

[2] Mechanical & Construction Engineering Department, Northumbria University, Newcastle Upon Tyne, NE1 8ST, UK

[3] Department of Mechanical Engineering, Faculty of Engineering & Technology, The University of Lahore, Lahore 54000, Pakistan

[4] Mechanical Department of Mechanical Engineering, University of Engineering and Technology, Lahore, 54890, Punjab, Pakistan

## 1. ABSTRACT

The gas turbine power plants are included in the net-zero energy scenario to meet the peak energy demand. The energy efficiency improvement of the gas turbine system can further strengthen to achieve the net-zero goal with the optimal consumption of natural gas. In this paper, we formulated a multi-objective optimization problem that integrates the interpretable data information integrated neural network (DINN) based process models for thermal efficiency, power and turbine heat rate, and the problem is solved by two-step robust optimization approach under various plant capacities for optimizing the operation of the gas turbine system.

## 2. INTRODUCTION

The combined cycle power plants have a pivotal role to play for meeting the peak energy demand in various net-zero energy scenarios considering the intermittent nature of energy supply from the renewable energy systems [1]. In this regard, it is important to maintain the energy-efficient operation of the gas power plants on the optimal consumption of natural gas for power generation. Thus, the system-level analysis of the gas turbine system can be challenging considering the large system-design and hyperdimensional control space.

Machine learning (ML) offers flexible and computational inexpensive modelling algorithms for the system's modelling with high predictive accuracy. Considering the black-box nature of various ML algorithms, the interpretability of the ML algorithms is weak posing hurdle for the policy makers and plant engineers to understand the predictive mechanism of the algorithms. To address the interpretability issues of ML, recently data information integrated neural network (DINN) algorithm is reported in literature [2] that offers improved interpretability and modelling performance, and is used for the modelling tasks in this work.

The operation of gas turbine system has three key performance indicators namely thermal efficiency, power generation and turbine heat rate that are critically monitored. However, these key performance indicators are not modelled and investigated for the industrial-scale gas turbine system by ML algorithms. We have modelled these three performance indicators on the plant-level and relevant operating variables by DINN. Later, the optimization problem is formulated that attempts to maximize the thermal efficiency and power while minimizing the turbine heat rate. The optimization problem is solved by robust optimization that introduces the operational uncertainty in the recorded measurements of the sensors to estimate the robust-

*Corresponding Author: Waqar.ashraf.21@ucl.ac.uk, v.dua@ucl.ac.uk

optimal solution for the formulated multi-objective optimization problem. The DINN based modelling and robust optimization present computational inexpensive approach to estimate the robust solutions for gas turbine system.

## 3. METHDOLOGY

The thermal efficiency, power and turbine heat rate of industrial gas turbine system, installed in combined cycle gas power plant, are modelled by gas temperature at the inlet of combustion chamber, gas temperature at the outlet of performance heater, gas flow rate, temperature of air at the compressor discharge, pressure of air at the compressor discharge, ambient air temperature, ambient air pressure and ambient air humidity. 577 observations averaged over fifteen-minutes are deployed to construct the process models by DINN. The nonlinear programming based multi-objective optimization problem is formulated which is given as:

$$\min_x f(x) = f_{\text{thermal efficiency}}(x) + f_{\text{power}}(x) + f_{\text{turbine heat rate}}(x) \quad (1)$$

subject to:

$$h(x) = 0$$
$$x = x_1, x_2, \ldots, x_m \quad (2)$$
$$x \epsilon X \subseteq R^n$$
$$x^L \leq x \leq x^U$$

here, $x$ is the set of "$m$" input variables deployed for the modelling tasks; $h(x)$ is the equality constraint representing the DINN models. While, $x^L$ and $x^U$ are the lower and upper bounds on $x$ respectively.

The solutions ($x^*$) obtained after solving the multi-objective optimization problem corresponding to different initial conditions are retained. In the next step, the region around the solution is explored ($\delta_k$ – gaussian perturbations) in order to investigate the robustness of solution. For this purpose, "$H$" number of Monte Carlo technique-based experiments are constructed around the solution space $((x^* + \delta_k))$, are simulated from the multi-objective function and the average function response is computed given by:

$$F(x^*) = \frac{\sum_{k=1}^{H} f(x^* + \delta_k)}{H} \quad (3)$$

The solution is regarded as robust if the variance ($V(x^*)$) corresponding to the experiments is less than $\varepsilon$:

$$V(x^*) = \frac{\|F(x^*) - f(x^*)\|}{\|f(x^*)\|} < \varepsilon \quad (4)$$

## 4. RESULTS

Three output variables namely thermal efficiency, power and turbine heat rate of gas turbine system are

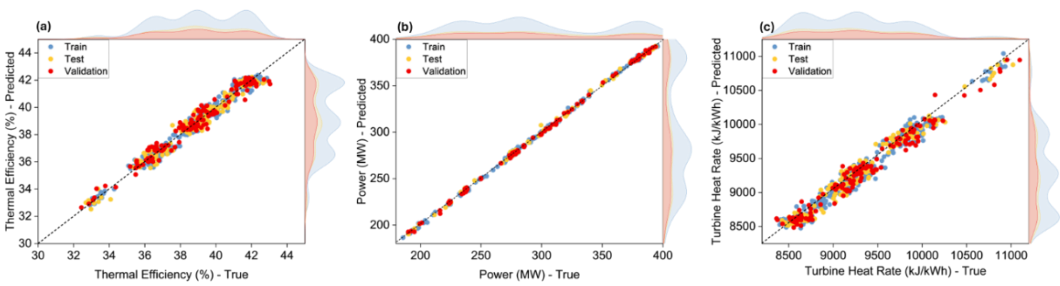


Figure 1. The modelling performance of DINN to construct the process models for (a) thermal efficiency, (b) power and (c) turbine heat rate of gas turbine system.

trained by DINN. The modelling accuracy of the DINN models to predict thermal efficiency, power and turbine heat rate of gas turbine system on training, testing and validation dataset is computed and presented on Figure 1(a-c). The DINN models demonstrate the modelling accuracy more than 0.95 on testing and validation dataset for the three output variables. Similarly, RMSE computed on test dataset for thermal efficiency, power and turbine heat rate are 0.44%, 1.4 MW and 94 kJ/kWh respectively. The performance metrics computed for the three output variables depict the excellent predictive performance of the trained DINN models.

The robust optimal solutions for different state of power generation are determined by solving the formulated multi-objective optimization problem. Figure 2 presents the determined robust optimal solution for thermal efficiency, power and turbine heat rate of gas turbine system for three scenarios of the power generation, i.e., scenario 1: 220 – 225 MW, scenario 2: 278 – 283 MW, and scenario 3: 390 – 395 MW. The robust optimal value of thermal efficiency is calculated to be 36.85 ± 0.21%, 39.13± 0.12%, and 42.87± 0.11% corresponding to scenarios 1, 2 and 3 respectively as shown on Figure 2(a). A narrow variation in the state of power generation is observed corresponding to different power generation scenarios as depicted on Figure 2(b). Whereas, turbine heat rate is varied from 9997 ± 94 kJ/kWh, 9225 ± 41 kJ/kWh, and 8428 ± 36 kJ/kWh for three power generation scenarios respectively as shown on Figure 2(c). Moreover, uncertainty distribution profile around robust optimal solutions for three output variables are also depicted as violin plots on Figure 2.

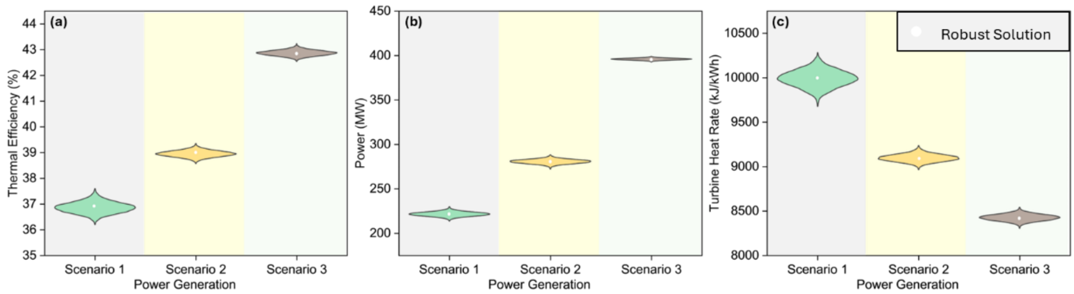


Figure 2. The robust optimal solution estimation for gas turbine system for (a) thermal efficiency, (b) power and (c) turbine heat rate. The uncertainty bound around the robust solution is depicted by the distribution profile of the violins.

## 5. CONCLUSIONS

We have modelled thermal efficiency, power and turbine heat rate of gas turbine system installed in 1180 MW combined cycle gas power plant by DINN algorithm. The DINN-based process models are trained with more than 95% predictive accuracy, are embedded in the multi-objective optimization problem and the robust-optimal solution is determined under different power generation scenarios. A narrow range of variation around the robust optimal solution is estimated depicting the determination of robust solutions for the energy efficient operation of gas turbine system.

## 6. ACKNOWLEDGMENT

Waqar Muhammad Ashraf received funding The Punjab Endowment Fund (funding number: CMMS-PHD-2021-006) to pursue doctoral studies at University College London, United Kingdom.

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