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Modelling of Dry-Low Emission Gas Turbine Fuel System using First Principle Data-Driven Method

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Abstract

Achieving reliable power generation from Dry Low Emission gas turbines together with low CO2 and NOx discharge is a great challenge, as the rigorous control strategy is susceptible to frequent trips. Therefore, it is crucial to establish a dynamic model of the turbine (such as the one commonly attributed to Rowen) to ascertain the stability of the system. However, the major distinctive fuel system design in the DLE gas turbine is not constructed in the well-established model. With this issue in mind, this paper proposes a modelling approach to the DLE gas turbine fuel system which consists of integrating the main and pilot gas fuel valve into Rowen's model, using the First Principle Data-Driven (FPDD) method. First, the structure of the fuel system is determined and generated in system identification. Subsequently, the validated valve models are integrated into Rowen's model as the actual setup of the DLE gas turbine system. Ultimately, the core of this modelling approach is fuel system integration based on the FPDD method to accurately represent the actual signals of the pilot and main gas fuel valves, gas fuel flow and average turbine temperature. Then, the actual signals are used to validate the whole structure of the model using MAE and RMSE analysis. The results demonstrate the high accuracy of the DLE gas turbine model representation for future utilization in fault identification and prediction study.

Keywords: Rowen's Model, System Identification, Transfer Function, Low Emission, Gas Turbine

1 Introduction

Gas turbines are widely used in power generation, due to the efficiency, reliability and stability of the turbines during operation [1]. The gas turbine works on the principle of Brayton cycle, where compressed air is combined with fuel and burnt under constant pressure, causing the resulting hot gas to expand across the turbine and perform work [2]. Power generation, however, emits NOx and COx gases, which pose a challenge to achieving pollution targets [3]; [4]. The drive for an environmentally friendly solution led to the introduction of the Dry Low Emission (DLE) gas turbine [5]; [6]. As shown in Fig. 1, the DLE gas turbine uses Lean Premixed (LPM) combustion to deliver CO_x and NO_x reduction [7]. LPM technology diffuses the high atmospheric nitrogen content before delivery to the combustion chamber [8] with a view to preventing "local hotspots". The optimum temperature for lower emissions is achieved through controlling the fuel opening of the pilot gas fuel valve and changing the amount of air supplied to the combustor [9].

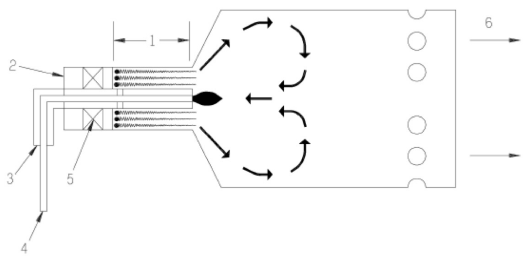

Figure 1: Lean Premix combustion with Premixing Zone in 1, Air Inlet in 2, main Fuel in 3, Pilot Fuel in 4, Swirler in 5 and Combustion Inlet Temperature in 6

Nevertheless, rigorous DLE gas turbine regulation in maintaining the specific air-to-fuel ratio during disturbances contributes to frequent gas turbine trips [10]; [11]; [12]. Therefore, a model that reflects the actual behavior of the DLE gas turbine is needed to represent the dynamic stability of the system [13]; [14]; [15].

There are numerous gas turbine models in dynamic studies such as; Rowen's model [14]; [16] , physical model [17]; [18]; [19]; [20]; [21]; [22]; [23], IEEE model [24], GAST model [19], WECC/GG0V1 model [25], aero-derivative model [26], CIGRE model and frequency-dependent model. In addition, the black-box model is proposed in [27]. The black box method, though, has limitations in the depiction of the operation, as it neglects interpretation of the parameter relationship. Rowen's model is widely

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adopted due to its ability to imitate actual gas turbine operation from the functional derivation of the operating curves [24]; [28]. Since it became known in 1983, Rowen's model has been used in various applications in dynamic study. It offers a stable model for gas turbine modification in temperature control and stability [29], load frequency control [30]; [31] and PID control [32]. In [33] integration of Bayesian and Dempster-Shafer theory into Rowen's model created a performance monitoring tool for gas turbines. The well-known model also found use in a fault characterization study in [34] for Lean Blowout trips during frequency excursion. The growing role of Rowen's model in recent years is notable and work in [35] highlights the model's suitability for representing the actual operation of the DLE gas turbine. Nevertheless, Rowen's model has not been adapted to actual representation of the DLE gas turbine fuel system, which differs from the conventional gas turbine. This paper aims to highlight the extension of Rowen's model for DLE gas turbine representation by integrating the fuel system model into the available structure.

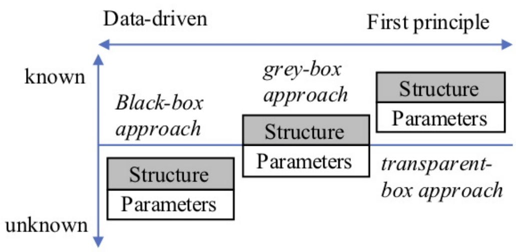

Figure 2: First Principle and Data Driven approach comparison

As a continuation from the previous work, this paper's contributions can be summarized as follows:

The fundamental aspect of theoretical modelling is the existence of structure in the initial development process. The information will determine the final type of model, the accuracy requirement and complexity of the model [36]. According to Fig. 2, it is either First Principle (FP) where the structure and parameters of the model are known, Data-driven (DD) where both structure and parameters are unknown, or a combination of both methods can be applied to build the model. The advantage of FP model is deep understanding of system behavior, but it is costly to develop as it requires an expert in the field. Besides, FP systems are typically modified using a trial-and-error approach to conform a model to the data, which can lead to a problem of non-convex optimization [37]. In the DD model, it adopts system test data to derive the mathematical representation [38]. From this approach, an accurate model can be formed due to actual data utilization for the system. Nonetheless, the DD model is at a disadvantage in handling multiple data sets to cover whole system operation. The last method, the First Principle Data-Driven (FPDD) approach or grey box, is an exemplary tool to cover both system accuracy and flexibility for whole DLE fuel system operation. With a known structure and operational data available, computational time to estimate the parameter will be reduced and a high accuracy DLE gas turbine fuel system can be obtained.

- Actual DLE gas turbine fuel system setup, which consists of a pilot and main gas fuel valves, is developed according to the gas turbine manual
- Main valve and pilot valve models is proposed according to the FPDD method using system identification
- A novel simulation model of DLE gas turbine is designed, integrating its comprehensive fuel system model into Rowen's model using available operational data.

Following integration, a high accuracy model and comprehensive understanding of DLE gas turbine behavior are acquired for diagnostic, monitoring and fault prediction applications.

The next part of this paper is organized as follows: Section 2 contains a description of Rowen's model and the proposed fuel system setup for DLE gas turbine; Section 3 shows the development steps of the main and pilot fuel valve models together with the Rowen integration; Section 4 proposes the simulation model of both valves and DLE gas turbine fuel system; Section 5 presents the conclusion and future work for this study.

2 Rowen's Model and DLE Gas Turbine

2.1 Rowen's Model

Rowen's model is shown in Fig. 3 and the values of the transfer functions are taken from [39]. The model assumes no heat recovery in the system and operates at a constant speed of 95% to 107%. The input and output signals are generated in per unit (p.u), where the operation signal is divided by the rotor speed nominal signal, N . The model consists of three main control components. The first component is the speed governor. It controls the speed of the system and maneuvers the frequency, exhaust temperature and compressor output as required by load demand. The second component is the fuel temperature control. It regulates the output temperature so that it is lower than the constant maximum or increases the

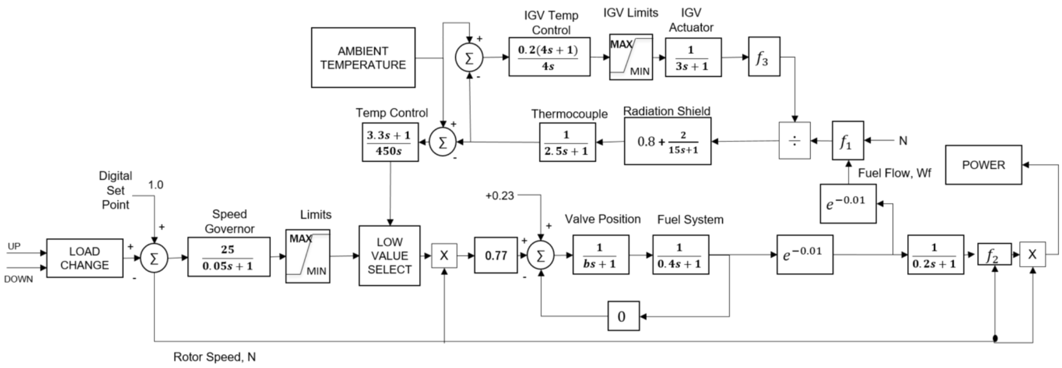

Figure 3: Rowen's model for gas turbine representation

temperature for more energy when demand increases. The third component is the IGV temperature control, which plays a major role in balancing the temperature by opening or closing the air intake.

The simulation functions are the turbine exhaust temperature as calculated in Equation **??**, with T_R as the turbine rated exhaust temperature, 950°F, N is the speed signal line and W_f is the fuel flow line,

$$f_1 = T_R - (700\,(1 - W_f) + 550\,(1 - N))$$

turbine torque is calculated from Equation **??**,

$$f_2 = 1.3\,(W_f - 0.23) + 0.5\,(1 - N)\,2$$

and turbine exhaust flow calculation as in Equation **??** with L_{IGV} as the IGV opening and T_a

$$f_3 = N\left({L_{IGV}}^{0.257}\right)\left(\frac{519}{T_a + 460}\right)$$

is the ambient temperature, 59°F.

This model provides a basis for the DLE gas turbine fuel system, which needs to be modelled in the form of a transfer function.

2.2 DLE Gas Turbine Fuel System

2.3

DLE gas turbines are designed for low emission operation, which is achieved by LPM combustion to produce a uniform temperature in the chamber [40]; [41]. Fig. **??** illustrates a comparison between the DLE gas turbine and the conventional type, highlighting the differences in fuel system design. The primary feature of the DLE gas turbine is the introduction of a pilot gas fuel valve to the main gas fuel valve used in the conventional model [42]. The DLE combustion chamber has a larger volume due to the space

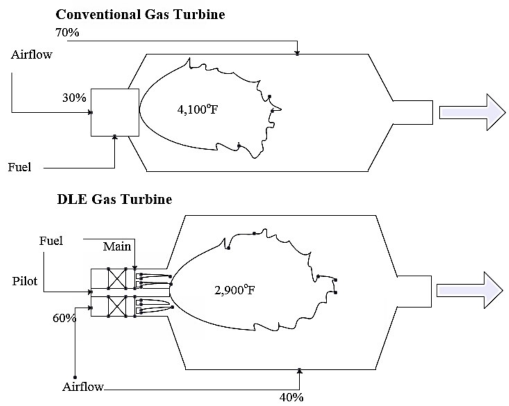

Figure 4: DLE and conventional gas turbine comparison

utilization for the pilot gas fuel valve integration. In DLE gas turbine operation, the air intake is drawn into the compressor and compressed before it reaches the premixing chamber. In the premixing chamber, 60% of the air is diffused into the fuel and an additional 40% is sent to the combustion chamber. The diffusion is controlled by varying the opening of the pilot fuel valve to maintain a consistent turbine temperature during the entire operation [43]; [2]. As the setup differs from the conventional, modelling of the fuel valves and system for DLE gas turbine representation is required.

The first step for technical modelling of the fuel valves and the system is to collect available knowledge. From Figure 3 the valve positioner model is a first-order transfer function, as in Equation **??** b in the equation denotes the time constant for the valve to reach steady state.

$$G_{Rowen}(s) = \frac{1}{bs + 1}$$

Based on Tavakoli in [44], the operating time of a valve to reach steady-state from the manufacturer is assumed at ~200 ms and b is expressed as 0.05. However, in this study, b for pilot and main gas fuel valves are estimated using system identification in MATLAB.

The actual setup of the valves in the DLE gas turbine package was examined as shown in Fig. 5.

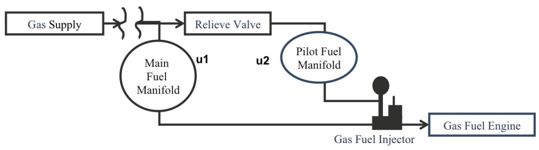

Figure 5: DLE gas turbine fuel system representation DLE gas turbine ratio of main and pilot valve opening during operation

u_1 indicates the entire system of the main fuel valve and u_2 is the whole illustration of the pilot fuel valve. The main gas supply is the source for both systems, as it goes to the main and pilot fuel manifold. The fuel flow from both valves is transferred to the gas injector and the mixture flows to the gas fuel engine. A relief valve also installed in the loop to prevent overpressure. From the representation, it can be justified that both valves are working parallel to each other for the ignition. The actual implementation of the available information to produce a DLE gas turbine fuel system is explained further in the Methodology Section.

3 Methodology

Type	Component
Input 1	Pilot Gas Fuel Valve Command
Output 1	Pilot Gas Fuel Valve Actual Position
Input 2	Main Gas Fuel Valve Command
Output 2	Main Gas Fuel Valve Actual Position

Table 1: Nominal values of DLE gas turbine

This study utilized a 4.2 MW single shaft DLE gas turbine with a 12-stage axial compressor at Universiti Teknologi PETRONAS, Malaysia as a case study. The gas turbine operates as a cogeneration unit to produce electricity and chilled water for academic and operational use. The nominal values are listed in Table 1, obtained from the gas turbine catalog during the design stage.

Customarily, the nominal values will diverge when the turbine is installed in different ambient conditions. Table 2 summarized the typical operating data from the power for development of the model. As shown in Fig. 6, development of the model starts with the data

Operating Parameter	Unit	Value
Output power	MW	4.4
Turbine inlet temperature	°C	1000
Exhaust gas temperature	°C	532
Ambient temperature	°C	27.3
Exhaust mass flow	kg/s	438.1
Fuel flow	kg/s	0.38
Lower heating value of fuel	kJ/kg	48930

Table 2: Typical operating data of DLE gas turbine

collection process. Healthy operational data in August 2016 are collected: 267804 samples. The samples are divided into a training dataset (50%), testing dataset (30%) and validation dataset (20%).

Following the data collection process, the pilot and main gas fuel valve models are developed using the same approach but a distinct set of variables. The first step in the development process is variable selection, which is assisted by an expert in the field and tabulated in Table 3. The inputs are the control signals to both pilot and main fuel valves, and the outputs are the signals of the actual position of the valve. The training inputs and outputs behavior are discussed in Section 4. In the second step, the whole training dataset of the selected signals is transferred to the system identification in MATLAB. The training data is simulated to determine the transfer function block as pre-defined in Section 2.2. For this part, the models are trained using the First Order and Second Order transfer function. The output objectives for the system identification are $G_1(s)$ for the pilot fuel valve model, $G_2(s)$ for the main fuel valve models, valve positioner time constant, b_{pilot} for pilot and b_{main} for main gas fuel valve model. Then, the

	MAE	RMSE
Main Gas Fuel Valve	0	0.01
Pilot Gas Fuel Valve	0	0
Engine Gas Fuel Flow	1.64	17.85
Temperature Average	0.04	0.06

Table 3: Plant data input and output component

output models are tested using the testing dataset. The error evaluation is performed in terms of MAE as in Equation **??** and RMSE as in Equation **??**. y in the equation denotes the actual value and $\hat{y}$ is the predicted value.

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y-\hat{y}|$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y-\hat{y})^2}$$

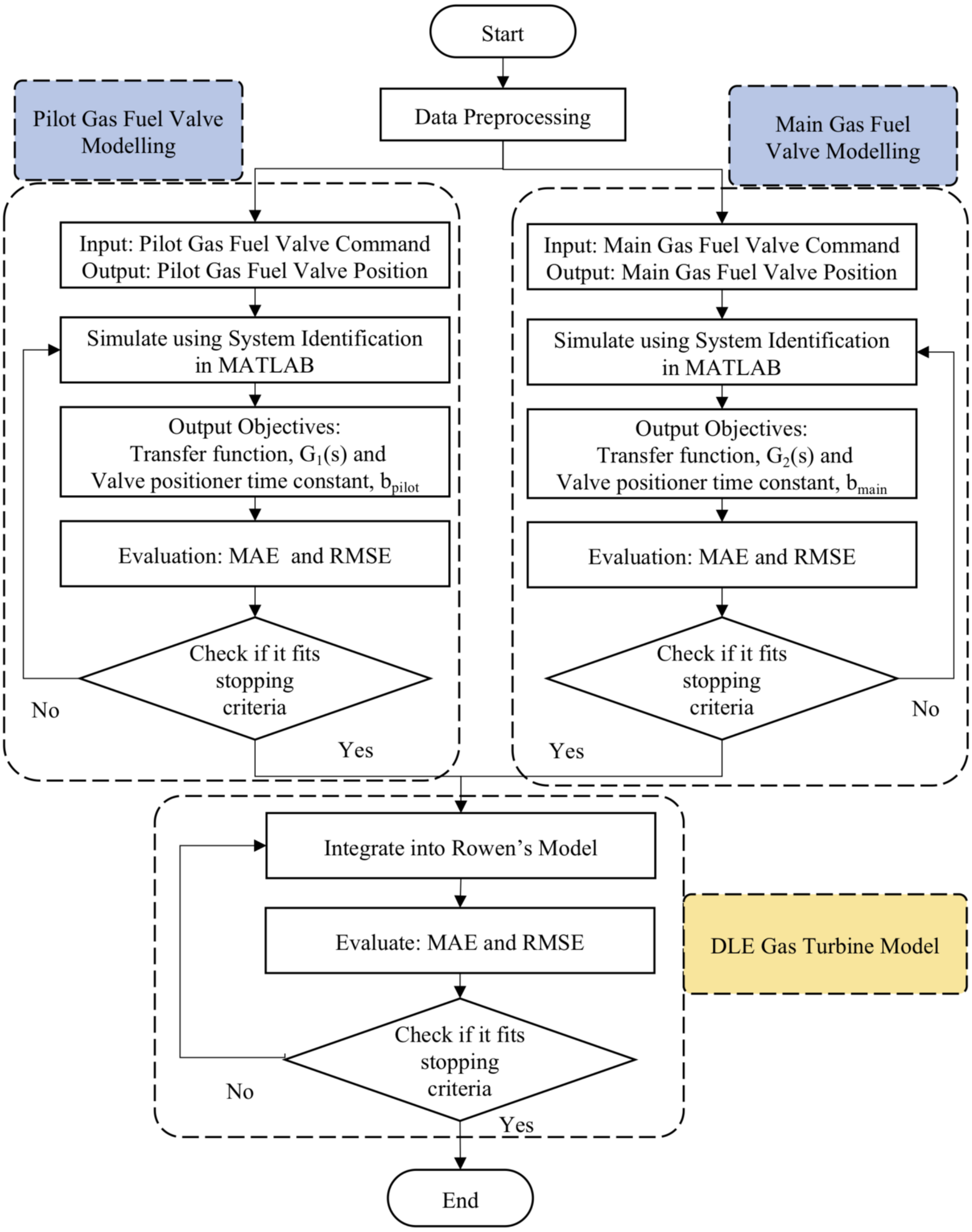

Figure 6: Flowchart of pilot and main gas fuel valve modelling for DLE gas turbine model

The lowest MAE and RMSE of the models are selected to represent $G_1(s)$ and $G_2(s)$. In the final step, $G_1(s)$ and $G_2(s)$ are further verified using validation dataset in parameter fit testing to obtain an optimum value of b_{pilot} and b_{main}. The least error of simulated b is the stopping criteria for the valve models. The simulation results are presented in Section 4.1.

Finally, the two models are integrated into Rowen's model to produce a DLE gas turbine with the actual fuel system model representation. The integration consists of two vital steps. The first one is the replication process of the DLE fuel system setup based on the actual design in Fig. 5. The proposed fuel system is integrated into Rowen's model in Section 4.2 to imitate the actual DLE gas turbine fuel system operation. After the integration, the model is simulated using one-day actual load change and ambient temperature signals in the second steps. The simulated signals of pilot and main gas fuel valves, engine fuel flow and turbine temperature are compared with the actual data, using MAE and RMSE analysis to measure the model's accuracy. The simulated speed signal is also analyzed for system stability, which expected to maintain 1.0 p.u throughout the simulation. The proposed DLE gas turbine model is expected to have 99% accuracy to represent the actual operation for stability study, fault analysis and detection and fault prediction. The results are presented and discussed in the Results and Discussion section.

4 Results and Discussion

This section is divided into two parts; pilot and main gas fuel valve modelling in Section 4.1 and DLE gas turbine model with the integrated fuel system in Section 4.2.

4.1 Pilot and Main Gas Fuel Valve Modelling

The pilot valve training dataset is illustrated in Fig. 7 with the output trend in (a) and input trend in (b). The valve output follows the trend of the input and no time delay is observed. As the data represent 15 days' operation of the DLE gas turbine, the 0% opening indicates the shutdown of the gas turbine and step up to 100% for the start-up. The pilot valve is constant at 55% after the load reaches 50% of the capacity for dry low emission mode.

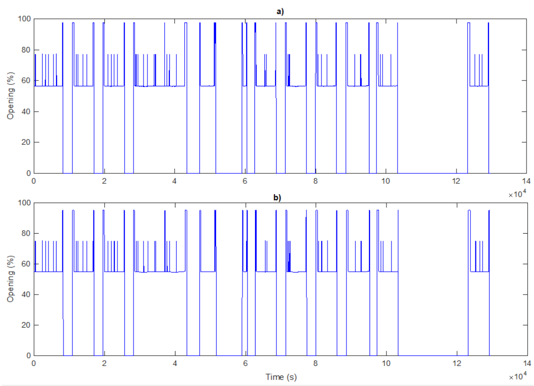

Figure 7: Pilot gas fuel valve training output

The main valve training dataset is shown in Fig. 8 with the output in (a) and input in (b). The trend is also identical between the input and the output. The shutdown lies in 0% opening and start-up to 40-45% opening. However, it does not change from any position to a specific position even though the turbine is in DLE mode as compared with the pilot gas fuel valve. Thus, the main function of the pilot gas fuel valve in sustaining low emission is proven from the actual behavior of DLE gas turbine operation.

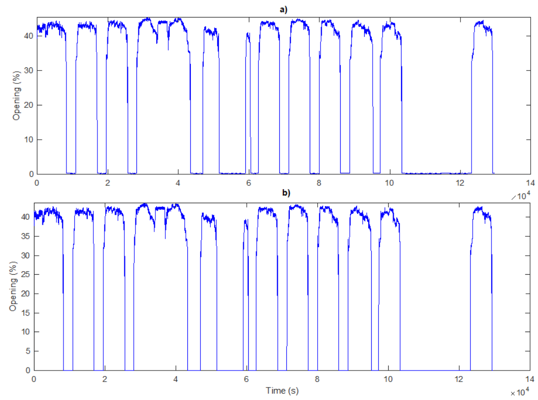

Figure 8: Main gas fuel valve training output

Fig. 9(a) demonstrates the performance of the transfer function models in predicting 10 days' testing dataset. For greater clarity, the chart is further enhanced in (b). In (a), the shutdown, start-up and transition mode to DLE are accurately predicted by both the first and second-order systems. Accuracy is contributed from the linear operation of the input and output of the valve. Signal spikes also estimated close to the actual operation. With the percentage opening zoomed into 2 decimal places, it can be observed that the second-order transfer function shows a closer estimation of the actual data than the first-order transfer function. The highest order indicates greater accuracy due to the addition of s_{2} in the function for higher resolution estimation. The trend of the actual signal is not precisely estimated in 2 decimal places in (b), but the trend in (a) is adequate to prove the model's ability in representing the pilot gas fuel valve operation.

The main gas fuel valve is also tested using the testing dataset and the result is illustrated in Fig. 10(a) for ten days and zoomed in (b). It can be observed that the second-order transfer function exhibits a closer estimation of the actual data compared to the first-order transfer function. This is similar to the pilot gas fuel valve analysis. The proposed model successfully estimates the 10 day trends and in zoomed-in.

The simulated pilot and main gas fuel models are further analyzed using MAE and RMSE analysis, as tabulated in Table 4. The error of the second-order and first-order systems is almost identical, with a very small deviation for both valves in training and testing results. The first-order transfer function is therefore preferred due to low complexity and the accuracy of the predictions is almost the same with the second-order system. Hence, the pilot gas fuel valve model is

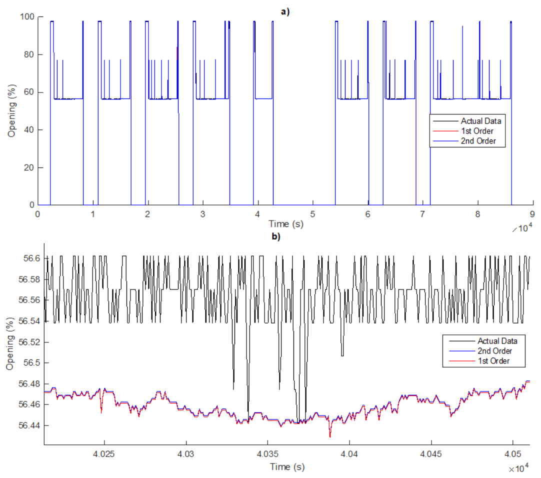

Figure 9: Pilot gas fuel valve a)Ten days and b) zoomed-in testing data

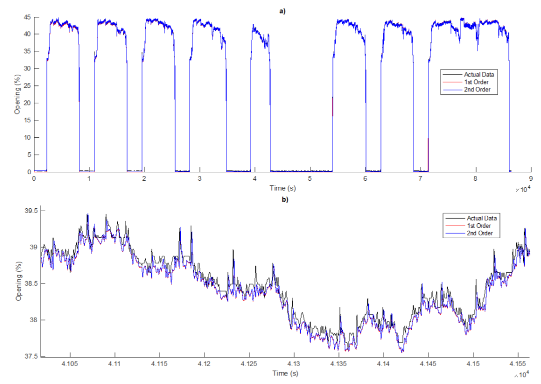

Figure 10: Main gas fuel valve a) ten days b) zoomed in testing result

Transfer Function	Set
MAR	RMSE
1st Order	Training
2nd Order	Testing
1st Order	Training
2nd Order	Testing
Transfer Function	Set
1st Order	Training
2nd Order	Testing
1st Order	Training
2nd Order	Testing
Pilot Gas Fuel Valve	
4.35	1.34
4.57	1.34
4.35	1.34
4.57	1.34
Main Gas Fuel Valve	
2.02	2.02
2.02	2.02
1.95	1.95
1.95	1.95

Table 4: Pilot and main gas fuel valve error analysis

Pilot Gas Fuel Valve			
	b	MAE	RMSE
Rowen	0.05	1.35	3.24
System Identification	0.17	0.04	2.9
Main Gas Fuel Valve			
	b	MAE	RMSE
Rowen	0.05	1.32	1.43
System Identification	0.22	0.09	0.2

Table 5: Parameter fit testing of pilot and main gas fuel valve

expressed in Equation **??** and the main gas fuel valve model is shown in Equation **??**.

$$G_1(s) = \frac{1}{0.172s + 1}$$

$$G_1\,(s) = \frac{1}{0.222s + 1}$$

The proposed models from system identification are validated further using a validation dataset in parameter testing to determine the best *b* . The first evaluation is a comparison of the proposed system identification model with Rowen's model as in Table 5. The proposed system identification parameter, b for both pilot and main gas fuel valves, exhibits very high accuracy with improved MAE and RMSE compared to Rowen's parameter assumption. Parameter fit testing for the system identification of pilot and main gas fuel valve models are illustrated in Fig. 11 and Fig. 12 respectively. MAE and RMSE for the analysis are increased when the parameter is below or higher than the optimum value. Pilot gas fuel valve analysis indicates that the optimum parameter can be 0.172 as proposed or 0.173.

For this study, 0.173 is selected due to the low MAE and low RMSE compared to the proposed, 0.172. Two optimum values also observed in the main gas fuel valve parameter analysis at 0.222 as proposed and 0.223. However, parameter 0.222 exhibits low RMSE high MAE compared to parameter 0.223 with high RMSE but low MAE. In this scenario, low RMSE is desirable compared to MAE to produce a low variance of individual errors in the sample. Thus, 0.222 remained as proposed for main gas fuel valve parameter.

This section ends when the valves model is acquired and the model is substituted into Rowen's model to build a DLE gas fuel valve system.

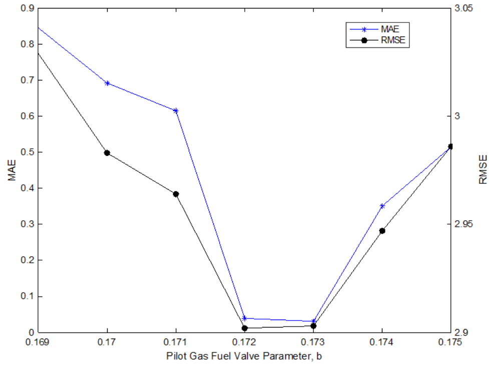

Figure 11: Gas fuel valve parameter fit testing result for pilot gas fuel valve

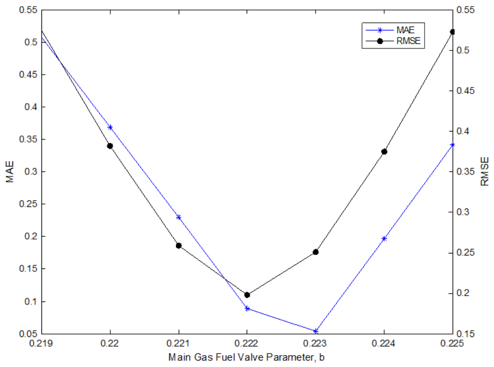

Figure 12: Main gas fuel valve parameter fit testing result for main gas fuel valve

4.2 DLE Gas Turbine Fuel System

In this section, the actual representation and operation of the pilot and main gas fuel valves were investigated further.

The normal operating behavior of the valves in the fuel system is presented in Fig. 13. The pilot fuel valve opening is on average 55% and the main gas fuel valve is at 40% opening. The total opening of the valve is around 95% and this provides a basis ratio for valve modelling in the DLE gas turbine. The ratios of the valves are approximated at 0.45 p.u for the main valve and 0.55 p.u for the pilot gas fuel valve.

Based on the operation and actual setup in Section 2.2, the fuel valve system is proposed as in Figure 14. $G_1(s)$ is the pilot gas fuel valve model and $G_2(s)$ is the main gas fuel valve model. The ratio of the pilot fuel valve, x_1 valves is approximated at 0.55 as previously. The ratio for the main fuel valve, x_2 is 0.45 as in the previous investigation. The sum of the valves values is sent to the fuel system.

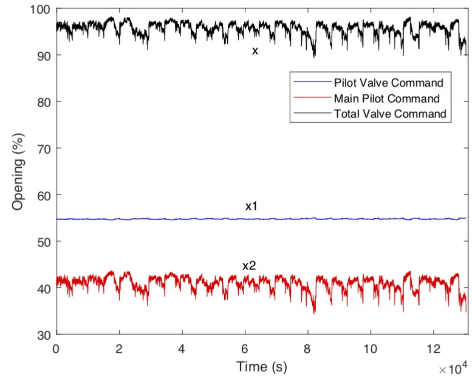

Figure 13: DLE gas turbine ratio of main and pilot valve opening during operation

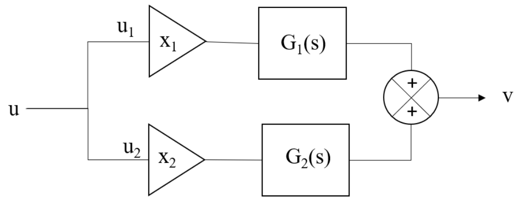

Figure 14: DLE gas turbine valve positioner function for Rowen's integration.

The proposed transfer functions for the valves in Section 4.1 are integrated into Rowen's model with the specified ratio, x_1 and x_2. The integration of the proposed structure of the DLE gas fuel system into Rowen's model is presented in Fig. 15. All parameters of the transfer function are calculated according to the case study of the selected DLE gas turbine.

One day load change from another set of data is fed to Rowen's model as an input and illustrated in Fig. 16. The trend indicates the low and high demand profile, usually in the middle of the day where all academic and research works took place.

The second input for the integration is ambient temperature, as in Fig. 17. The value is 80 at midnight and increases to a peak of 96°F daytime. This is the actual temperature in Malaysia and the profile is almost the same every day due to the climate in the country. This input is fed into Rowen's model alongside with the actual load demand to simulate main and pilot gas fuel valves, engine gas fuel flow and temperature average signals.

The simulated signals are compared with the actual signals in Fig. 18 for for pilot valve, Fig. 19 for main valve, Fig. 20 for engine fuel flow and Fig. 21 for the turbine temperature signals. The performance of the DLE gas turbine model also analyzed using MAE and RMSE to measure model accuracy. Gas turbine speed

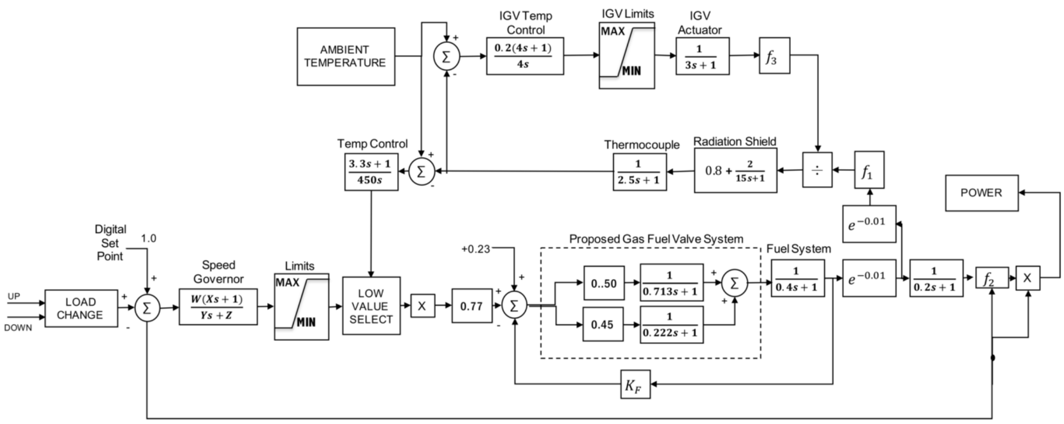

Figure 15: Integration of the main and pilot gas fuel valves into Rowen's model

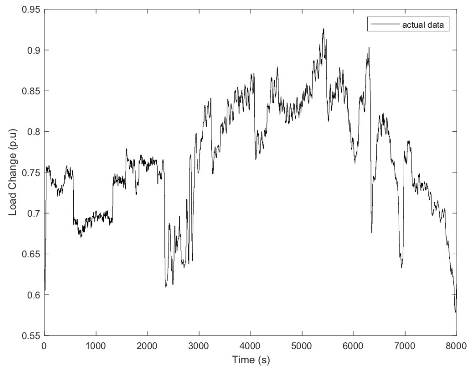

Figure 16: DLE gas turbine load change input for one day

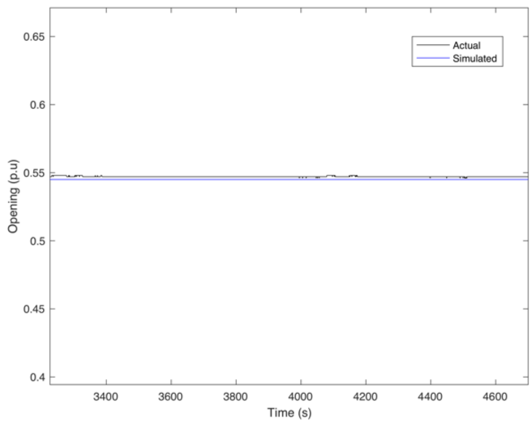

Figure 18: Simulated and actual results of pilot valve

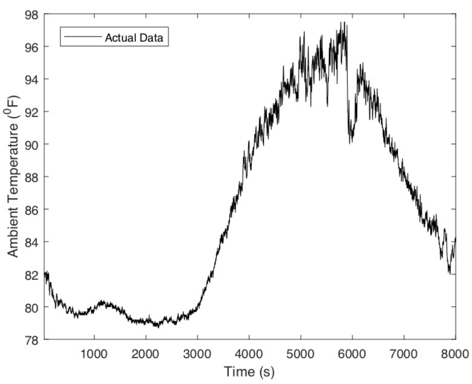

Figure 17: DLE gas turbine ambient temperature input for one day

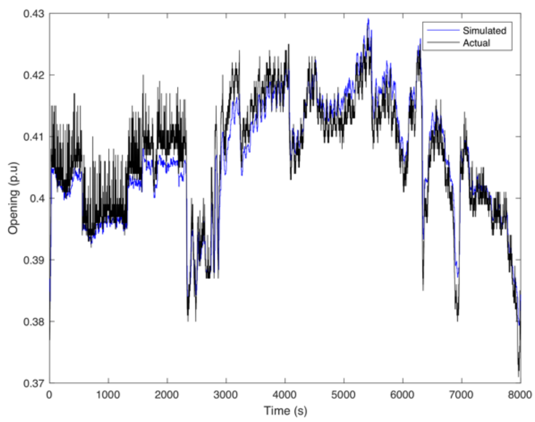

Figure 19: Simulated and actual results of main valve

for the turbine is stable at 1 p.u or 100% at a constant speed.

The first output to be investigated is the pilot gas fuel valve as illustrated in Fig. 18. The actual data lies in 0.55 p.u opening, and the simulated data is projected very close to it.

The second output is the main gas fuel valve comparison as in Fig. 19. The simulated trend exhibits a good estimation of the actual trend with only a small devi-

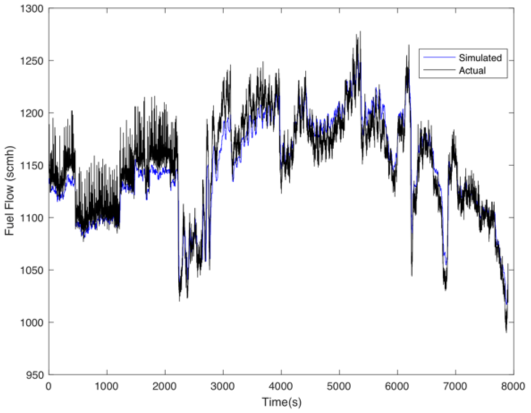

Figure 20: Simulated and actual results of engine fuel flow

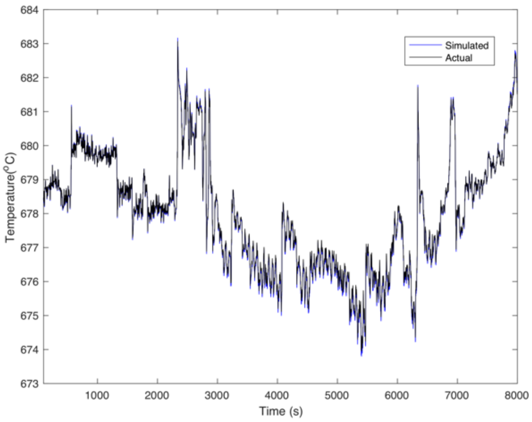

Figure 21: Simulated and actual results of turbine temperature

ation. As both of the trends are compared, the pilot gas fuel valve remains constant at 0.55 for DLE mode but the main gas fuel valve is modulated according to the load demand in Fig. 16.

The third output from the simulation is the engine fuel flow as shown in Fig. 20. The simulated signal captures the same trend of the actual signal and indicates its capability to represent DLE gas turbine operation. The signals imitate the load signal according to the gas turbine operation; which increases the fuel flow demand when the load increases.

Last output to be studied is the thermocouple temperature. This output also crucial in a DLE gas turbine due to the rigid control of the temperature that must lie in the targeted temperature zone to reduce the emission. The temperature of the gas turbine is closely monitored during the operation compared to the conventional gas turbine that normally unattended. The result of the simulated temperature is illustrated in Fig. 21. A good fit of the simulated temperature profile is observed from the trend. This indicates that the introduction of the pilot and main gas fuel valves does not deteriorate the performance of the temperature profile of the DLE gas turbine.

The simulation outputs are further analyzed in terms of MAE and RMSE and the results are tabulated in Table 1. The main gas fuel valve, pilot gas fuel valve and temperature average signals exhibit very high accuracy with an error of less than 0.1 for both MAE and RMSE. Engine gas fuel flow exhibits quite high error compared to the three signals with MAE 1.644 and RMSE 17.85. This is due to the inheritance error from the pilot and main gas fuel valves that carries into the engine fuel flow measurement. However, the signal performance is still acceptable for this study, due to the good trend fit to the actual signal. Error analysis proves that the simulated signals are accurate enough to represent the real DLE gas turbine operation.

	MAE	RMSE
Main Gas Fuel Valve	0	0.01
Pilot Gas Fuel Valve	0	0
Engine Gas Fuel Flow	1.64	17.85
Temperature Average	0.04	0.06

Table 6: MAE and RMSE analysis for the simulated output compared to the actual signal

5 Conclusion

The DLE gas turbine, with a pilot gas fuel valve added to the fuel system, achieves low emission operation. However, the turbine is susceptible to frequent trips and a dynamic model for operational representation is required. In this modelling study, a DLE gas turbine fuel system model was proposed for operational study using the First Principle Data-Driven (FPDD) method. There are three major contributions in this paper to represent the DLE gas turbine fuel system in Rowen's model. First, the actual DLE gas turbine fuel system setup, which consists of pilot and main gas fuel valves, was developed according to the gas turbine manual. Second, the main valve and pilot valve models were proposed according to the FPDD method, using system identification. Finally, the novel simulation model of the DLE gas turbine was designed, integrating its comprehensive fuel system model into Rowen's model, using available operational data. To verify the proposed method, the simulation output of the pilot and main fuel valve, engine gas fuel flow and turbine temperature signals were compared with the actual signals from the power plant. The results clearly demonstrated the accuracy of the proposed model, with very low MAE and RMSE. We believe that this DLE model can be applied in condition monitoring, fault diagnostics and trip prediction study. To further improve utilization of the model, a compressor pressure discharge parameter can be added and the tripping mechanism of the turbine can be developed.

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