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# Modelling and Parameter Estimation of the Excitation System and the Governor System of a Synchronous Generator at Sapugaskanda Power Station

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**Abstract:** As the power system continues to evolve, the dynamic nature of synchronous generator control systems, excitation, and governor systems play important roles in determining the power system's behaviour and performance. These systems consist of specific parameters, and their values change over time due to factors such as regular maintenance, frequent start-ups and shutdowns, and aging equipment. Hence, a standardized and locally applicable methodology is essential for parameter estimation, mainly in aged power plants of Sri Lanka. Recent research focuses on improving and optimizing existing parameter estimation techniques. In contrast, this research proposes a systematic approach for parameter estimation combined with field tests, which are conducted using customized test kits developed for the available excitation system in the Sapugaskanda power station. The proposed methodology is applied to a 20 MW heavy fuel synchronous generator in the power station, which has been in operation for about 40 years. The parameter estimator tool in MATLAB was used for parameter estimation methodology. The results evidenced that the proposed methodology is suitable to address the challenges of parameter estimation, especially in aged power plants. This can provide a practical and cost-effective solution, and the findings of this study can be adapted to other power plants that are facing similar challenges.

**Keywords:** Automatic Voltage Regulator (AVR), Excitation system, Governor, Parameter estimation, Sapugaskanda Power Station, Synchronous generator

## 1. Introduction

A power system is a complex network consisting of generation, transmission, and distribution networks that serve electrical energy from power plants to the consumers. The heart of this system is the synchronous generator, which is the primary source of electricity in power generation, where mechanical energy is converted to electrical energy. For a power system to work effectively, there should be a balance between power generation and demand while maintaining the frequency and voltage levels within predetermined limits. Synchronous generators are equipped with control systems such as the automatic voltage regulator (AVR), exciter and governor to achieve this balance by regulating reactive power and active power separately. The combination of AVR and exciter, called the excitation system, controls the terminal voltage output while the governor system controls the speed of the engine or the prime mover to maintain the system frequency.

To analyse this power system performance and for its stability studies, proper modelling of the excitation systems and governor systems is essential [3]. The variations in these parameters can drastically affect the stability and performance of the power system.

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Hence, proper modelling and parameter estimation process is required to estimate the control system parameters that help to predict the synchronous generator's behaviour and the performance of the power system, and this process should be continual.
In this research, a systematic approach of parameter estimation of the synchronous generator control systems is introduced, initiating the separate modelling of the excitation system and governor system of Sapugaskanda power station using MATLAB software and conducting relevant field tests using a self-designed test kit. The final step involves estimating the key control system parameters and analysing their deviations from standard or predefined values. These findings allow machine operators and power system engineers to get a better understanding of how such parameter deviations affect the synchronous generator's behaviour and performance. The proposed approach will be capable of conducting the parameter estimation process in any plant using a customized test kit that can be tailored in a suitable way. The suggested approach will consist of simulation models separately for the excitation system and governor systems, resulting in simulation curves and test curves and the estimated parameters.

## 2. Sapugaskanda Power Station

Sapugaskanda Power Station is a base load power plant in Sri Lanka, which consists of two stations, where each station has 80MW capacity. Sapugaskanda is a heavy fuel power plant that has a lower operating cost than diesel power plants, with a faster startup and shutdown time. In a country like Sri Lanka, where the power system is relatively small, the inertia requirement becomes highly significant, and it undergoes frequent power interruptions and sudden load losses. Such conditions require fast responding governor systems and reliable nursery plants to stabilize the grid quickly. In this context, Sapugaskanda stands out as a vital power plant in Sri Lanka.
The commissioning of the plant occurred in 1984, and it has been operated since then; however, the equipment has aged internally and externally through several operational stresses. Due to the aging factor of this plant, parameter estimation is important because parameters need to be continuously identified to predict the behavior of the system. Hence, this study seeks to estimate the parameters of one of the aged machines of a 20MW unit. This unit has an AC excitation system where rectified DC will be supplied to the main field winding according to the control signals from the AVR. Unlike other systems that use an excitation transformer, this unit relies on a permanent magnet generator (PMG) to provide the AC power to the AVR, which is in the same rotating shaft as the synchronous generator, as shown in Figure 1.

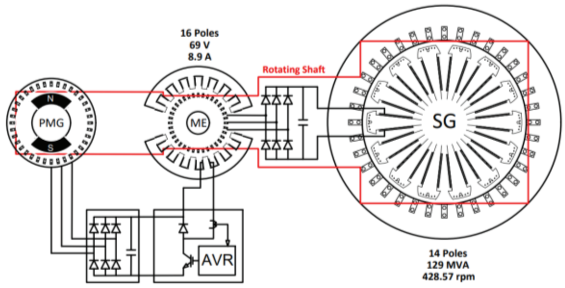


**Figure 1 - Excitation system of Sapugaskanda Power Plant**

## 3. Research Focus

Within this research, mainly two key approaches are being focused on. The first approach mainly focuses on modelling validated and accurate simulation models that can represent realistic exciter, AVR, and governor systems of the Sapugaskanda power station. The second approach focuses on the use of these models with specific reference to their parameter estimation in determining the deviations of the parameters from their standard or predefined values.

### 3.1 Modelling of Exciter, AVR, and Governor Systems

Modelling of excitation and governor system is a significant component in realistic power system simulation. There are several standard models, such as those included in IEEE Std 421.5-2016 [1], typically utilized for stability studies in power systems. Such are, especially the AC1C model of the excitation system and the DEGOV1 model of the turbine-governor, considered in this research because they apply to the Sapugaskanda power station, and it was identified from the operational manuals of the power plant.
Previous studies have also employed IEEE standard models for system-wide simulation compatibility. It used IEEE standard models to analyse small-signal stability in a multi-machine power system. Similarly investigated dynamic synchronous machine modelling based on standard exciter and governor models was investigated and confirmed their validity for transient studies [3], [5]. But all of them employ assumed or standard parameter sets,

which limit the validity of the model to real power plants. This research overcame that drawback by building models from the actual block diagrams of AC1C and TGOV1 in MATLAB, adjusted to the steady state model of the synchronous generator with its true settings at Sapugaskanda power station.

### 3.2 Parameter Estimation Approach based on Field Tests

Parameter estimation is important for dynamic model calibration in order to determine the real-world behavior of the equipment under actual working conditions. Different AVR, exciter, and governor system parameter estimation methodologies exist, including time-domain system identification, optimization techniques, and response matching methods [6], [7]. In some cases, a multi-step process for obtaining AVR parameters from field measurements and time-domain simulation is carried out, while some proposed a hybrid Particle Swarm Optimization (PSO) - Genetic Algorithm (GA) technique to optimize the error between simulated and observed responses [7], [8]. To obtain the real-world field test data, some dynamic tests are often used, which include step disturbances that assess system behavior and steady-state tests to identify parameters under constant conditions [11]. Despite the existence of such methodologies, it is still challenging to balance model complexity, estimation accuracy, and computation time, especially with noisy or sparse field test data. Many studies also do not test their results against real-time operational data from actual power plants.

Parameter estimation in this study is performed according to field test data obtained using a dynamic signal injection testing kit built on-site. Curve fitting, optimization tools, and the parameter estimator tool in MATLAB are utilized to iteratively fit the simulated response to the actual system output or the test curve, focusing on significant performance measures. This addresses a serious omission in existing methodologies by utilizing actual field tests of an operating heavy fuel synchronous generator and carrying out parameter estimation based on quantitative test and simulation matching.

## 4. Modelling of the Exciter, AVR, and Governor

For the accurate modelling of exciter, AVR, and governor in the Sapugaskanda power station, selecting standard models that closely match the actual operational characteristics of the installed systems ensures that the simulation results reflect real-world behaviour.

Through the operational manual and the field data of the power plant, the AC1C excitation model in [1] and DEGOV1 turbine governor model in [2] were identified as suitable representations of the existing equipment. These models offer sufficient flexibility and accuracy to capture the essential dynamics, making them well-suited for detailed system studies and parameter estimation.

### 4.1 Exciter and AVR Modeling

According to the power station’s operational manual, Sapugaskanda has the AC rotating exciter, as given in Figure 2. To represent the configuration accurately, the IEEE Type AC1C model has been adopted as shown in Figure 3. The key parameters associated with this excitation system model and used in this study are presented in Table 1.

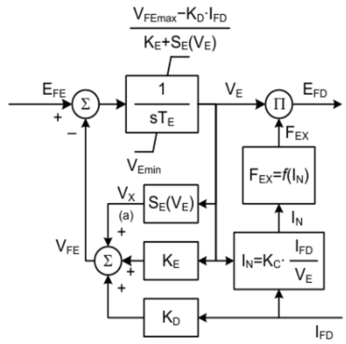


**Figure 2 - AC rotating exciter model [1]**

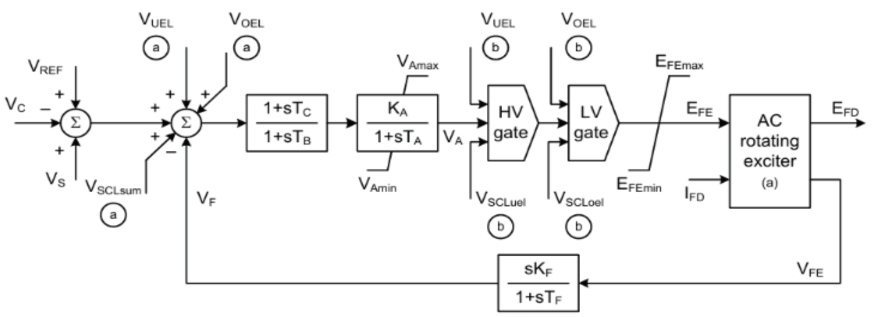


**Figure 3 - Type AC1C model [1]**

**Table 1 - Key Parameters of the Excitation System [1]**

| Parameter | Description |
|---|---|
| $K_A$ | Regulator output gain |
| $K_C$ | Rectifier loading factor proportional to commutating reactance |
| $K_D$ | Demagnetizing factor |
| $K_E$ | Exciter field proportional constant |
| $K_F$ | Rate feedback excitation system stabilizer gain |
| $T_A$ | Regulator output time constant |
| $T_B$ | Regulator denominator (lag) time constant |
| $T_C$ | Regulator numerator (lead) time constant |
| $T_E$ | Exciter field time constant |
| $T_F$ | Rate feedback time constant |
| $T_R$ | Regulator input filter time constant |

In MATLAB, the AC1C model is available as a built-in block that includes all system components. However, it limits access to individual parameters, making it difficult to analyse their specific effects. To overcome this, the system was manually modelled in MATLAB based on Figure 3, rather than using the standard AC1C block.

Figure 5 illustrates the developed overall excitation system, which includes a step pulse input to provide a disturbance signal, an AVR model, an exciter model and a generator model. The generator is represented using its steady-state model, configured with the actual settings of the Sapugaskanda synchronous generator.

Before proceeding further, it is important to verify the stability of the developed model in Figure 5. To do so, MATLAB software features are used to obtain the pole-zero map of the developed model as depicted in Figure 4. Since, all the poles and zeros are in the left-half of the plane (negative real part), the system is confirmed to be stable.

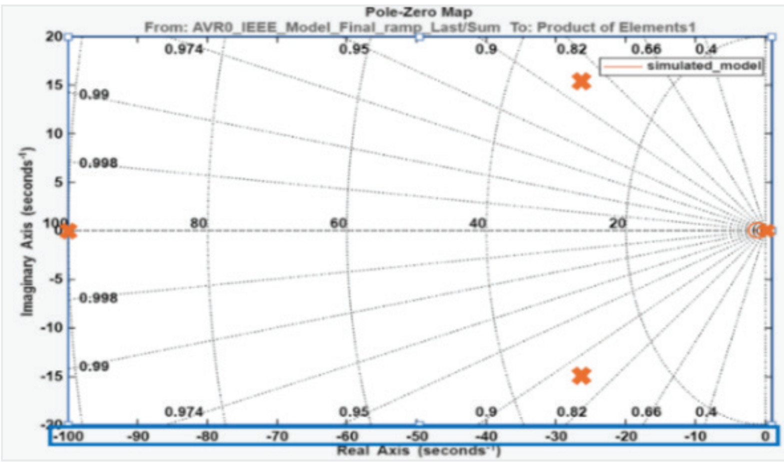


**Figure 4 - Pole-zero map of excitation system model**

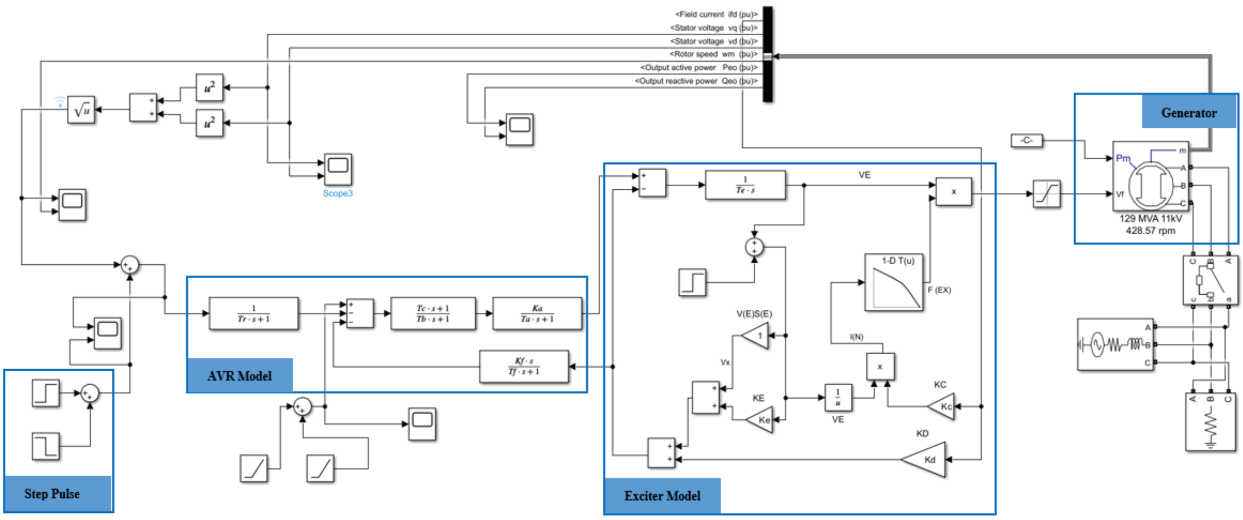


**Figure 5 - Simulation model of the excitation system**

## 4.2 Governor Modelling

To model the governor system available in the Sapugaskanda power station IEEE DEGOV1 [2] model is used as shown in Figure 6 and the key parameters associated with this turbine governor model are presented in Table 2. This model is widely adopted for representing the dynamic response of the heavy fuel turbine governors in power system studies, offering an adequate balance between simplicity and accuracy.

**Table 2 - Key Parameters of the Governor System [2]**

| Parameter | Description |
|---|---|
| K | Turbine gain |
| $T_1$ | Time constant (Electrical Control Box) |
| $T_2$ | Time constant (Electrical Control Box) |
| $T_3$ | Time constant (Electrical Control Box) |
| $T_4$ | Time constant (Actuator) |
| $T_5$ | Time constant (Actuator) |
| $T_6$ | Time constant (Actuator) |
| $T_D$ | Time Delay (Engine Block Delay) |
| $T_E$ | Power time constant |

Figure 8 illustrates the developed MATLAB governor system simulation model, comprising the engine control box, actuator block, and engine block. It is integrated with the generator's steady-state model, configured using the actual parameters of the Sapugaskanda synchronous generator.

The stability of the developed governor model was also verified before analysis. In here also, using MATLAB's control system tools, the pole-zero map of the simulation model is obtained as shown in Figure 7 to assess its dynamic behavior. Since all poles and zeros of the model lie in the left-half of the complex plane, the system is deemed to be stable, ensuring reliable performance for further studies.

In both cases, this stability verification step is essential to confirm that the simulated system will not exhibit oscillatory or divergent behavior under normal conditions, thereby providing confidence in the accuracy of subsequent time-domain simulations and parameter estimation tasks.

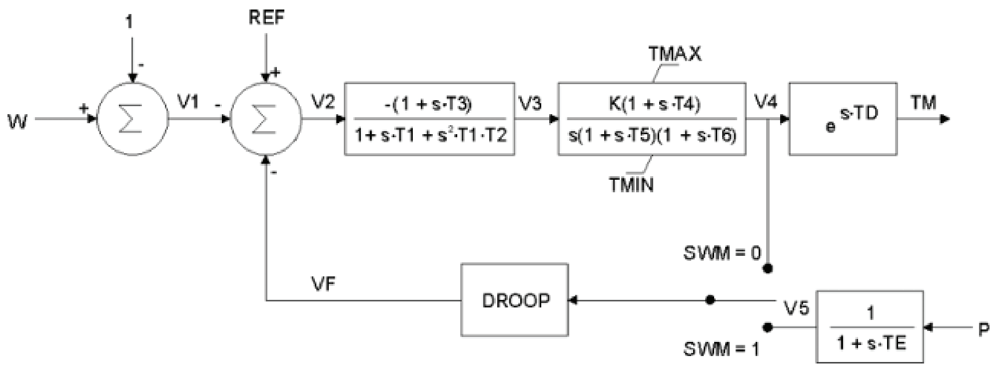


**Figure 6 - Degov1 model [2]**

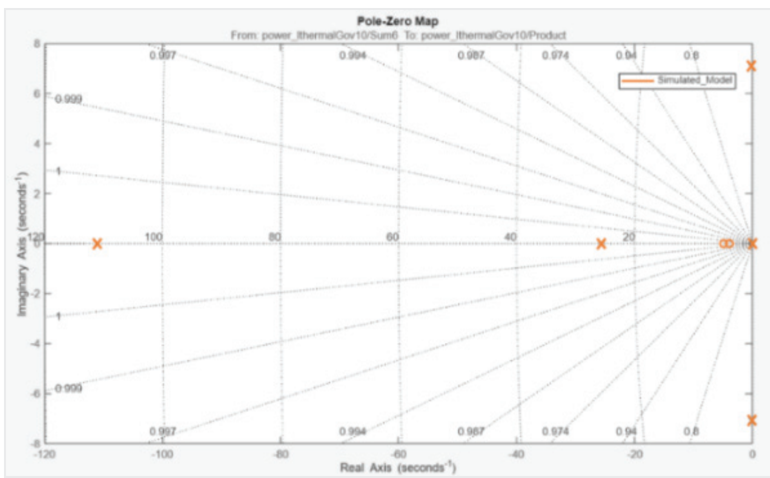


**Figure 7 - Pole-zero map of governor system model**

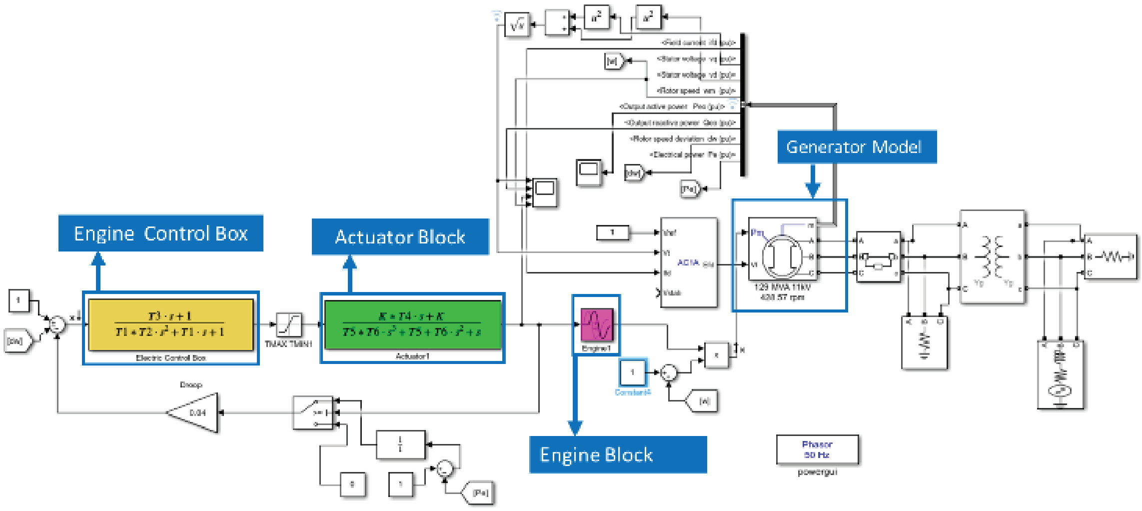


Figure 8 – Simulation model of a Governor System

## 5. Parameter Estimation of the Systems

### 5.1 Exciter and AVR Parameter Estimation

To obtain the field test curve, the dynamic small signal injection test was carried out by keeping the AVR in automatic mode. To create this step disturbance, a specialized test kit, as in Figure 9, has been designed and developed specifically for use with the AVR system at Sapugaskanda power station. This kit enables controlled injection of a step disturbance signal into the AVR's voltage-sensing input, allowing observation of the AVR's dynamic response. Key components of the test kit mainly include centre-tapped transformers, switches, and relays to regulate the output voltage.

The optimal point for injecting the disturbances was identified between the 110 V side of the 11kV/110V voltage transformer and the AVR control unit inside the AVR cubicle. This location was selected as it provides safe access to the voltage sensing input without interfering with the main power circuit of the synchronous generator, while accurately reflecting the terminal voltage variations perceived by the AVR. The test kit is designed to operate within the acceptable overvoltage and undervoltage ranges of the AVR and can be adapted for use with other AVR systems in different power stations, offering a repeatable method for performing similar field tests in various setups.

The test curve was obtained by performing this test, which was the AVR's dynamic response to the applied disturbance signal. The simulation curve was generated by applying the identical disturbance signal, same as the field test. This allowed for a simulated dynamic response under the same conditions as the actual system.

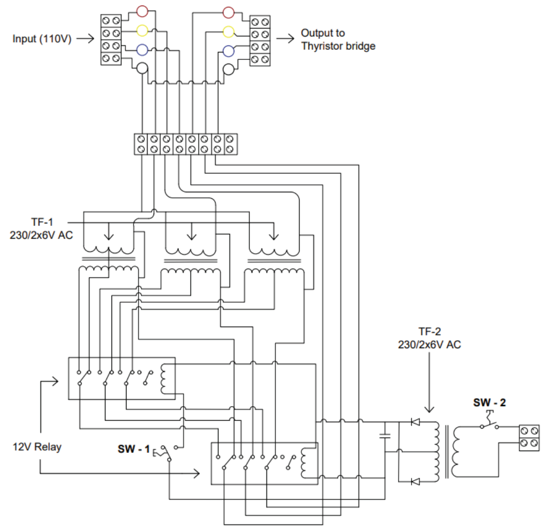


Figure 9 - Design of the test circuit

### 5.2 Governor Parameter Estimation

The load rejection test was conducted for the governor, which determines the ability to operate stably along with the governor system at the time of load rejection or disconnection of the synchronous generator. This test was carried out by disconnecting 30% of the 20MW total load, which is 6MW, by operating the circuit breaker. Initially, the breaker is kept at a closed position, and after a time period of 65ms, the circuit breaker is opened and rejects the load. The performance of the synchronous generator due to load rejection has been obtained as a data set that includes three-phase active power, three-phase reactive power, frequency, time, three-phase terminal voltage, three-phase terminal current, and the governor gate position.

The test curve was obtained by drawing the relevant curve from the data set obtained from the load rejection test. The simulation curve was then generated by applying the same load rejection scenario to the developed generator model in MATLAB. This simulated response replicates the same operating conditions as the field test, allowing a direct comparison with the test curve for the dynamic analysis of the governor system.

## 6. Results and Discussion

### 6.1 Results

The field test curve and the corresponding simulation curve were imported and compared within the MATLAB workspace for both the excitation system and the governor system. The simulation curves for each system were initially developed based on standard predefined parameter values provided in the standards. Ideally, if the real-world system had parameters with identical values as the standard or predefined values, the simulated and the test curves would closely overlap. However, the comparison revealed noticeable discrepancies between the two curves in both cases, indicating a shift in the parameters. This mismatch suggests that the actual AVR and governor systems at the Sapugaskanda power station do not exhibit the same parameter values as those defined in the standard at present. Hence, these deviations underline the necessity of parameter estimation in order to identify and predict the system’s behavior and performance.

The following two figures, Figure 10 and Figure 11, illustrate the comparison of the two curves for the excitation system and governor system before parameter estimation, respectively.

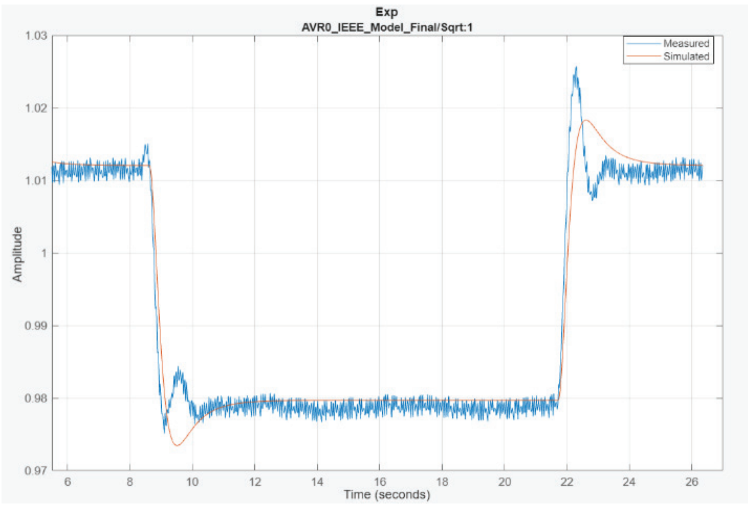


**Figure 10 - Comparison of simulation and test curve of excitation system before parameter estimation**

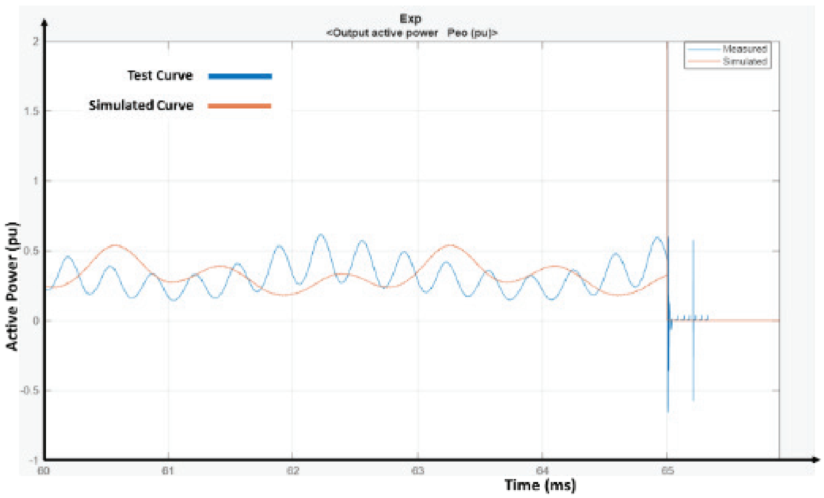


**Figure 11 - Comparison of simulation and test curve of governor system before parameter estimation**

### 6.2 Discussion

The key objective of parameter estimation is to determine the actual values of the system's parameters and quantify their deviations from the standard values. Accurately determining these real-world parameter values helps to identify the dynamic behavior of the control system more precisely, allowing for better prediction of the synchronous generator's overall behavior and its performance.

To achieve this, MATLAB's parameter estimator tool was used, which employs an optimization-based approach. This method iteratively adjusts the parameters of the simulation model by minimizing the difference between the simulated output and the field test response. The optimization process is guided by curve fitting techniques, where the tool modifies the standard parameters across multiple iterations to achieve the best possible alignment between the two sets of curves.

For the excitation system, the overlapped curves as shown in Figure 12 demonstrate a significant improvement in the alignment compared to Figure 10, enhancing the smoothness of the response, especially at critical dynamic points such as the peak deviation points and settling periods. A similar improvement is observed in the governor system, where the resulting curve comparison, as shown in Figure 13, represents a visible improvement in the curve fitting than in Figure 11.

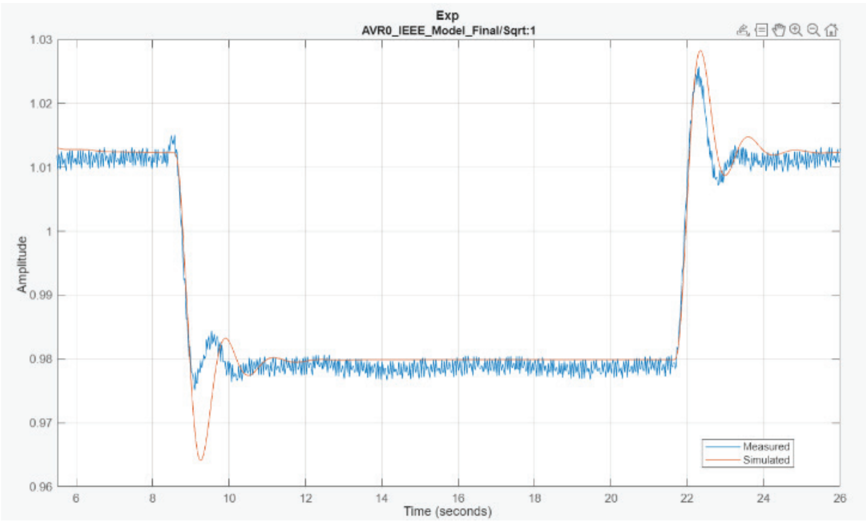


**Figure 12 - Comparison of simulation and test curve of excitation system after parameter estimation**

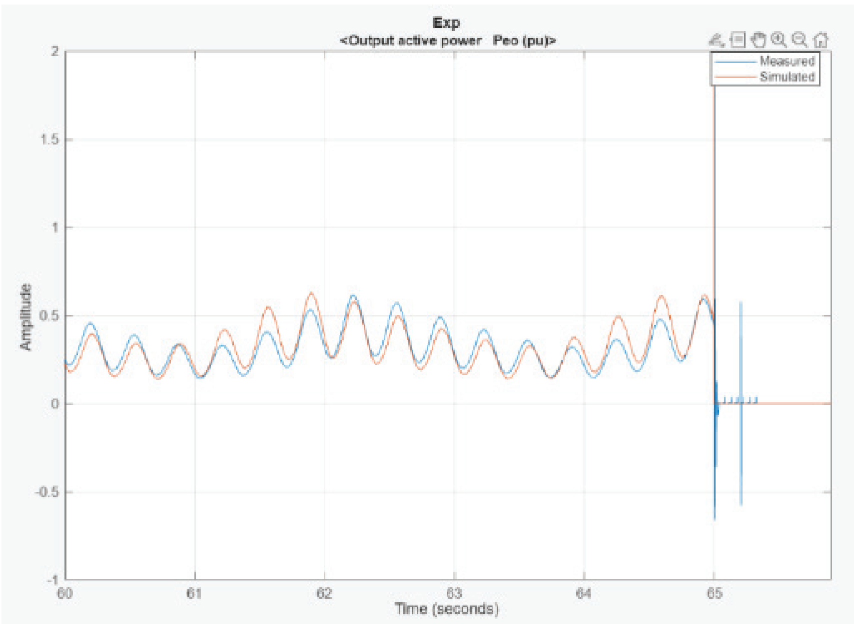


**Figure 13 - Comparison of simulation and test curve of governor system after parameter estimation**

Table 3 summarizes the comparison between the standard and estimated parameter values, which reflect the current real-world parameter values of the excitation and governor systems at Sapugaskanda power station.

**Table 3 - Comparison Between Standard and Estimated Values of Excitation System**

| Excitation system's parameters | | |
|---|---|---|
| Parameter | Standard Value | Estimated Value |
| $K_A$ | 400 | 365.379 |
| $K_C$ | 0.2 | 0.357 |
| $K_D$ | 0.38 | 0.636 |
| $K_E$ | 1.0 | 0.656 |
| $K_F$ | 0.03 | 0.01 |
| $T_E$ | 0.8 | 0.573 |
| $T_A$ | 0.02 | 0.028 |
| $T_B$ | 0.0 | 0.015 |
| $T_C$ | 0.0 | 0.015 |
| $T_F$ | 1.0 | 0.847 |
| $T_R$ | 0.0 | 0.0 |

**Table 4 - Comparison Between Standard and Estimated Values of Governor System**

| Governor system's parameters | | |
|---|---|---|
| Parameter | Standard Value | Estimated Value |
| K | 3.5000 | 2.1977 |
| $T_1$ | 0.0100 | 0.0100 |
| $T_2$ | 2.0000 | 0.1429 |
| $T_3$ | 0.2000 | 0.1987 |
| $T_4$ | 0.2500 | 0.2366 |
| $T_5$ | 0.0390 | 0.0396 |
| $T_6$ | 0.0090 | 0.0076 |
| $T_D$ | 0.0500 | 0.0499 |

The excitation system's dynamics were notably influenced by $K_A$ and $K_E$, indicating a slower system response with smoother voltage regulation. A reduced $K_F$ resulted in decreased damping, and the slight increase in $T_A$ improved system stability. The introduction of values for $T_B$ and $T_C$, previously assumed to be zero, contributed to better oscillation control and transient response.

In the governor system, the estimated K value decreased significantly, suggesting lower power output for the same input, indicating a conservative operational response. A drastic reduction in $T_2$ implies a much faster system reaction, but with potential stability concerns. Minimal changes in $T_3$, $T_4$, and $T_5$ fine-tuned damping and feedback, while slight variations in $T_D$ and $T_6$ helped optimize speed and stability balance.

During the parameter estimation process, the parameters of both the exciter system & governor system were initially varied individually to observe how each affected the model's output curve with respect to the actual generator response. However, this approach did not result in a satisfactory match between the simulated and experimental responses, as changing one parameter at a time could not accurately represent the dynamic behaviour of the real generator. Subsequently, all essential parameters were allowed to vary simultaneously within their physically acceptable ranges during the curve-fitting process. To verify the validity of the obtained parameter set, the estimation process was repeated under identical operating conditions of the generator. Each iteration consistently produced the same parameter values, confirming that these values are not random or dependent on initial guesses but represent the actual dynamic characteristics of the generator and its excitation system.

Furthermore, according to standards, sensitivity analysis was performed by intentionally varying each estimated parameter to study its effect on the system response. The results indicated that any deviation from the estimated values led to significant discrepancies between the simulated and real responses. This provides additional evidence that the obtained parameter set represents the most suitable and realistic values for the given machine and operating condition.

## 7. Conclusion

This research proposes a systematic approach for modelling and parameter estimation of exciter, AVR and governor systems of a synchronous generator. The primary objective of this study is to identify the deviations in system parameter values and to emphasize the importance of estimating those parameters to ensure the proper system behavior and performance. By obtaining real-world parameter values, plant operators and engineers can better understand the current operational behavior of the AVR and governor systems, enabling timely corrective actions to maintain reliable system operation. The unique aspect of this study is the design of test kits tailored specifically to the Sapugaskanda plant, enabling accurate field data collection. Parameter estimation of these systems is done by using the parameter estimator tool in MATLAB. The estimation results demonstrate that the proposed approach effectively reflects parameter variations, improving the understanding of the synchronous generator dynamics, especially in aging plants like the Sapugaskanda power plant in Sri Lanka.

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