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Real-Life Frequency Response Test

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System Parameter Identification of Thermal Generation Unit in the Mongolian Electrical Grid: Real-Life Frequency Response Test

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***Abstract*— Mongolian power grid (MPG) is becoming more eco-friendly as the power system is continuously integrating renewable energy, which reached 20% of the total installed capacity of Mongolia in 2020. With such growth of renewable energy in the system, the daily operation and the safety of the MPG has become a challenge. Therefore, the dynamic behaviour of conventional power plants (CPPs) must be demonstrated to fulfil the requirements of integrating more renewable energy in the MPG, especially for frequency stability. This paper illustrates the results of the system parameter identification of an actual steam turbine and a governor system with PID controller by using a real-life test performed on Generator 1 (G1) of the biggest thermal power plant (TPP-4) in Mongolia on 6th March 2020. The main contribution of this paper is to clear uncertainties about the PID controller's parameters installed in the steam turbine of G1 in early 2019, as a consequence, giving the system operator an accurate dynamic model of the generation unit. The steam turbine and governor are modelled in DIgSILENT® PowerFactory, and the Particle Swarm Optimization (PSO) method is used for identifying the parameters of the PID controller of the G1 at TPP-4. Simulation results from the PowerFactory software matched firmly (error <0.3%) with the measured frequency from the Phasor Measurement Unit (PMU).**

Keywords— ***Frequency, frequency response, governor model, parameter estimation, PID control, particle swarm optimisation, system identification.***

I. Introduction

The dynamic modelling of conventional power plants (CPPs) is essential in studying power system behaviour and design. It is a challenging task because of a data shortage and complex nonlinear systems [1], [2], [3]. Nowadays, most power systems are equipped with phasor measurement units (PMUs) for monitor and control functionalities; furthermore, these measurement devices can be used for estimating or validating the parameters of the generators and the behaviour of the power system [4], [5]. PMU events are helpful for improving the dynamic models because they are based on the actual system disturbance events [6]. The dynamic models of generators are usually provided by manufactories or calculated by using the design data [7].

During the operation life of power components, some electro-mechanical parameters can be changed significantly due to maintenances, upgrades, repairs, etc. In this case, the parameter estimation technique helps to test and validate the power components' dynamic models accurately. The main focus of this paper is performing the parameter estimation of one of the essential generation units in the MPG, Generator 1 (G1) of Thermal Power Plant-4 (TPP-4) [8]. The steam turbine governor of the G1 of the TPP-4 was subject to a massive improvement in 2019; a proportional-integral-derivative (PID) controller replaced a proportional controller. However, a dynamic test to estimate the actual parameter of the model had not been performed yet. The study of this paper concludes the use of parameter estimation technique to define the model of the steam turbine governor of the G1 at the TPP-4. Standard IEEEG1 models for steam turbines have been used, and the parameters are estimated based on several inherent characteristics such as a number of stages, availability of speed control and servomotor.

Therefore, the parameter identification of the dynamic models is necessary to be studied in MPG for planning, designing accurately, and an excellent understanding of the power system's dynamic behaviour. The study was able to identify the PID controller parameters by using a PSO method with measured data from a real-life frequency response test in March 2020. The main contribution of this paper is to clear uncertainties about the PID controller's parameters installed in the steam turbine of G1 in early 2019, as a consequence, giving the system operator an accurate dynamic model of the generation unit.

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II. SYSTEM MODELLING

A. *Description of the Power Plant-4*

The TPP-4 is a coal-fired plant, which has seven steam turbines, each of them driving a 10.5 kV synchronous generator ranging with a maximum capacity of 137.5 MVA (see Fig. 1).

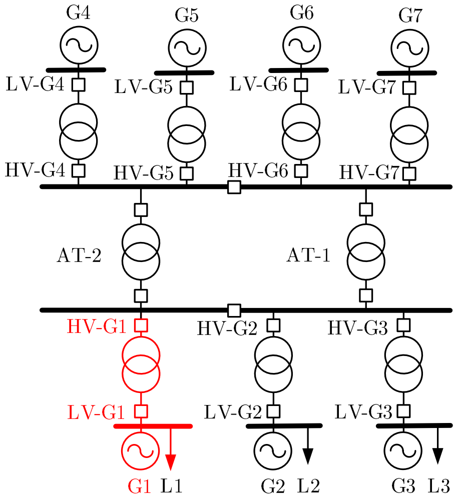

Fig. 1. Single line diagram of the TPP-4. External transmission lines and interconnections are not depicted. G1 is highlighted in red colour. Disconnection of G1 is performed by intentionally opening LV-G1.

Each generator has its step-up transformer, and the connections of the power plant to the transmission system are at the 110 kV and 220 kV levels. Each unit's prime-mover is a steam turbine with a nominal speed of 3,000 rpm, with two stages and no re-heater. All generation units of the TPP-4 had a manual power control, mechanical-hydraulic governor, until 2019. The mechanical-hydraulic control operates the frequency control, and that alone is challenging due to not having high-speed regulation as other classical power plants such as hydro and gas power plant. Also, the TPP-4 did not have high sampling and digital measurement devices; as a consequence, complete validation of the dynamic model of the power plant was a complicated process.

In 2019, the mechanical speed governors upgraded to electronic governors, and control systems and instrumentations were replaced in TPP-4's generators. All of the governor systems were equipped with a servo module for controlling the servo valve opening; it included a PID block in AGS83 servo module and PARMA PП4.12 PMUs. These PMUs receive deterministic data every 20 ms, as well as each data, is equipped with a time tag with an accuracy 1μS. The PMU has specific functions that receive time-synchronised data, are used for state estimation before a contingency, contingency detection, and load shedding based on active power shortage.

B. *Modelling of a steam turbine and governor*

The G1 of the TPP-4 is a steam turbine whose dynamic model is represented by the IEEEG1 model [9]–[11] (see Fig. 2). The steam turbine model of the IEEEG1 consists of the constants, K_1, K_3, K_5, and K_7, defining the fractions of the steam turbine different stages, while K_2, K_4, K_6, and K_8 are set equal to zero because of the tandem construction of the steam turbine. The time constants, T_4, T_5, T_6 and T_7, are encountered in controlling the steam flow, and the turbine power is associated with the no reheat [2], [12].

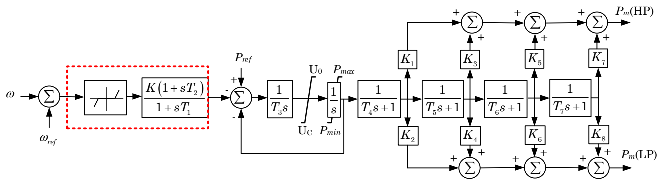

Fig. 2. Block diagram of the steam turbine at the G1 of TPP-4

The authors decided to use DIgSIELNT PowerFactory [5], [13] as a modelling and simulation tool in this paper; as a consequence, IEEEG1 model defined in the global library of the software was used. After the refurbishment of the governors and turbines in 2019, a new model-based adaptive PID controller is used in AGS813 Servo Module for steam turbine governor (see Fig. 3). The red box in Fig. 2 represents the location where the IEEEG1 governor is modified to include a PID controller at G1 to improve the dynamic response. The model is selected based on the flexibility to represent different configurations (i.e., number of stages).

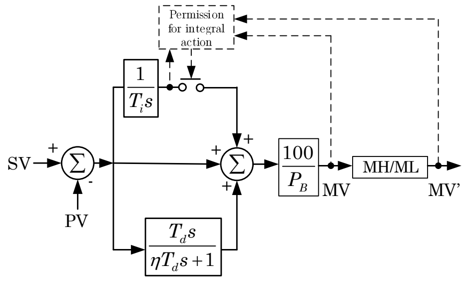

Fig. 3. Improved PID controller with permision logic.

III. PREPARE SYSTEM IDENTIFICATION

The phase system identification refers to the process of mathematical models by using appropriate measurements of the dynamic system's input and output signals [14], [15]. If appropriate measurement data of the system's input and outputs are available, the system identification process is straightforward. In this case, the system identification is performed considering the structure of the dynamic model is known: the synchronous generator, the governor, and the steam turbine model [1], [16], [17]. The identification can be easily formulated as an optimisation problem where the target is minimising the error between the measured output ($\mathbf{Y}_{\mathbf{meas}}$) and the output obtained from simulations ($\mathbf{Y}_{\mathbf{sim}}$):

$$\min_{\mathbf{x}} \left\| \mathbf{Y}_{\mathbf{meas}} - \mathbf{Y}_{\mathbf{sim}} \right\| \tag{1}$$

where the decision vector $\mathbf{x}$ is subject to a set of restrictions in the form of inequality shown:

$$\mathbf{x} \leq \mathbf{b} \tag{2}$$

where $\mathbf{b}$ is the limit of the decision vector.

The system identification is based on the use of the *System Parameter Identification* function of the PowerFactory. The function is called *ComIdent*, command identification, and it includes a high-performance nonlinear optimisation tool, which is able to perform a multi-parameter identification for one or more dynamic models with a set of measured input and output signals. The analysis function has several optimisation methods, Particle Swarm Optimisation (PSO), Nelder Mead, DIRECT (dividing rectangles), and Legacy (Quasi-Newton).

PSO method was used for tuning the PID controller. As the PSO optimisation method is also compared with the above methods, it is validated that the PSO-based controller is more efficient in minimising the steady-state errors; the minimum frequency, overshooting value, rising and settling time in speed control of the governor.

The optimiser is used to find the PID controller's optimal parameters gains, K_p, K_i, and K_d, and parameters of the steam turbine such as transient time constants and inertia constant H.

PowerFactory requires the data coming from measurements to be in the form of an element file (*ElmFile*). This PowerFactory object is used to map the raw measured data onto one or more measurement signals. These signals may contain measurements from the network, elements, or response signals. The element file (*ElmFile)* can be either a text file or a result object (*ElmRes*) from another simulation. The output signals of the power system elements are fed into a comparator together with the corresponding measured signals. The comparator (*ElmDiff*) is thus given the measured response on the governor and the simulated response of the element models. The comparator is used to evaluate the objective function, which is the weighted sum of the differences between the measured and the simulated response (see (1)), raised to a full-power (by default to the power of 2). The *ComIdent* command will collect all objective functions from all comparator objects in the currently active study case and will minimise the resulting overall objective function. To do this, the *ComIdent* command is given a list of parameters that are to be identified [18]. The objective functions are minimised by altering these parameters.

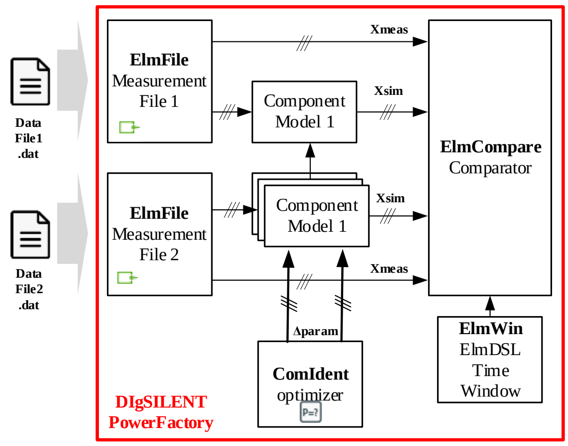

Fig. 4. Block diagram of the system identification principle suing DIgSILENT PowerFactory. Taken and modified from the User's Manual.

IV. Numerical Results

MPG was modelled in PowerFactory, and the system identification is performed using a simulation model in the loop. The command identification, *ComIdent*, was configured to use PSO with a number of swarm particles that are equal to 10, and the number of iterations is 50 in this case.

Using the model of steam turbine and the governor of G1, system parameter identification was performed with a real-life event, and measurements were recorded by the locally installed PMU, PARMA PΠ4.12. The PΠ4.12 is a type of PMU model that can be used as a recorder of emergency events and transient processes. It allows recording the data every 20 ms, and each data is equipped with a time tag with an accuracy 1µS and can be shared by using C37.111-2013 (COMTRADE - 2013) C37.118-2011 protocol.

Early in March 2020, the steam turbine governor system's selected performances of G1 of the TPP-4 were completed on 6th March, 2020, at 01:17:44.30 am. A real-life event, disconnection of the generation unit G1, was created intentionally in the MPG. G1 was operating in the steady-state conditions and generating 60 MW to the power system with its own usage (auxiliaries services of the local plant) of 3.4 MW. Then, the circuit breaker of the low voltage side of the step-up transformer, LV-G1 (see Fig. 1), was intentionally opened by a direct command from the system operator, which caused the disconnection of a G1 from the power system, while the generator response was recorded by PMU. As a result, the generator output power decreased, leading to an increase in the governor valve closing and control frequency.

The research used 500 seconds of measured data collected during the event, which are an active (P), a reactive power (Q), a terminal voltage (V), and a frequency (f). For comparison purposes, three main cases were considered: (1) data measured during the event, (2) simulation results replicating the event using the PID controller with the default parameters installed, and (3) simulation results after the system parameter identification is performed.

TABLE I. Main Indicators of the Generator Frequency Response During the Test

Case	Maximum frequency f_{max} [Hz]	Minimum frequency f_{min} [Hz]	Steady-state frequency f_{ss} [Hz]
Event of PMU	52.79	48.82	49.79
Without identified parameters	53.42	48.59	49.92
With identified parameters	52.88	48.94	49.81

Simulation results have shown a significant discrepancy between the frequency indicators obtained from the measured data and the PID controller's simulation (without parameter identification) results. For instance, there was an access of 0.63 Hz (~1.77%) in the maximum frequency (f_{max}) obtained during the over-frequency event; the situation was depicted in Fig. 5. The PID controller's dynamic model with the governor system of the G1 created in PowerFactory to replicate the specific controller's full dynamic, as shown in Fig. 3. However, the most significant discrepancy is the post-disturbance steady-state frequency, where the discrepancy is around 130mHz, indicating some potential issues with the governor parameters. Looking at the details, the maximum and minimum frequency were significantly overshooting, and steady-state frequency was recovered differently.

The identified parameters were tested by replicating the real-life frequency event, and the main frequency indicators were closer to the measured data. In fact, there was less than 0.3% error in the worst indicators (minimum frequency and maximum frequency). Simulations results show the parameters of the PID controller governor system exhibit minor discrepancies compared to measured data such as overshoots. However, other indicators firmly matched, like the minimum frequency and steady-state frequency. Some of the frequency deviations were identified from the simulation results (shown in Fig. 6).

However, there was a gap between the simulated and measured frequency in the period from 35 seconds to 122 seconds. The results showed there is a need for further investigation.

A summary of the dynamic model parameter identified in this paper is shown in Table II and compared with the parameters previously used (without parameter identification).

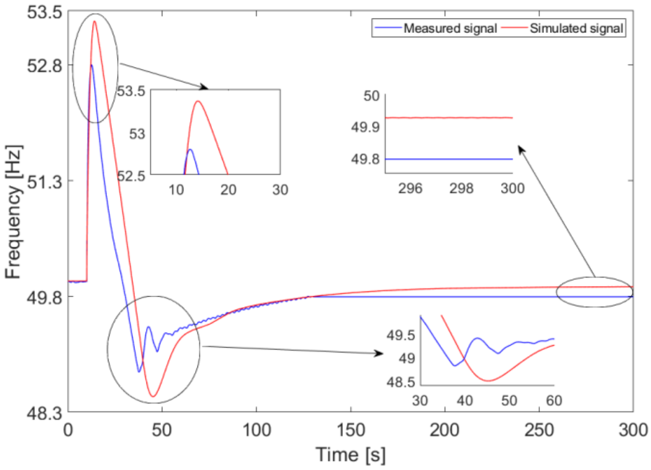

Fig. 5. Fig.5 Comparison between real and simulated steam turbine response without optimisation

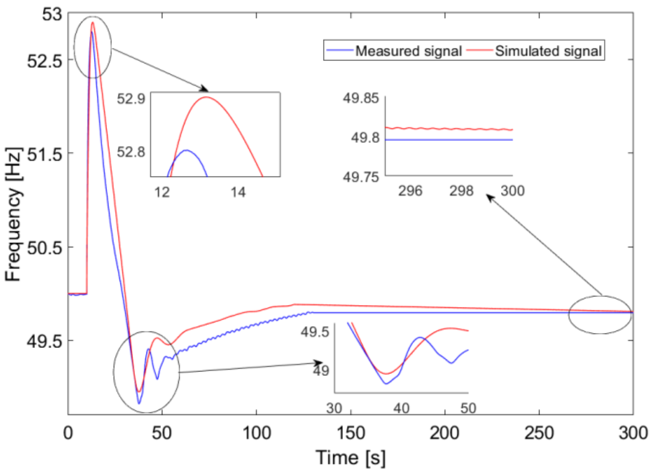

Fig. 6. Comparison between real and simulated steam turbine response with optimisation

TABLE II. SUMMARY OF THE PID CONTROLLER GOVERNOR SYSTEM AND STEAM TURBINE PARAMETERS

Parameter	Description	Initial values [s]	Identified parameter [s]
K_p	Proportional gain [pu]	25	15.112
K_i	Integral gain [pu]	150	331.66
K_d	Derivative gain [pu]	2,000	3,101.73
T_d	Derivative term time constant[s]	0.1	0.08
T_i	Integer time constant[s]	0.3	0.50
T_3	Servo Time Constant [s]	0.1	0.07
H	Inertia Constant (rated so S_{gn})	3.00	4.01
$T_{d0'}$	Transient time constant d-axis [s]	6.77	6.81
$T_{q0'}$	Transient time Constant *q*-axis [s]	6.77	6.81

V. CONCLUSIONS

The largest thermal power plant in Mongolia, TPP-4, received a refurbishment to improve efficiency and extend service life in 2019. One crucial improvement was adding a PID block in AGS83 servo module to the steam turbine governor model. This research paper uses measured data recorded during a real-life frequency response test (March 2020) to identify the PID controller parameters installed in the steam turbine of G1 in early 2019. DIgSILENT PowerFactory and the recorded PMU data are using together with Particle Swarm Optimization (PSO) to identify the parameters of the PID controller of the G1 at TPP-4. The results are auspicious as the results show a close match on the primary frequency indicators (error <0.3%) when simulations are compared with the test results. However, the authors recognise there is a need for further investigation of the slow transient frequency response during the recovering process. In the future, this validated dynamic model will be used significantly for planning and studying within the Mongolian power system. Also, the installation of PMUs in Mongolia grid's will help to enhance the capacity of identifying other dynamic models such as the excitation system, governors, BESS's controller and wind turbine model, and even create a method for adaptive under frequency load shedding and emergency frequency control using WAMS, which was implemented in 2020.

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