Aalborg Universitet

Procedure for parameter identification and validation of governor and automatic voltage regulator dynamic models

Tróndheim, Helma Maria; Silva, Filipe Miguel Faria da; Bak, Claus Leth; Nielsen, Terji; Niclasen, Bárður Arnsteinsson; Nielsen, Rasmus; Weikop, Nicolas

Published in:
7th International Hybrid Power Plants and Systems Workshop, HYB 2023

DOI (link to publication from Publisher):
10.1049/icp.2023.1440

Publication date:
2023

Document Version
Accepted author manuscript, peer reviewed version

Link to publication from Aalborg University

Citation for published version (APA):
Tróndheim, H. M., Silva, F. M. F. D., Bak, C. L., Nielsen, T., Niclasen, B. A., Nielsen, R., & Weikop, N. (2023). Procedure for parameter identification and validation of governor and automatic voltage regulator dynamic models. In *7th International Hybrid Power Plants and Systems Workshop, HYB 2023* (3 ed., Vol. 2023, pp. 108-115). Article 10220142 IEEE. https://doi.org/10.1049/icp.2023.1440

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal -

Take down policy
If you believe that this document breaches copyright please contact us at vbn@aub.aau.dk providing details, and we will remove access to the work immediately and investigate your claim.

Alternative and Combined Procedure for Parameter Identification and Validation of Governor and Automatic Voltage Regulator Dynamic Models

Helma Maria Tróndheim[1,2,3], Filipe F. da Silva[2], Claus L. Bak[2], Terji Nielsen[1], Bárður A. Niclasen[3], Rasmus S. Nielsen[4] and Nicolas Weikop[4]*

[1]*R&D Department, Power Company SEV, Tórshavn, Faroe Islands*
[2]*AAU Energy, Aalborg University, Aalborg, Denmark*
[3]*Department of Science and Technology, University of the Faroe Islands, Tórshavn, Faroe Islands*
[4]*AFRY, Copenhagen, Denmark*
**hmt@sev.fo*

Keywords: ISLANDED POWER SYSTEM, PARAMETER IDENTIFICATION, DYNAMIC MODEL VALIDATION, FAROE ISLANDS, RENEWABLE ENERGY

Abstract

The Faroe Islands are aiming for 100% renewable electricity generation. The complexity of operational power systems with a high level of renewable generation necessitates accurate dynamic models. Many power systems, including the Faroe Islands, do however consist of generation units with old governors and automatic voltage regulators, in which suitable models and parameters are unknown. Obtaining dynamic models with parameters that replicated measurements proved to be challenging using existing procedures. Therefore, this paper presents an alternative and combined procedure for identifying and validating the controllers and parameters. The procedure utilises measurement data from trip tests, standard controller models, and an optimisation algorithm. The procedure also combines hybrid simulations and system-wide simulations. A successful application of the proposed procedure on the power system of the Faroe Islands is presented. The proposed approach can be applied to other power systems and is especially suitable for other island power systems of similar size to the Faroese power system.

1 Introduction

Climate changes due to carbon emissions are a global concern, and a big contributor to this is electrical power generation. The electricity and heat sectors have previously been estimated to be 25% of the global greenhouse gas emissions [1]. Power systems worldwide are however replacing the carbon-based generation with renewables to decrease the emissions. The thermal generators are replaced by wind turbines, photovoltaic panels (solar), nuclear power plants and hydro turbines, depending on the local geography and resources available. The environmental advantages of renewable energy are obvious, but there are several disadvantages regarding the power system operation, e.g., the intermittent nature of wind speeds and solar irradiation. Intermittent production from a wind power plant or photovoltaic power plant is especially an issue in small power systems, as in larger systems it can be evened out by other power plants. In addition to this, the consumption on islands is small and fluctuating, which is why oil and if possible, hydro has traditionally been used to produce electricity on islands.

In 2014 the Faroe Islands, see Figure 1, announced its so-called green vision (100by2030), becoming 100% green in terms of electricity production by 2030. The islands are surrounded by an abundance of renewable resources in terms of wind, hydro, tidal streams and to a certain extent solar energy, but balancing the system at 100% is challenging. Although the hydro resource is available, it is limited relative to the size. Also, the mild climate and moderate mountains mean that hydro does not get a seasonal input from melting ice.

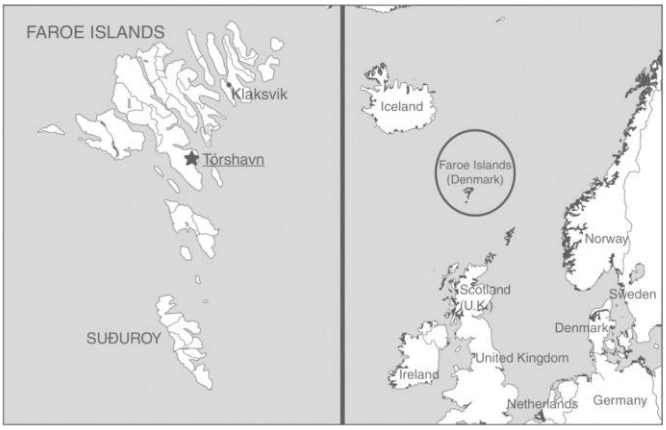

Figure 1 Map of the Faroe Islands [2]

An economically optimised and tangible RoadMap towards 100% in 2030 ensuring a balance between supply and demand in the years under investigation (2020-2030) has been made for the Faroese power system [3]. This study reveals that wind power will be the main provider of energy complemented by solar energy in the summer months when the wind resources typically are low. To bridge the energy gap at times with low renewable resources available, a relatively large-scale pumped hydro system is proposed.

The increasing penetration of intermittent and inverter-based renewable energy into a relatively small, isolated power system, calls for precise and validated simulation models to ensure the frequency- and voltage stability in the power system as the inverter-based technologies steadily substitute the synchronous generators and their inherent system services. These system services are inertia, short circuit power and active/reactive power regulation. The active and reactive power regulation after a disturbance is conducted by the governors and automatic voltage regulators (AVR), which compensate for the power deficit between the generation and demand.

High accuracy power system models are essential in power system planning and operation. Analyses and validations of these models have to occur continuously [4]–[8]. A power system model, which has not been validated with measurements, can only be used for academic exercises [6] and assessing power systems without computer simulations is inconceivable [5]. The application of dynamic power system models is not only for analyses after large disturbances but also relevant for voltage- and frequency stability studies, protection schemes and restoration plans. A validated power system model can minimise disruption in the operation and risks to equipment [4]. However, obtaining a full system validated model can be difficult, as one sub-model [4] or even one single parameter [5], can change the simulation results significantly. Old generation units, e.g., diesel generators and hydro turbines, are commonly found in small, isolated grids, like the power system in the Faroe Islands. The available information about suitable computer models and respective parameters for these is limited or even non-existent, which makes the task of obtaining a fully validated model even more challenging. Even with correct models, this is a difficult task, as each parameter is associated with an inaccuracy.

Validation of power system models is usually conducted as either System-Wide Simulations (SWS) or Hybrid Simulations (HS), see e.g. reference [9] and [10] respectively. These two methods have been compared by den Boer [11]. The first method, i.e. SWS, is a simulation of a full system replicating a previously recorded event. The dynamic response is compared to field measurements. In HS a sub-network is isolated, and then e.g., voltage and frequency time series are injected into this sub-network. The dynamic behaviour of the sub-network, e.g., generators' active and reactive power, is compared to measurements. A study case [11] shows that neither method perfectly resembles the measurements. HS showed a better resemblance with the measurements, but it must be considered that this is a simulation with measured frequency and voltage as inputs. This means that the measurements are partly controlling the simulation results. Validating a whole network (using SWS) instead of a sub-network (using HS), obviously gives a better indication of the accuracy of the system model, but it can lead to high computational time due to the complexity of the system model. The advantage of using HS in the validation process is the simplification to a sub-network and it is said to be crucial for validations [6], but complementary tools are needed [12], as HS is not always sufficient. This issue is also addressed in another study [13], which proposes a two-level online parameter identification, by parameterising models using HS and then validating throughout the whole system.

Measurement data used for parameterisation is usually obtained from planned tests, but studies have also suggested using actual disturbances [4], [5]. The advantage of staged tests is that it can easier to parameterise, as the disturbance, exact operation scenario etc. is known. On the other hand, the advantage of online validation is that it does not require taking a unit out of service. It can however take a long time to obtain enough data from natural disturbances to be able to accurately parameterise models, and a staged test might not reflect some of the interactions and dynamic behaviour between the different governors and voltage regulators etc.

The parametrisation of models can be done manually, by trial-and-error varying the parameters, but it can be very difficult to find the correct parameters, especially when looking at a whole system as many parameters are interdependent. Thus, multiple optimisation algorithms have been applied to parameterise dynamic models, by minimising the difference between measured and simulated dynamic responses see e.g. references [14]–[17]. Reference [8] suggests automating the comparison of simulation and measurements during validation, and use this for calibrating the parameters respectively. It also divides the response into two during validation, the oscillatory behaviour and the slow governor response. There are however also disadvantages with such an automatic optimisation, e.g. reference [18] states that optimising the parameters does not ensure the sensitivity of the parameters.

In the past parameterisation was commonly conducted using frequency response [19], [20], but this is not common in newer literature. Huang et al. [21] use a Kalman filter with event playback (of disturbance). However, the need to improve the event playback method due to limitations of phasor measurement units (PMU) has also been identified [22]. This is done by using a multi-model adaptive Kalman filtering, singular spectrum analysis and initialising the event playback after the first fast transients, which cannot be captured by the PMU. The particle swarm optimisation algorithm (PSO), is also commonly used to identify parameters, but a previous study [9] proposes a modified version of PSO to improve the results. This study also states that parameters can be identified using different events. Weaknesses have not only been identified with the algorithms used, but also with the standard models available. A study [23] claims that the standard models must be extended with frequency ramp rate, activity range and dead-band to accurately represent reality. One method developed to estimate the parameters of a diesel generator is proposed in [24]. This study presents a hierarchical optimisation method, which is based on how each parameter affects the response of the generator, i.e. if it has an impact on the reactive power, active power or if it is neutral. The case study is based on a microgrid. In reference [25] the diesel governors on Kinmen island (Taiwan) are parameterised and validated using a reduced order governor, as high order models are complicated, and the risk of finding a local optimum with high order optimisation is higher than when fewer parameters are validated. The study utilised the HS method using a PSO algorithm to find suitable parameters. The generators, governors and AVRs in Cyprus have been validated based on past disturbances by Stavrinos et al. [26] using a manual approach. Information about generators and governors was available, while AVRs were modelled using standard models with default parameters. In cases where the resemblance between measured and simulation was not good enough, the parameters were adjusted. A study on the validation of a generating unit in Poland combines a genetic algorithm with a gradient algorithm [27]. Reference [10] focuses on validating hydro governors in three power plants in the Pacific North West in North America. Another attempt at validating a power system is found in [28], in which Bonaire Island (Caribbean Sea) is the study case. This study does not explain how the power system has been modelled but emphasises the importance of validating the load models, as the air conditioners in Bonaire are a significant contributor to the dynamic system response. These few study cases show that different approaches and algorithms are used to validate power system models, from manual adjustment to using optimisation algorithms to find suitable parameters.

Most previous studies use one event to parameterise models, which could result in finding a very specific local set of fitting parameters, i.e., the found parameters might only be valid for one event. Using multiple scenarios for parameterisation can prevent this, if not obtaining a global parameter set, it at least fits for a wider range of events [4], [7]. Reference [7] used multiple events to parameterise generator parameters, and a better set of parameters was obtained compared to a parameterisation using one event.

The model of the Faroese power system has been developed in DIgSILENT's PowerFactory over several years. The model has been load-flow validated, while the dynamic validation showed to be a challenging task. It started with using HS validation with manual adjustment of parameters, but the SWS simulation using these HS manually adjusted parameters did not replicate the measurements. The need to use automatization to test different combinations of parameters was identified. A script was written to test different combinations using SWS, and through a brute force algorithm, the simulation closest to the measurements could be identified. It was however difficult to find the best parameters, and even with the small system of the Faroe Islands, the computational time was an issue. The authors then utilised the system parameter identification (SPI) tool in PowerFactory, which, as the name implies, is suitable for this type of assignment.

This paper presents an alternative combined procedure for identifying and validating parameters of governors and AVR of a whole system using multiple staged tests/disturbances, in which most models and respective parameters are unavailable. The advantage of the proposed procedure is that it uses the simple HS for initial parameterisation by SPI and validates the models with SWS. The parameterisation is conducted using multiple events simultaneously to prevent obtaining a local set of suitable parameters. In the case where the validation shows that the parameterisation with HS is insufficient, which is an issue addressed previously, a second parameterisation with SWS is conducted. Using SWS for parameterisation is computationally heavy, which is why HS is preferred in cases where the response is acceptable. This procedure is ideal for islanded power systems of similar sizes to the Faroe Islands. The main disadvantage with SWS is the computational time, so a system smaller than the power system in the Faroe Islands can parameterise models without issues using only SWS parameterisation. For systems significantly larger than the Faroese power system, the time required for SWS parameterisation is too high, so this is not even considered an option. This study does not focus on the optimisation algorithm itself, but rather on the improvement of the combined procedure of parameterisation and validation described further in section 2. The proposed procedure has been applied to two independent grids in the power system in the Faroe Islands, as seen in section 3. The dynamic simulation results show a satisfactory resemblance with the 10 Hz online measurements.

2. Proposed Procedure

A flowchart of the proposed approach is shown in Figure 2. To utilise this approach, a validated static load-flow model is required. The method has been applied using DIgSILENT's PowerFactory. Generally, the procedure is not restricted to PowerFactory only, but adaptions might be necessary when using other software tools. The proposed methodology combines SWS and HS. The main idea is that the primary controllers are parameterised using HS together with PowerFactory's System Parameter Identification (SPI) tool, and then validated with SWS. If the SWS shows a behaviour deviating significantly from the measurements, the second parameterisation of user-selected parameters using SWS with SPI is conducted. SPI minimises the difference between measured and simulated responses, by optimising user-selected parameters. In this study case, the Particle Swarm Optimisation (PSO) algorithm was used, mainly due to its computational efficiency. SPI is a time demanding process, and thus utilising HS is a great advantage as the simplification of the grid makes the parameterisation faster. However, when validating the parameters in SWS, the parameters did not replicate the measurements accurately in all cases, which is why it is necessary to run SPI with SWS for regulators which cannot be validated after HS parameterisation. Each step of the flowchart is described in detail in the following paragraphs.

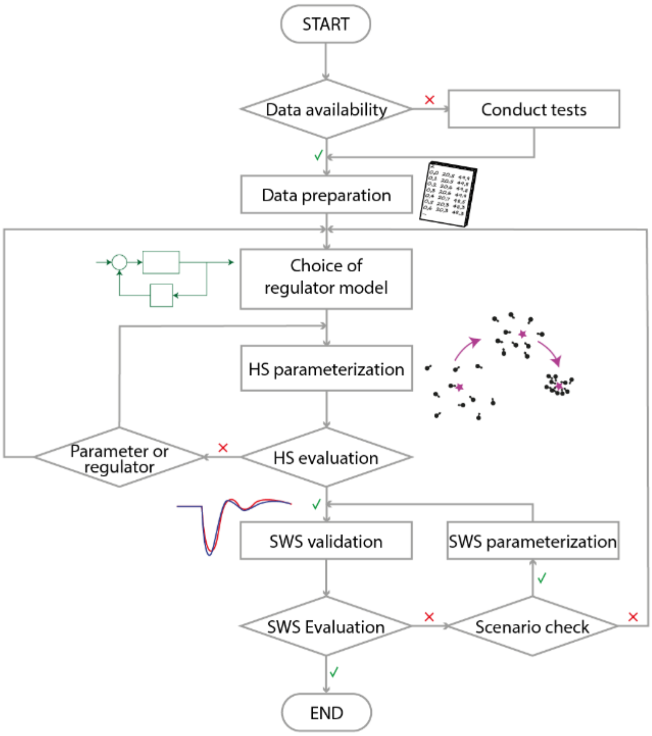

Figure 2 Flowchart for proposed parameter identification and validation procedure

- **Data availability:** The first step of the proposed procedure is to check whether useful measurement data are available. For data to be classified as useful, the generators' have to have had a clear primary response, which has been measured with a sufficient resolution e.g., 10 Hz. This data can originate from previous disturbances or tests conducted for the purpose. The data, which was used in this study case, was the active and reactive power of the generators online and the frequency and voltages measured at the generators' busbars. The measurements with the highest resolution in the Faroese power system are 10 Hz, and these were the measurements used in the examples described in this paper. Each generator must be online in e.g., 3 datasets, to ensure that the parameterisation, and thus, validation is valid for multiple events.
- **Conduct tests:** In the case where no useful data is available, it is necessary to conduct tests on the system and record needed measurements with a suitable resolution (e.g., 10 Hz). This could for example be a generator trip or sudden load changes, which result in a clear primary response for the remaining generators online.
- **Data preparation:** The data needed for the parameterisation and validation must be prepared according to the required setup of the simulations and made suitable for the specific software. This can be extracting irrelevant parameters from a data file, limiting the period, converting parameters to p.u. etc. Also, the data must be analysed and corrected for any faulty data points.
- **Choice of regulator model:** A model for each regulator can be chosen from the software library or custom designed. It can be challenging to find a model, which fits the regulator exactly, but the IEEE Recommended Practice for Excitation System Models for Power System Stability Studies [29] and support from the manufacturer can be helpful or even required sometimes.
- **HS parameterisation:** Each regulator is parameterised separately using HS and SPI with PSO, but with all relevant datasets for the regulator simultaneously. This is done by making multiple identical sub-networks all representing the same generator, but with voltage and frequency inputs from different scenarios. The default parameters are used as start values. A so-called "configuration script" for the regulator is used to make sure that the regulators in each subnetwork keep the same parameters when running SPI, so the parameters are optimised according to all relevant scenarios.
- **HS evaluation:** A qualitative evaluation of whether the responses can be improved through additional HS parameterisation, or if one should proceed to the SWS validation.
- **Parameter or regulator:** A qualitative evaluation of whether optimising other regulator parameters or using different boundaries can improve the response, or if another regulator model must be used.
- **SWS validation:** The validation is an RMS simulation (SWS) which replicates the tests/disturbances and compares the simulation results with recorded measurements.
- **SWS evaluation:** The validation is evaluated qualitative, and if the results are sufficient with regards to pattern, min/max and settling time, it is concluded that an accurate model has been obtained. There are no standards for defining when a model is sufficiently accurate, and thus this is up to the engineer criteria. If the results for a specific regulator are insufficient, a second parameterisation is required.
- **Scenario check:** The second parameterisation can be done for all relevant scenarios individually. This step checks whether any available scenarios have not been SWS parameterised. If SWS parameterisation has been run for every relevant scenario, and the validation still is insufficient, it is concluded that a sufficient result cannot be obtained with the specific regulator model, and thus, the process should be restarted with another regulator model.
- **SWS parameterisation:** The second parameterisation uses SPI with SWS. It is not possible to run multiple scenarios simultaneously with SWS, thus the SWS parameterisation is conducted for one scenario, and the new parameters are validated and evaluated. If these are insufficient the SWS parameterisation is run again with another scenario. SPI is in this case configured to optimise

only the parameters of the regulator(s), which show insufficient results.

3 Application to the Faroese Power System

The procedure proposed in the previous section has been applied to the Faroese power system, specifically the synchronous generators in the main grid which connects 11 out of 18 islands, and the isolated grid on the island of Suðuroy. The synchronous generation capacity, i.e., diesel and hydro, is 124 MW in the main grid and 17 MW in Suðuroy. A list of power plants, the respective grid, the type, number of units and the total generation capacity at the plant can be found in Table 1 [30]. In addition to the synchronous generation capacity, the Faroese power system includes wind turbines of 24.5 MW in total and a small photovoltaic plant of 0.24 MW. Models for all wind turbines (except the 3x660kW windfarm at Mýrarnar) with the actual parameters have been provided by the manufacturer, and the performance has been validated using SWS simulations, thus the need for a validation procedure considering the wind turbines is not needed. The photovoltaic plant of 0.24 MW is relatively small, is not equipped with any active or reactive power regulation capabilities to support the grid and is connected to the distribution grid, thus this plant has not been modelled. The biogas plant is likewise relatively small and placed in the distribution grid and has not been modelled. The generator is a synchronous machine, but the active and reactive power regulation from this unit is negligible.

Table 1 List of power plants, type, number of units and total plant capacity in the main grid and the grid in Suðuroy, Faroe Islands [30].

Grid	Plant	Type	Units (#)	Capacity (MW)
Main	Sundsverkið	Heavy fuel oil	9	82.5
	Elverkið á Strond	Heavy fuel oil and hydro	2	5
	Eiðisverkið	Hydro	3	22.1
	Fossáverkið	Hydro	2	6.5
	Heygaverkið	Hydro	1	5.4
	Mýruverkið	Hydro	1	2.4
	Neshagi	Wind	5	4.5
	Húsahagi	Wind	13	11.7
	Mýrarnar	Wind	3	2
	Förka	Biogas	1	1.5
Suðuroy	Vágsverkið	Heavy fuel oil	4	13.6
	Botnur	Hydro	2	3
	Porkerishagi	Wind	7	6.3
	Sumba	Photovoltaics	-	0.24

Multiple staged tests have been conducted to obtain enough measurement data to parameterise and validate the governors and AVRs in the main grid and Suðuroy. The tests were done by tripping one of the online generators. In most of the tests the generator, which was tripped, had a high production of either active or reactive power, not both. This was done to capture e.g., a frequency drop, which was mostly associated with the loss of active power, not impacted by a large voltage drop due to reactive power loss. This makes it possible to parameterise the AVRs in a scenario where the response from the governors was limited. Some of the tests were however conducted by tripping a generator with a high production of both active and reactive power. This paper highlights the results from three examples of parametrisation and validation.

Figure 3 shows an example of the reactive power and voltage validation of one of the events in Suðuroy with the final regulator parameters. In this scenario it was not necessary to conduct a second parameterisation using SWS, i.e., the parameters were identified using the HS parameterisation only. The staged test in this example is that a diesel generator (VG G4) producing 80 kW and 510 kvar is tripped. The other generators online are two hydro turbines (BO G1 and BO G2) and another diesel generator (VG G3). The plot clearly shows a good resemblance between measured (blue) and simulated (red) responses. For BO G1, there are two relatively high spikes in the measurements after the event, and these are not seen in the simulation. However, this inaccuracy looks worse than it is, as it is due to the resolution of the measurement, 0.01 MW. The generator is small and is only producing 20 kvar steady state, which is why this difference is so visible. There is also an offset for VG G3, but this is caused by an overall reactive power offset in the static load flow model. An offset in the static model must be compensated by one of the generators in the dynamic simulation, and in this case, it is VG G3, the largest generator online during the test.

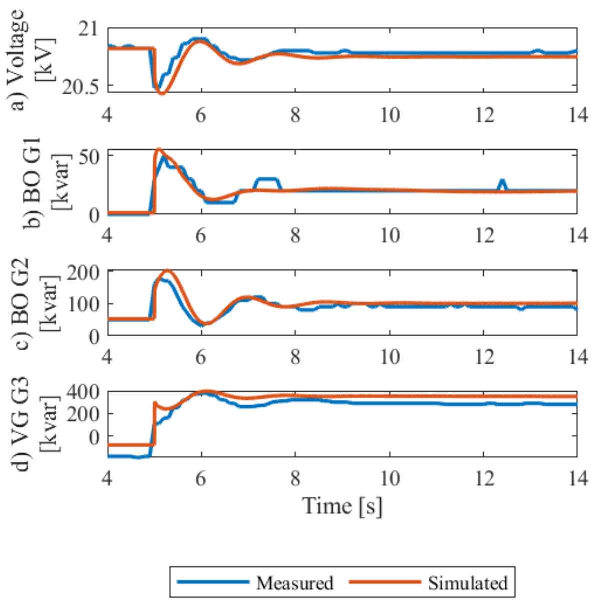

Figure 3 Example from reactive power/voltage validation (SWS) in Suðuroy. Red is simulated and blue is measured.

An example with active power and frequency validation for the main grid is shown in Figure 4. The total generation capacity in the main grid is significantly larger in the main grid than in Suðuroy and the number of generation units is higher, see Table 1. This makes the task of validating the model of the main grid more difficult than the grid in Suðuroy. Figure 3 shows the grid frequency and active power for one of the diesel engines which was online (SD G6) and two of the hydro turbines (EI G2 and HE G1) during the staged test. Other engines were online, but these are some of the largest, and thus, some of the most interesting units. The measurements and simulations show very similar behaviour, for both EI G2 and SD G6, the simulation response is much more stable before, during and post the event. The generators shown here were parameterised through HS only. There is a difference between the simulated and measured inertial response for HE G1, but the difference might be associated with limitations in the measurements rather than the simulation, as the measured inertial response for HE G1 seems to happen in two steps rather than one continuous. The grid frequency shows acceptable ROCOF, frequency nadir and steady-state frequency. The consequence of applying a method which would not lead to an as good validation is that the model could not be used to plan a future expansion or analyse past disturbances to the same degree. The frequency does have a steady-state deviation from 50 Hz, due to the secondary control in the Faroe Islands being manual.

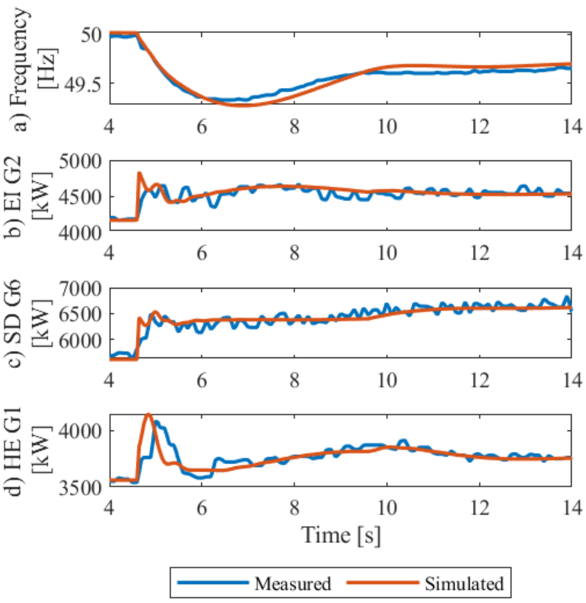

Figure 4 Example from active power/frequency validation (SWS) in the main grid. Red is simulated and blue is measured.

Gomez et al. (2011) state, as previously discussed, that HS parameterisation does not always lead to simulation results which can be validated, and this was also experienced during the validation of the Faroese power system, which is why SWS parameterisation was included as a step in Figure 1. Figure 5 shows the reactive power response of two hydro turbines in one plant (Fossáverkið in Table 1) to one of the staged tests. Blue is the measured reactive power, SWS validation using parameters from the HS parameterisation is in yellow, and red shows the validation after the SWS parameterisation. The yellow curves show a response which is far from the actual response, while the SWS parameterisation improves the responses of both generators, especially FO G1. The response of FO G2 has a steady-state error but is improved significantly during the first seconds after the test, and the steady-state deviation is also smaller than using only HS parameterisation.

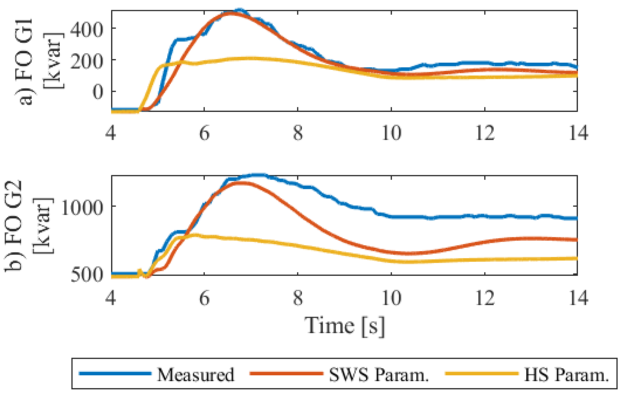

Figure 5 Example where SWS parameterisation was needed to improve resemblance between simulated and measured response. Blue is measured, yellow is a simulation after only HS parameterisation and red is after SWS parameterisation.

4 Conclusion

There are many methods and approaches to parameterise and validate power system models. Validating the power system model of the Faroe Islands has been a long process, and different approaches have been used ending with a procedure combining different approaches available, which has resulted in a successful application to two isolated grids in the Faroe Islands. The proposed method, which is a significant scientific contribution, takes advantage of the simple and fast HS parameterisation, but also identifies the need for SWS in validation and parameterisation, as HS in some cases leads to system-wide simulations which cannot be validated. The method also considers multiple staged tests, to ensure that the parameters found can be validated for multiple scenarios, which also increases the possibility to find a global optimum during the parameter optimisation, rather than a local optimum. Power systems smaller than the Faroe Islands might not see the need to use HS parameterisation instead of SWS, while SWS parameterisation is not an option for larger systems, due to the complexity and computational time, which is why the method shown here is especially interesting for islanded power systems of similar sizes as the Faroe Islands. In the application to the Faroese power system, PowerFactory was used together with the PSO algorithm, but the approach can be used in other software and with other optimisation algorithms. It is expected that this procedure will show similar improvements in finding controller parameters of similar island systems.

5 Acknowledgements

This paper is a part of an industrial dual degree PhD project between the Power Company SEV (Faroe Islands), Aalborg University (Denmark) and the University of the Faroe Islands (UFI). The PhD project is funded by Research Council Faroe Islands, SEV and the UFI. This paper is conducted in cooperation with AFRY Denmark. The authors would like to thank electrical engineer Eirikur Norðberg, SEV, who assisted in conducting trip tests on the system.

6 References

[1] IPCC, 'Mitigation of climate change', *Contrib. Work. Gr. III to Fifth Assess. Rep. Intergov. Panel Clim. Chang.*, vol. 1454, 2014.

[2] M. G. Schug, A. Gottlieb, and J. DeLoache, '"Equal Children Play Best": Raising Independent Children in a Nordic Welfare State', in *A World of Babies*, Cambridge: Cambridge University Press, 2016, pp. 261–292.

[3] H. M. Trondheim, B. A. Niclasen, T. Nielsen, F. F. Da Silva, and C. L. Bak, '100% Sustainable Electricity in the Faroe Islands: Expansion Planning Through Economic Optimization', *IEEE Open Access J. Power Energy*, vol. 8, no. August 2020, pp. 23–34, 2021, doi: 10.1109/oajpe.2021.3051917.

[4] J. W. Feltes and L. T. G. Lima, 'Validation of dynamic model parameters for stability analysis; industry need, current practices and future trends', in *2003 IEEE Power Engineering Society General Meeting (IEEE Cat. No.03CH37491)*, 2003, vol. 3, pp. 1295-1301 Vol. 3, doi: 10.1109/PES.2003.1267336.

[5] L. T. G. Lima, 'Dynamic model validation for compliance with NERC standards', in *2009 IEEE Power Energy Society General Meeting*, 2009, pp. 1–7, doi: 10.1109/PES.2009.5275452.

[6] E. Allen, D. Kosterev, and P. Pourbeik, 'Validation of power system models', in *IEEE PES General Meeting*, 2010, pp. 1–7, doi: 10.1109/PES.2010.5589874.

[7] K. Mahapatra and H. Wang, 'Generator Dynamic Model Calibration using Multiple Disturbance Events', in *2020 IEEE Power Energy Society Innovative Smart Grid Technologies Conference (ISGT)*, 2020, pp. 1–5, doi: 10.1109/ISGT45199.2020.9087727.

[8] U. Agrawal, P. Etingov, and R. Huang, 'Advanced Performance Metrics and Their Application to the Sensitivity Analysis for Model Validation and Calibration', *IEEE Trans. Power Syst.*, vol. 36, no. 5, pp. 4503–4512, Sep. 2021, doi: 10.1109/TPWRS.2021.3066911.

[9] M. Sajjadi, H. Seifi, and H. Delkhosh, 'A new approach for system-wide power system frequency model validation via measurement data', *Eng. Reports*, Aug. 2021, doi: 10.1002/eng2.12446.

[10] D. Kosterev, 'Hydro Turbine-Governor Model Validation in Pacific Northwest', *IEEE Trans. Power Syst.*, vol. 19, no. 2, pp. 1144–1149, May 2004, doi: 10.1109/TPWRS.2003.821464.

[11] T. L. den Boer, 'Validation of Dynamic Power System Models using Synchrophasor Measurements'. TU Delft, 2019.

[12] J. E. Gomez, I. C. Decker, and R. A. Leon, 'Hybrid simulations, a smart way to perform parameter validation in power systems', in *2011 IEEE PES Conference on Innovative Smart Grid Technologies Latin America (ISGT LA)*, 2011, pp. 1–7, doi: 10.1109/ISGT-LA.2011.6083184.

[13] R. Chen, W. Wu, H. Sun, and B. Zhang, 'A two-level online parameter identification approach', in *2013 IEEE Power Energy Society General Meeting*, 2013, pp. 1–6, doi: 10.1109/PESMG.2013.6672162.

[14] A. A. Hajnoroozi, F. Aminifar, and H. Ayoubzadeh, 'Generating Unit Model Validation and Calibration Through Synchrophasor Measurements', *IEEE Trans. Smart Grid*, vol. 6, no. 1, pp. 441–449, 2015, doi: 10.1109/TSG.2014.2322821.

[15] S. Kittiwattanaphon, W. Wangdee, and S. Katithummarugs, 'Generator Excitation System Parameter Identification and Tuning by Using PSO', in *2019 7th International Electrical Engineering Congress (iEECON)*, 2019, pp. 1–4, doi: 10.1109/iEECON45304.2019.8939048.

[16] C. Li and J. Zhou, 'Parameters identification of hydraulic turbine governing system using improved gravitational search algorithm', *Energy Convers. Manag.*, vol. 52, no. 1, pp. 374–381, 2011, doi: https://doi.org/10.1016/j.enconman.2010.07.012.

[17] P. Yu and J. Zhang, 'Parameter Identification of Excitation System Based on Field Data and PSO', in *2010 International Conference on E-Product E-Service and E-Entertainment*, 2010, pp. 1–4, doi: 10.1109/ICEEE.2010.5660858.

[18] C. Zhang, T. Peng, J. Zhou, and M. S. Nazir, 'Parameter identification and uncertainty quantification of a non-linear pump-turbine governing system based on the differential evolution adaptive Metropolis algorithm', *IET Renew. Power Gener.*, vol. 15, no. 2, pp. 342–353, Feb. 2021, doi: 10.1049/rpg2.12027.

[19] K. E. Bollinger and R. Gilchrist, 'Voltage Regulator Models Using Automated Frequency Response Equipment', *IEEE Trans. Power Appar. Syst.*, vol. PAS-101, no. 8, pp. 2899–2905, Aug. 1982, doi: 10.1109/TPAS.1982.317616.

[20] M. J. Gibbard and Q. H. Kaan, 'Identification of excitation system parameters', *IEEE Trans. Power Appar. Syst.*, vol. 94, no. 4, pp. 1201–1207, Jul. 1975, doi: 10.1109/T-PAS.1975.31955.

[21] R. Huang *et al.*, 'Calibrating Parameters of Power System Stability Models Using Advanced Ensemble Kalman Filter', *IEEE Trans. Power Syst.*, vol. 33, no. 3, pp. 2895–2905, 2018, doi: 10.1109/TPWRS.2017.2760163.

[22] S. Akhlaghi, N. Zhou, and H. Chiang, 'Starting point selection approach for power system model validation using

event playback', *IET Gener. Transm. Distrib.*, vol. 14, no. 19, pp. 3972–3982, Oct. 2020, doi: 10.1049/iet-gtd.2020.0094.

[23] H. Delkhosh and H. Seifi, 'Quantitative model validation from the frequency perspective considering governor frequency ramp rate and activity range', *Int. J. Electr. Power Energy Syst.*, vol. 107, pp. 668–679, May 2019, doi: 10.1016/j.ijepes.2018.12.030.

[24] C.-M. Huang, Y.-C. Huang, S.-J. Chen, and S.-P. Yang, 'A Hierarchical Optimization Method for Parameter Estimation of Diesel Generators', *IEEE Access*, vol. 8, pp. 176467–176479, 2020, doi: 10.1109/ACCESS.2020.3026670.

[25] C. Lin, C. Wu, J. Yang, and C. Liao, 'Parameters identification of reduced governor system model for diesel-engine generator by using hybrid particle swarm optimisation', *IET Electr. Power Appl.*, vol. 12, no. 9, pp. 1265–1271, Nov. 2018, doi: 10.1049/iet-epa.2017.0851.

[26] S. Stavrinos, A. G. Petoussis, A. L. Theophanous, S. Pillutla, and F. S. Prabhakara, 'Development of a validated dynamic model of Cyprus transmission system', in *7th Mediterranean Conference and Exhibition on Power Generation, Transmission, Distribution and Energy Conversion (MedPower 2010)*, 2010, pp. 238–238, doi: 10.1049/cp.2010.0946.

[27] Ł. Majka and S. Paszek, 'Mathematical model parameter estimation of a generating unit operating in the Polish National Power System', *Bull. Polish Acad. Sci. Tech. Sci.*, vol. 64, no. 2, pp. 409–416, Jun. 2016, doi: 10.1515/bpasts-2016-0046.

[28] Y. Sun, W. G. Kuijpers, E. C. W. de Jong, and H. Pustjens, 'Dynamic Study of Bonaire Island Power System: Model Validation and Project Experience', in *Proceedings of the 3rd Internation Hybrid Power Systems Workshop*, 2018.

[29] IEEE, 'IEEE Recommended Practice for Excitation System Models for Power System Stability Studies', *IEEE Std 421.5-2016 (Revision IEEE Std 421.5-2005)*, pp. 1–207, 2016, doi: 10.1109/IEEESTD.2016.7553421.

[30] The Power Company SEV, 'The Power Supply System', *The Power Company SEV*, 2022. [Online]. Available: https://www.sev.fo/english/the-power-supply-system/. [Accessed: 13-Jan-2022].