1. MODELLING AS A TOOL FOR PERFORMANCE ANALYSIS OF ELECTRICAL POWER SYSTEM

Mathematical modelling of objects (systems) has been the main tool for system performance analysis, design and extreme testing. Modelling significantly reduces design costs and allows cutting the potential costs of failure or destruction due to an extreme state of equipment. It also decreases exposure of humans, animals and the environment in general.

The mathematical models which represent actual objects are generated in two ways:

- mathematical modelling – an analytical approach in which the relationships to define the model are derived from laws of physics, including the known structure of objects and functional interdependencies of their components;
- system identification – an experimental approach in which the object model is obtained from the data acquired by measurements of an existing (actual) object using a suitable method of estimating the model parameters.

The mathematical models based on mathematical modelling are generated with the assumption of numerous simplifications. This necessitates verifying the mathematical modelling validity. This can concern both the model structure and parameters. The model is verified by comparing its response (i.e. the response of an independently developed mode) or any other function which characterises the object dynamics to the experimental results.

Note, however, that the identification is not perfectly reliable. The primary difficulties are:

- The lack of ideal measurement data. The data usually contains significant magnitudes of noise which can degrade the identification process. Suitable measurement data is not always available.
- The difficulty of determining the proper model structure in non-linear systems.
- The difficulty or impossibility of building stationary models for non-stationary systems (processes).

This paper presents a method for identification of parameters in a relatively complete model. The thesis states that there is a complete model of an actual electrical power system; the model parameters are identified on the basis of actual object measurements.

Transmission system operators utilize multi-machine models of electrical power systems, both for development design and ongoing system maintenance. The electrical power system model which is construed in this manner consists of defined component model types: transmission lines, transformers, loads, generators and models of automated and control systems. The structure of component models is usually strictly defined and is not (and most usually cannot be) modified by the user of the model. The data which defines the components model can be modified.

Abstract

This paper presents a concept of a tool for verification of model parameters applicable to dynamic elements of the electric power system. The tool uses the PSLF design software, which is in general use by the transmission system operator. The innovation consists in using an additional application (in MS Windows environment) which controls the work of the design software. This results in a tandem of a user-friendly interface for control and analysis of obtained results and of the calculation software engine which can simulate operating states of an electrical power system. The optimisation algorithms of the application adapt the simulation response to the actual course recorded for the verified object and thus estimates the validity of the given model.
It is obvious that model-based results depend on the input component data. The simulation tests define the requirements for safe operation of an electrical power system, which also translates into certain financial terms. This is why it is critical to correctly determine the data values which define the specific system components in order to ensure that the actual system is represented at the lowest error rate possible.

2. MODEL VERIFICATION METHOD

PSE Operator SA uses the PSLF software to analyse the dynamic states of the electrical power system. This software utilizes an IEEE-compliant library of dynamic models in the simulation generation process. This means that the software user can access models with strictly defined structures, apart from a few exceptions. Regarding the Polish Power System model, its has been established what models should be used for representation of specific elements of the given power unit, which is based on the knowledge of the control and regulating system structures of actual power plant power units. There are four dynamic models available for most power units. These models are: the synchronous generator model, the model of a turbine with its governor, the model of the excitation system with its voltage regulator (AVR) and the model of a power system stabiliser (PSS).

The problem is to determine the values of parameters which define the given model. It is not always possible obtain a model dataset from the technical manuals of the equipment in question. The data included in the manuals is not always reliable or corresponding to the actual setup. The divergences may arise from changes in the parameter settings of controllers/governors done during operation, which are not always on record. Another source of divergences between the technical specifications and the actual systems they describe may be a change in the object properties due to operational wear. It is necessary for the transmission system operator to have a tool which allows one to determine or verify the parameters used in the model simulation software.

The generally used methods for model parameter estimations are:

• The frequency response method. This method uses sinusoidal courses of varying frequencies as the input signals. The actual object is measured which allows producing its frequency characteristics. The frequency characteristics are widely used to asses the effectiveness of damping electromechanical swings by system stabilisers. They are also a valuable source of information on electromechanical oscillations in the system.

• The time response method. This method consists in comparing the model response with the actual object response. The most frequently used test function is the preset generator voltage peak. The method usually involves testing of bi-directional forcing magnitude changes, e.g. discrete preset voltage increase and decrease. This approach is adopted in this paper.

The processes of parameter identification have been covered in many published papers; however, the difference of the method developed by the authors is that identification is performed by using the same model the system operator uses. This means that when the model parameters are sought, the method uses a comparison between the courses measured for the actual object and the runs determined for the model, which are obtained with the same simulation software which will be used by the system operator once the identification process is complete. The concept of the identification process is presented in Fig. 1.

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1 The software also allows creating user models, which sometimes are used in analysis.
The software developed by the authors and used for identification or verification of dynamic model parameters benefits from integration of two programs.

The first program is the control application, henceforth referred to as SDMP (Selection of Dynamic Model Parameters). This application has been developed in Visual Basic for MS Windows. The main program window is presented in Fig. 2. The purpose of this program is to provide an interface for the user who identifies the dynamic model data. The application allows selecting the model for which the parameters will be verified. The model selection process has two steps: first, the system model is selected (i.e. the PSLF files *.save and *.dyd), then the user selects the element model (turbine, system stabiliser, voltage regulator) to be verified. The SDMP application requires the user to submit information about the data measured on a real object and used for identification. The program allows reading measured data directly from recorders by supporting the COMTRADE format.  

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2 COMTRADE is the world's generally accepted standard of data recording format. It has been developed by IEEE and defined in the C37111-1991 standard, “IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems”; it was updated in 1999 (C37111-1999). This standard is enforced in Poland as PN-EN 60255-24:2004, “Electrical Relays – Part 24: Common Format for Transient Data Exchange (COMTRADE) for Power Systems”, which is the Polish translation of the international standard IEC 60255-24:2001.
Fig. 2 Main window of SDMP testing environment

The program allows one to compare courses measured on actual objects to courses derived from three simulation types. Simulations of the following can be performed:

- a generator model running running idle (the simulations are performed in the SDMP software by using the model of a generator, excitation system and voltage regulator described by a set of algebraic and differential equations);
- single machine infinite bus system (the simulations are performed in the PSLF software, while the single-machine model is automatically generated from the data on the multi-machine system);
- a multi-machine model (the simulations are performed in the PSLF software by using the data files applicable to the Polish Power System.

The SDMP software requires the determination of the disturbance type to which the loaded response applies (or a selected part of this response³). The disturbance type selection to be modelled depends on the model type to be used in the calculations. The specific model types allow modelling of the following disturbances:

- generator running idle:
  - reference voltage step change
- single-machine system:
  - reference voltage step change
  - reference power step change
- multi-machine system:
  - reference voltage step change
  - reference power step change
  - power unit shutdown
  - 3-phase short-circuit on selected bus
  - 3-phase short-circuit on selected line

³ In reality, a single response may include more than one disturbance.
The second main purpose of the SDMP program is to evaluate the response from the simulation and to compare this response to the response measured on a real object. This process automatically selects the estimated parameters to approximate the model response as much as possible to the real object response. The measurement of the difference between the model and object responses is a defined scalar function. The program uses a fairly common function which is the sum of distance squares between the model response and the object response:

\[
V(X) = \sum_{t_{sk}=t_{sk_0}}^{t_{koniec}} (y_m(t) - y_o(t))^2
\]

where:
- \(V(X)\) is the scalar function;
- \(X = \{p_1, p_2, ..., p_K\}\) is the vector of estimated parameters;
- \(y_m(t), y_o(t)\) are the model response (index \(m\)) and the object response (index \(o\)) in moment \(t\);
- \(T_{sk_0}\) is the initial moment from which the function \(V(X)\) is calculated;
- \(T_{koniec}\) is the terminal moment to which the function \(V(X)\) is calculated.

The initial moment \(T_{sk_0}\), from which the value of \(V(X)\) is calculated, should correspond to the time at which the operating state disturbance occurs, e.g. an incremental change of the preset voltage. Inclusion of an earlier course part of the measured magnitude is not substantiated.

The terminal moment \(T_{koniec}\), to which the value of \(V(X)\) is calculated, may affect the quality of parameter estimation. Too high a value of \(T_{koniec}\), which causes a long interval of the stabilized state in the course of the function \(y(t)\), results in a condition under which the transient course has little effect on the value of the function \(V(X)\).

The process of estimating the parameters of the model \(X\) for the defined function \(V(X)\) consists in optimizing the function, or more precisely, minimizing it. This process can be performed by using the algorithms for searching of a local or global optimum.

The first group of these algorithms are gradient algorithms. These algorithm exhibit a relatively fast action. Their primary limitation (drawback) is the dependence of the result on the initial point. These algorithms find the local optimum. If the target function \(V(X)\) is a multi-extrema function, the usefulness of gradient algorithms is very limited.

The other group of algorithms includes the Monte Carlo algorithms and genetic algorithms. The strength and advantage of these algorithms is their ability to search the entire space stretched along the vector of the parameters being estimated. Their drawback is the inability (or a very limited ability at least) to precisely indicate the location of the \(V(X)\) extremum.

Both algorithm types feature specific drawbacks, but since they also have advantages which complement each other in a certain way, sometimes both types are used to indicate the area in which the global extremum is. Hence it is determined with a Monte Carlo or genetic algorithm, and further the precise location of the extremum is determined with a gradient algorithm.

The SDMP software user can choose from two optimisation methods: genetic or gradient. It is also possible to use both methods in a sequence, however, due to their varying specifics, the genetic method is applied first. Then the gradient method is applied based on the results obtained by the genetic approach.

### 3. VERIFICATION OF SDMP OPERATION

The operation of the SDMP software has been verified with the simulations of a generator in running idle, a single-machine system and a multi-machine system. This paper presents the selected results of completed analyses.

Fig. 3 presents the results of the estimation of the generator voltage regulator gain in one of the power units at the Belchatów power plant. The presented results have been obtained by using both methods simultaneously (in sequence), i.e. where the first step consists in determination of the parameter by using the genetic method and then the estimation process switches to the gradient method which accounts for the new value from the first step.
An example of an improper approach to the estimation process is shown in Fig. 4. It pertains to the estimation of selected parameters of the power system stabiliser, which are based on the system's response to the change of the preset power by -10 MW at Power Unit 3 of the Belchatów power plant. The results obtained by the genetic method in relation to time constants do not significantly depart from the initial values, but they vary to a large extent for the PSS gain $k_s$. This is due to the fact that the parameter values of the power system stabiliser (provided that they do not destabilise the system) affect only the initial section of the response shown in Fig. 4. The value of the target function being optimised is calculated from the complete response shown. In such case, even a slight but long-lasting deviation of the response causes an error (i.e. the target function change) larger than the one caused by the change of the parameter being estimated (the power system stabiliser parameter).
Fig. 5 shows the calculation results obtained for the reference voltage step change by -5% of Generator 3 at the Belchatów power plant. The calculations have been completed with the genetic method where the following parameters of the generator voltage regulator have been estimated: $ka$, $ta$, $tc$, $tb$. The figure indicates that the obtained parameters allow to match the generator response well.

4. SUMMARY

The paper presents the concept and operating results of the application which enables verification and estimation of the parameters of the dynamic models for elements of power generating units. The developed tool benefits from the advantages of the PSLF software which is the calculation platform allowing obtaining the simulation courses for any electrical power unit operated within the Polish Power System, as well as from the advantages of the peripheral MS Windows application which provides freedom of programming possibilities. The software functionality described here would have not been possible if only one of the presented environments was used. The EPCL language of the PSLF software is too simple to enable production of complex applications – it lacks the capacity of including GUI elements, which are friendly to the user (e.g. drop-down lists, check boxes, etc.), or advanced mathematical functions. On the other hand, development of a professional simulation software as advanced as PSLF is a very complex task.

The resulting application allows for a comfortable and effective verification of the models used by the system operator, which authenticate the results of the Polish Power System analyses. This undoubtedly contributes to improvements of the operating safety of the Polish Power System.

Note that the method proposed by the authors coupling dedicated calculation tools (PSLF, PLANS, DIgSILENT PowerFactory, etc.) with applications customized for the transmission or distribution system operators enables a significant improvement of software functionalities. This opens completely new and more powerful possibilities of using calculation software suites for operating analysis and development of electrical power systems.

REFERENCES