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A New Identification-Based Power Unit Model for Load-Frequency Control Purposes

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This paper presents a new power generating unit dynamic model that requires only one experiment for parameter identification. This model represents boiler pressure effects as a differentiating process with its subsequent identification through a new approach. In addition, a novel procedure is proposed for the model parameter correction in case that the identification test is not sufficiently informative. This dynamic model is developed in the vicinity of the steady-state operation mode. It can be used for load-frequency control purposes, boiler-turbine coordinated control tuning or its redesign, as well as a base for real-time simulators for dispatcher training. The modeling of 350 MW power units of the Israel Electric is fulfilled through implementation of this model yielding sufficiently good results. A similar though less sophisticated approach was used by the authors [4] for the same purposes.

Keywords: Boiler-Turbine Models; Transfer Function Identification; Power System Modeling

1. Introduction

We consider a load-frequency control unit model (LFCUM) of a steam generation unit that models unit load responses to network frequency deviations and to load set point changes in the vicinity of steady-state mode.

1.1. LFCUM Objectives and Identification Problems

A dynamic model is needed first for the analysis of the "primary grid-frequency control". Actually, the LFCUM is required to keep the dynamic response quality [11] by tuning of unit coordinated control which influences directly on this response in the vicinity of ±(5–10)% of the steady-state mode parameters. This problem is especially important for networks with limited energy reserve such as the Israeli or California networks.

Furthermore, LFCUM may be needed for adequate description of the power unit's dynamics required by the "secondary grid-frequency control" (load-frequency control by remote dispatcher). In addition, such LFCUM may also be used as a part of a real time simulator for operation staff and dispatcher training.

General nonlinear models for a steam generation plant (see, e.g. [1,5,9]) are related to physical and construction data. Obtaining the data needed for accurate model calculation may be problematic for some working units. Actually, these models are often applied as a basis for developing corresponding LFCUM through identification technique [2,4,10,13]. We also use this approach oriented to the more appropriate models [4,5] as a foundation for our LFCUM. The choice of these models determines transfer function identification techniques for computation of model dynamic links.

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The transfer function identification (TFI) technique is used very widely in power system applications [2–4,12,13]. Of the two main methods, ARMA TFI and Prony TFI [12], only the first one is directly related to the TFI problem.

According to ARMA TFI, a pseudo-random binary sequence (PRBS) or many uncorrelated PRBS are usually applied to the input of a system operating in closed loop (closed-loop identification) and a single input many output (SIMO) or a MIMO process is identified by this method using response data [2,10,13]. However, even if identification of a system operating in a closed loop is theoretically possible, the estimates obtained may in practice be very poor, due to the effect of the MIMO feedback terms in the input signal [3]. For this reason the closed loop MIMO experiment may be inferior to an open loop one or to SISO closed-loop experiment. From these considerations, the individual SISO identification procedure for each link transfer function (for each equation) of a model may be more effective [4,10]. On the other hand, such individual SISO identification requires several identification experiments [2,4,10,13] and because of this the full model creation can be time and cost consuming.

Another problem relates to the identification method [4,6]. This method is successful if frequency response (FR) data is informative enough for the transfer function (TF) identification. Frequency interval in which FR is identified depends on signal-to-noise ratio. This interval must be reduced if this ratio decreases which causes loss of identification accuracy.

An additional accuracy identification problem [3,6] may arise due to limited performances of an identification experiment. For example, a load set point change can have a limited rate for a working unit determining “slow identification data”. If TF will be identified using such data, the identified TF may be not be enough informative to adequately represent a process in the high frequency domain. It means that the identified TF does not give an adequate representation of fast processes.

1.2. Novel Contributions of this Paper

The novel contributions are as follows:

(a) The proposed LFCUM represents boiler pressure effects as a differentiating process which allows to develop LFCUM based only on one identification experiment.
(b) This paper presents a new approach for correcting TF (identified by “slow data”) by using network frequency abrupt deviations which lead to fast load changes.
(c) This paper modifies the identification method [4,6] to overcome a problem of frequency interval reducing (in which TF is identified) because of decreasing signal to noise ratio.

The behavior of LFCUM described here represents the basic dynamics of a 350 MW unit at the Maor David Power Station (Israel).

The paper is organized as follows. The model development is presented in Section 2. The model identification principles are described in Sections 3 and 4. The practical identification and validation results are presented in Sections 5 and 6. Some of the conclusions are given in Section 7.

2. Model Development

2.1. Steam Generator Structure

For load-frequency control purposes, LFCUM is required to represent load and throttle pressure behavior. So, a model of boiler pressure effects has to be developed in the first instance.

The nonlinear equation suggested by [5] relates the steam flow S_F to the throttle pressures P_T and the control valve area C_V:

$$S_F = k \cdot C_V \cdot P_T. \tag{1}$$

Expanding the right-hand side (1) into the Taylor series around an operating point (C_{V0}, P_{T0}, S_{F0}) we derive the linear equation about deviations (ΔC_V, ΔP_T, ΔS_F):

$$\Delta S_F = k(\Delta C_V \cdot P_{T0} + \Delta P_T \cdot C_{V0}), \tag{2}$$

where $k = S_{F0}/C_{V0}P_{T0}$.

Assume that the boiler pressure effect model is described by the following equation in the Laplace transform form:

$$\Delta P_T(s) = W_{BL}(s) \cdot \Delta C_V(s). \tag{3}$$

We consider that (3) presents this effect for a throttle pressure process operating in a closed control loop. In this operation the throttle pressure set point is assumed to be constant.

Substituting (3) into (2) and using the Laplace transform we arrive at the following incremental equation:

$$\Delta S_F(s) = (kP_{T0} + kC_{V0}W_{BL}(s))\Delta C_V(s). \tag{4}$$

As it follows from physical considerations, the transfer function $W_{BL}(s)$ possesses properties of a *differentiating* dynamic link. It is determined here as a link the transfer function of which has one zero in the