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Data-based model validation for locating the source of forced oscillations due to power plant governors

Sigurd Hofsmo Jakobsen
Energy systems
Sintef Energy Research
Trondheim, Norway
sigurd.jakobsen@sintef.no

Xavier Bombois
Laboratoire Ampère
Ecole Centrale de Lyon, Université de Lyon
Ecully, France

Salvatore D'Arco
Energy systems
Sintef Energy Research
Trondheim, Norway

Abstract—This paper investigates the use of an identified model between electrical power and rotor speed for detecting the source of forced oscillations in power systems due to power plant governing systems.

Index Terms—System identification, forced oscillations, governing systems

I. INTRODUCTION

Power system operation and control face several challenges. Among these challenges are power oscillations. These can be classified according to the cause of the oscillations. In this paper we will use the classification introduced in [1]. That is, oscillations due to poorly damped modes, stable limit cycles and forced oscillations. The mitigation actions required for these different causes of oscillations are different. For forced oscillations the most common action is to disconnect the source. Localising the source is therefore an important task. Several methods for localising the source of forced oscillations based on energy methods have been proposed [2]–[7].

Another popular class of methods for identifying the source of forced oscillations uses model validation. The underlying idea is that models correctly explaining the behavior of a component under normal conditions, will not explain the behavior if the component is causing forced oscillations. A model validation approach to determine within which area a forced oscillation is located was proposed in [8]. The approach uses PMU measurements from interface lines between areas, and simulates the areas separately with the measured interface line flows as inputs. In case the simulation is not validated for one of the areas, the area is identified as the one where the oscillation is located.

Other model based methods use the fact that, forced oscillations are typically modelled as an extra sinusoidal disturbance that is added at one particular location of a power plant in the grid. In case the governor of this particular plant is causing the forced oscillation, the relation between the electrical power and rotational speed of the rotor (a measurement of the electrical frequency is typically used) at this plant will contain a sinusoidal residual, whereas, the residual for the plants without forced oscillations will be filtered white noise. This observation is used in the papers [9]–[11]. All these papers require a model of the relation between two measured power

system quantities. In [11], this model is assumed known. In [10], a non-parametric frequency domain approach is used to derive a model relating the electrical power and frequency at generator bus bars. Even though this approach is elegant, the obtained model could suffer from a (relatively) high variance and a bias in the presence of an additional process disturbance. In this paper putting further the intuitive ideas in our previous contribution [9], we use time-domain prediction error identification method that we introduced in [12] to derive a parametric model of the relation between electrical power and frequency at generator bus bars. This model, which is under the form of a causal transfer function, that is generally more accurate than non-parametric models, allows to compute the residual in the time-domain and to detect the presence of a forced oscillation through the periodogram of the residual.

II. METHODOLOGY

The relation between the electrical power $\Delta P_{e,i}$ and the electrical rotor speed $\Delta\omega_i(t)$ of a given plant (say, plant i) in the electrical grid can be modelled as:

$$\Delta\omega_i(t) = G_{0,i}(z)\Delta P_{e,i}(t) + v_i(t) \quad (1)$$

where $G_{0,i}(z)$ is a transfer function consisting of the closed loop transfer function of the plant governor system, servo, turbine, and swing equation at plant i . The term $v_i(t)$ represents the part of $\Delta\omega_i(t)$ that cannot be explained from $\Delta P_{e,i}(t)$ i.e., the process disturbance at plant i (see [12]). In normal operations, $v_i(t)$ can be modelled as a filtered white noise. Suppose now that a forced oscillation appears in one plant (say plant k) and that we model this forced oscillation as an extra sinusoidal disturbance at the output of the governor of that particular plant. Then, the term $v_k(t)$ at plant k will also contain a sinusoidal term, while the term $v_i(t)$ in all the other plants will remain equal to filtered white noise. Indeed, the forced oscillations at plant k will influence the other plants through the electrical power and will therefore not change the process disturbances at the other plants.

Based on the above reasoning, locating the source of the forced oscillation could be achieved by detecting a sinusoidal signal in the residual signal:

$$\epsilon_i(t) = \Delta\omega_i(t) - G_{0,i}(z)\Delta P_{e,i}(t) \quad (2)$$

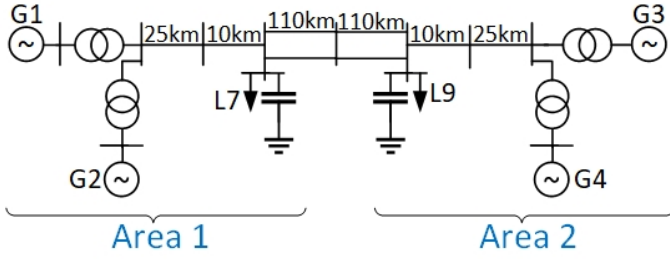


Fig. 1. Two area system from [13].

This residual signal must be computed at each plant using measurements $\Delta\omega_i(t)$ and $\Delta P_{e,i}$. If we would know $G_{0,i}$, we would have $\epsilon_i = v_i$. However, the true $G_{0,i}$ are all unknown and will be replaced in the computation of ϵ_i by models \hat{G}_i of $G_{0,i}$ identified during normal operation, using the system identification techniques developed in [12]. Consequently, the residual signal $\hat{\epsilon}_i$ is thus defined as:

$$\hat{\epsilon}_i = \Delta\omega_i(t) - \hat{G}_i(z)\Delta P_{e,i}(t) \quad (3)$$

at each plant i using the observed data $\Delta\omega_i(t)$ and $\Delta P_{e,i}(t)$. The presence of a sinusoidal component in $\hat{\epsilon}_i$ can be detected by looking at the periodogram of $\hat{\epsilon}_i$. The fact that \hat{G}_i is not precisely equal to $G_{0,i}$ will make that all $\hat{\epsilon}_i$ will contain some sinusoidal components, but the sinusoid at the plant where the forced oscillation is present will be the largest. When a forced oscillation thus appears in plant k , a large peak will appear in the periodogram of $\hat{\epsilon}_k$. It is also clear that the power of $\hat{\epsilon}_k$ will be increased with respect to the normal operations.

III. RESULTS

For demonstrating the methodology we will use the Kundur two area system depicted in Fig. 1. First we simulate the system without any forced oscillations. For the forced oscillations case we apply a sinusoidal perturbation with an amplitude of $0.01p.u.$ and a frequency of $1Hz$ to the head of the turbine penstock of power plant 1. This simulates pressure oscillations in the penstock.

The periodograms of the residuals for all the generators both with and without this forced oscillation is depicted in Fig. 2. From the figure we see that in the case with forced oscillations there is a large peak in the periodogram of $\hat{\epsilon}_1$ at the frequency of $1Hz$, while this peak is smaller for the other residuals, and not present when there is no forced oscillation.

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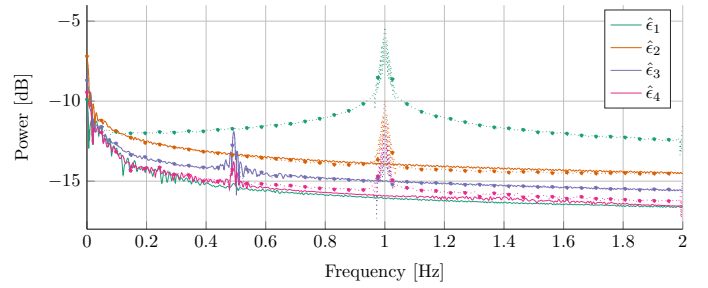


Fig. 2. Periodogram of residuals for all generators. Solid lines are results from the case with no forced oscillations and dotted lines are results from the case with forced oscillations.

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