SET-POINTS RECONFIGURATION IN NETWORKED DYNAMICAL SYSTEMS

Alessandro Casavola * **Domenico Famularo** **
Giuseppe Franzè * **Michela Sorbara** *

* *DEIS - Università degli Studi della Calabria, Rende(CS), 87036, ITALY,*
{casavola,franze,sorbara}@deis.unical.it
** *DIMET - Università degli Studi di Reggio Calabria, Reggio Calabria, Via Graziella, 89100, ITALY,*
famularo@ing.unirc.it

Abstract: In this paper we present a discrete-time predictive coordination strategy for load/frequency control problems in networked multi-area electrical power systems. The aim here is at finding a coordination strategy for the on-line modification of the prescribed set-points of each power generation unit, so as to ensure viable evolutions to the overall networked system, with respect to prescribed operative and safety constraints and despite of load variations and possible faults.

Keywords: Electric power systems, Electrical networks, Set-point control, Command Governor, Control with constraints.

1. INTRODUCTION

Traditional power system control approaches are facing several new challenges under deregulation. Some market-based functions call for greater decentralization, as in the allowance of bilateral contracts (Nobile *et al.*, 2001) and in the Regional Transmission Organizations (RTOs). The necessity of an open communication infrastructure is nowadays mandatory for independent generation companies to offer low-cost third party services. An improved communication infrastructure is also of paramount relevance for Independent System Operator (ISO), as they are responsible for the monitoring of all network components in their jurisdiction. An important aspect of the system operations is the load/frequency control (LFC) (Andersson, 2004), (Bhowmik *et al.*, 2004), (Çimen, 1998), (Lim *et al.*, 1997)-(Wang *et al.*, 1993). The LFC controller is in charge of keeping the system frequency and the inter-area exchanged powers as near as possible to their scheduled values. In fact, an unbalance in the generated or consumed power will lead to frequency deviation that, if too large, will have serious impacts on the system operations. An example of such a situation occurs when a generating unit is tripped due to a failure. In such a case, effective LFC strategies would be desirable in order to keep all system variables of interest inside acceptable limits during transients for avoiding out-of-services (Andersson, 2004).

Recent papers have addressed this problem from several points of view. In (Wang *et al.*, 1993), a robust LFC controller which ensures good performance in the presence of generation rate constraints for a single area has been proposed. A

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two/four-area power system has been considered in (Yang *et al.*, 2002) and a solution suggested via a decentralized control scheme. Saturation has been included in the turbine model in order to impose generation rate constraints.

Here a method based on predictive control ideas, used recently to synthesize *Command Governor* (CG) (Bemporad *et al.*, 1997), (Casavola *et al.*, 2006), (Casavola *et al.*, 2000), (Gilbert and Tin Tan, 1991) and *Parameter Governor* (PG) units (Kolmanovsky and Sun, 2006) in more traditional contexts, is proposed which enforces pointwise-in-time constraints on the evolutions of relevant system variables.
A control strategy is proposed which enforces pointwise-in-time constraints on the evolutions of relevant system variables. It consists of adding to a primal compensated system a nonlinear device called *Reference-Offset Governor* (ROG) whose action is based on the actual reference, current state and prescribed constraints. The aim of the ROG device is to modify, whenever necessary, the reference and to add an offset on the nominal control law in such a way that the constraints are enforced and the primal compensated system maintains its linear behavior. The ROG action is computed on-line by solving, at each time session, a constrained quadratic programming problem that usually requires low computational times also for systems of high order.
In this paper, for the first time upon our's best knowledge, an application of the ROG approach to the LFC problem is presented where bounds on the maximum power and frequency deviations are enforced pointwise-in-time. We focus on a two-area power system and the aim is to check the capability of ROG units to reconfigure the prescribed frequency and/or control offset set-points, whenever critical events occur, such as failures/faults or large unexpected load changes.
Consider the abstract scenerio depicted in Fig. 1, where the master represents the centralized LFC supervisor and the slaves the generation units. There, a single master station is in charge of supervising and coordinating several slave systems, which are assumed to be locally compensated dynamical systems equipped with independent sensors, actuators and (semi)-autonomous decision capability. In particular, r_i, z_i, x_i, y_i and c_i represent, respectively: the reference, the command (which includes both a modified reference and a control offset), the state, performance-related and coordination-related outputs for the i-th slave system. In such a context, the supervisory task can be expressed as the requirement of satisfying some tracking performance, whereas the coordination task consists of enforcing for all times t pointwise-in-time constraints of the form $c_i(t) \in \mathcal{C}_i$ on each slave system and/or $f(c_1(t), c_2(t), ..., c_N(t)) \in \mathcal{C}$ on the overall network evolutions. Specifically, at

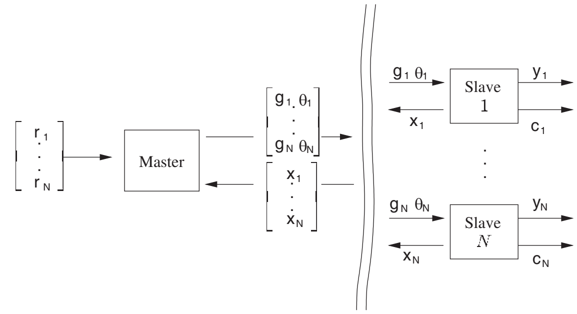

Fig. 1. A spatial network of dynamic systems

time t, the direct application of the reference $r(t) = [r_1(t) \dots r_N(t)]^T$ could lead to constraints violation. The ROG unit is in charge to modify such a reference into its best feasible version $g(t) = [g_1(t) \dots g_N(t)]^T$ and, if necessary, to add a control offset $\theta(t) = [\theta_1(t) \dots \theta_N(t)]^T$ on the nominal control law.

The paper is organized as follows. In Section 2, the ROG scheme is discussed and its relevant properties summarized. In Section 3, a two-area power system model is described and the problem formulated. Computer simulations are finally presented in Section 4 and some conclusions end the paper.

2. REFERENCE-OFFSET GOVERNOR (ROG) DESIGN

A ROG control scheme, with plant, primal controller (equipped with an integral action) and ROG device, is depicted in Fig 2. Consider the

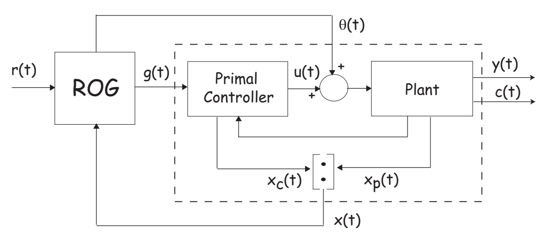

Fig. 2. The ROG control scheme

following linear, time-invariant system of the plant regulated by the primal controller

$$\begin{cases} x(t+1) = \Phi x(t) + G_g g(t) + G_\theta \theta(t) + G_d d(t) \\ y(t) = H_y x(t) \\ c(t) = H_c x(t) + L_g g(t) + L_\theta \theta(t) + L_d d(t) \end{cases} \quad (1)$$

with $x(t) \in \mathcal{R}^n$ the state vector (which includes the controller states); $g(t) \in \mathcal{R}^m$ the manipulable reference which, if no constraints were present, it would essentially coincide with the reference $r(t) \in \mathcal{R}^m$; $\theta(t) \in \mathcal{R}^m$ an adjustable offset on the nominal control law which we assume be selected from a given convex and compact set Θ, with