Control Engineering Practice 34 (2015) 61–67

Contents lists available at ScienceDirect

Control Engineering Practice

journal homepage: www.elsevier.com/locate/conengprac

Event-triggered variable horizon Supervisory Predictive control of hybrid power plants

Jean-Yves Dieulot [a,*], Fréderic Colas [b], Lamine Chalal [c], Geneviève Dauphin-Tanguy [d]

[a] LAGIS UMR CNRS 8219, Polytech-Lille/IAAL Cité Scientifique, 59650 Villeneuve d'Ascq, France
[b] L2EP, ENSAM ParisTech, 8 Bd Louis XIV, 59800 Lille, France
[c] L2EP, Université Lille1, 59650 Villeneuve d'Ascq, France
[d] LAGIS UMR CNRS 8219 Ecole Centrale de Lille BP 48, 59650 Villeneuve d'Ascq Cedex, France

ARTICLE INFO

Article history:
Received 7 January 2014
Accepted 6 October 2014
Available online 12 November 2014

Keywords:
Economic model predictive control
Power system control
Supervisory Predictive control
Renewable hybrid system
Hardware in the loop
Variable receding horizon

ABSTRACT

The supervision of a hybrid power plant, including solar panels, a gas microturbine and a storage unit operating under varying solar power profiles is considered. The Economic Supervisory Predictive controller assigns the power references to the controlled subsystems of the hybrid cell using a financial criterion. A prediction of the renewable sources power is embedded into the supervisor. Results deteriorate when the solar power is unsteady, owing to the inaccuracy of the predictions for a long-range horizon of 10 s. The receding horizon is switched between an upper and a lower value according to the amplitude of the solar power trend. Theoretical results show the relevance of horizon switching, according to a tradeoff between performance and prediction accuracy. Experimental results, obtained in a Hardware In the Loop (HIL) framework, show the relevance of the variable horizon approach. Power amplifiers allow us to simulate virtual components, such as a gas microturbine, and to blend their powers with that of real devices (storage unit, real solar panels). In this case, fuel savings, reaching 15%, obtained under unsteady operating conditions lead to a better overall performance of the hybrid cell. The overall savings obtained in the experiments amount to 12%.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Model Predictive Control (MPC) is a control algorithm that minimizes an objective function over a receding horizon. It is well suited for multivariable or large-scale systems which exhibit large time-constants, long time-delays or middle-range predicted disturbances, and is known to be robust with respect to forecast uncertainties and unmodelled dynamics (Scattolini, 2009).

MPC has been applied in the field of hybrid power cell supervision. It allows us to deliver an overall smooth power when intermittent and renewable power sources (wind turbines, solar panels) are combined with conventional sources and storage units (batteries, supercapacitors, etc.). Hence, a predictive supervisor helps us to promote the integration of the renewable sources into the grid (Chalal, Dieulot, Colas, & Dauphin-Tanguy, 2012; Guerin, Lefebvre, & Loisel, 2012; Liu, Chen, Christofides, & Qi, 2011a; Qi, Liu, & Christofides, 2013; Valenciaga & Puleston, 2005). Generating a smooth active power in a short time window, in a time scale around 10–30 s, is mandatory for a power cell (see a list of demonstrators in Daguzan & Galland, 2012). To set the context of this supervision in the power generation framework, the sampling period of local level power converters controllers is below the millisecond (Steinke, 1992). On the contrary, tertiary regulation has a time scale around 15 min. The supervisor provides the reference trajectories for the controlled units (in this case a microturbine and a storage unit). Moreover, unlike other algorithms, predictive controllers can consider the planned power reference and a short-time forecast of the intermittent sources powers which generally improves the results. When the predictive criterion is based on economic considerations (e.g. tariff policies, fuel or CO_2 emission cost, storage unit depreciation), it is very easy to tune the supervisor. Moreover, extra components can be integrated into the cell. It is sufficient to consider their dynamical models and to add their economic contribution to the objective function, which can depend on the operating regime as in the case of wind turbines (Chalal et al., 2012; Qi et al., 2013). Hence, a predictive approach allows for an (economically) optimal and modular way to tune a hybrid power cell supervisor. On the contrary, rule-based algorithms need to be fully designed anew in case of component modification or cell reconfiguration.

The choice of the receding horizon results in a compromise between the intermittent power prediction accuracy, which decreases with the horizon length, and the benefits of using a

---

* Corresponding author. Fax: +33 328767401.
E-mail addresses: jean-yves.dieulot@polytech-lille.fr (J.-Y. Dieulot), frederic.colas@ensam.eu (F. Colas), lamine.chalal@univ-lille1.fr (L. Chalal), genevieve.dauphin-tanguy@ec-lille.fr (G. Dauphin-Tanguy).

http://dx.doi.org/10.1016/j.conengprac.2014.10.003
0967-0661/© 2014 Elsevier Ltd. All rights reserved.

long-range control algorithm. Typically, in Chalal et al. (2012), this horizon was fixed around 10 s. However, whenever an abrupt change of the renewable power occurs, a possible false prediction can hamper the results given by the MPC algorithm. As an example, this could happen for solar panels when it quickly clouds over, or for wind turbines with squally conditions. In this case, it is possible to improve the predictions by using a shorter horizon. The so-called Variable-Horizon model predictive control (VH-MPC) which varies the horizon length according to a constrained optimization problem is well-suited to handle time-varying disturbances. The VH-MPC algorithm drives the system state to a closed set in finite time irrespective of bounded disturbances (Michalska & Mayne, 1993; Richards & How, 2006; Scokaert & Mayne, 1998; Shekhar & Maciejowski, 2012). It is possible to reduce the complexity of the algorithm by setting the variable horizon to predefinite values according to the onset of a disturbance. The horizon is kept to a nominal value when the prediction is accurate enough. Otherwise, it is triggered to a shorter value. This avoids important prediction biases, when the occurrence of a large disturbance is detected (Eqtami, Dimarogonas, & Kyriakopoulos, 2011). Note that this policy is quite different from multi-rate predictive control which triggers during a discrete step or uses adaptive step control algorithms (see e.g. Kowalska & von Mohrenschildt, 2011 and references therein).

To sum up, such an event-triggered predictive controller has not been used so far for the supervision of a hybrid power cell. This paper presents the design of an Economic Supervisory Predictive (ESP) controller, in which original criterion integrates tariff policies, storage units and conventional sources costs, whereas other papers generally propose a standard quadratic criterion. Next, it is shown how predictions can be integrated into the supervisor. Compared with existing papers, the economic tradeoff between the use of a longer horizon which may improve the overall cost and the accuracy of the renewable sources power prediction is evaluated, which shows the relevance of using a variable receding horizon strategy. The design of such an event-triggered variable horizon predictive supervisor, coupled with a detection algorithm, is addressed next. Eventually, the algorithm will be applied on a hybrid cell including a storage unit, solar panels and an emulated gas turbine. Real-time experiments in the framework of a Hardware In the Loop platform support the relevance of the proposed approach.

2. Hybrid cell economic supervisory control

2.1. Power cell, HIL platform and component models

The hybrid renewable power plant embeds a photovoltaic system (108 modules BP solar 3160 with a power of 160 W each, connected to a 3-phase grid via a Fronius IG30 inverter), a storage unit connected to the grid via electronic converters, and a gas microturbine. This microturbine is emulated by a real time digital simulator RT-Lab which is able to run real-time models on a multi-CPU computer (Fig. 1).

A power amplifier generates a real power signal from a model (e.g. the microturbine). The simulated sources can be blended with real power measurements, achieving the Power Hardware In the Loop principle. Another interest of the real-time simulator is the ability to emulate and reuse a previously measured power (typically here a solar power profile). Hence, a fair comparison of different algorithms is possible (see Chalal et al., 2012 for additional details).

The storage unit allows us to absorb the fluctuations of the renewable source power. A simplified model was used to represent the battery storage (Chungpaibulpatana, 2002):

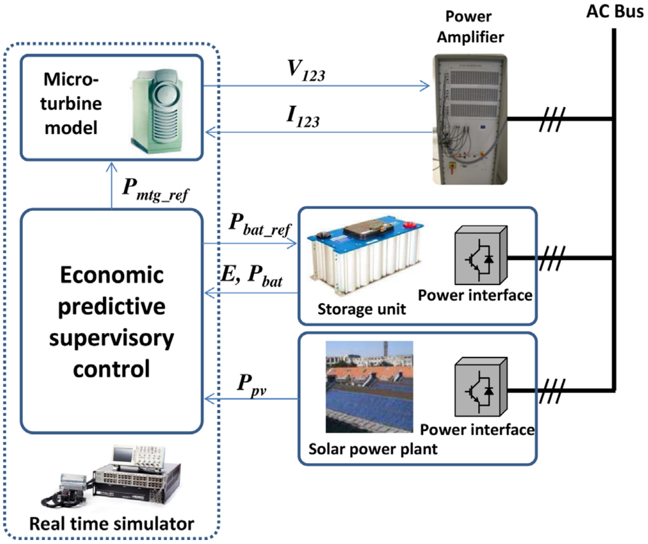

Fig. 1. Hybrid Cell and Power Hardware In the Loop architecture.

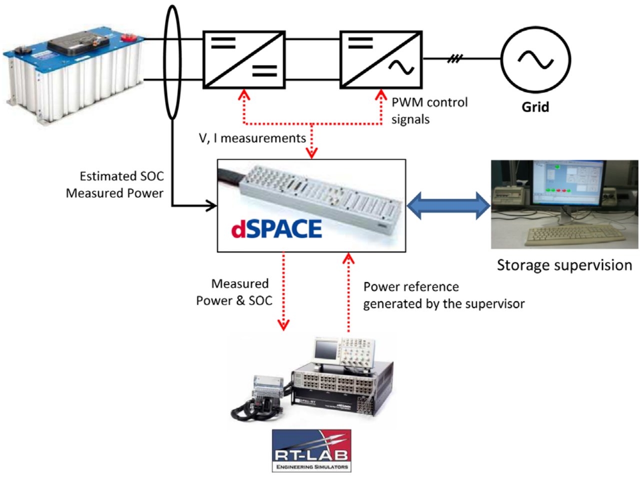

Fig. 2. Storage unit test bench.

$$P_{bat} = \frac{1}{\tau_p s + 1} P_{batref} \tag{1}$$

where P_{batref} and P_{bat} are the storage unit reference and real powers respectively. It is assumed that the storage unit State Of Charge (SOC) varies (in the working range) as the integral of the power. In case of State Of Charge saturation, if $\int_0^t P_{bat}\,d\tau > E_{max}$ or $\int_0^t P_{bat}\,d\tau < E_{min}$, then $P_{bat} = 0$. E_{max} and E_{min} are respectively the maximum and the minimum of stored energy. $\tau_p = 5$ s is the time constant of the battery.

This model is implemented using a dedicated test bench with supercapacitors. These consist of 6 Maxwell modules in series, the characteristics of each being 48 V, 160 F. The power reference is generated through a power amplifier. The supercapacitors are connected to the grid (Fig. 2).

The gas microturbine power is generated by a model which features a simplified representation of a turbine in closed loop. The supervisor does not manage the inner control loops and only provides the power references. A gas turbine consists of a gas compressor, turbine, a recuperator, a permanent magnet synchronous generator, and a power electronics interface. In this case, the microturbine works in operating mode. Start-up is discarded and only a turbine speed PID control loop is considered (see details in

Download English Version:

https://daneshyari.com/en/article/699931

Download Persian Version:

https://daneshyari.com/article/699931

Daneshyari.com