Real-time command strategies for smart grids based on the Robust Contract-based Collaboration Problem

Mario Levorato, Rosa Figueiredo, Yuri Frota, Antoine Jouglet, David Savourey

Real-time command strategies for smart grids based on the Robust Contract-based Collaboration Problem

Mario Levorato[a,b,*], Rosa Figueiredo[b,*], Yuri Frota[a], Antoine Jouglet[c], David Savourey[c]

[a] *Universidade Federal Fluminense, Niterói, Brasil*
[b] *Avignon Université, Avignon, France*
[c] *Université de Technologie de Compiègne, Compiègne, France*

Abstract

With the advent of smart grids, the use of sensors, online connections, computational resources and control strategies play a key role to ensure reliability, reduce costs and improve the efficiency of energy networks. Thanks to instant communication, control devices are important elements in this ecosystem. Based on a Real-Time Control Strategy (RTCS), they execute frequent commands according to fluctuations in energy production (e.g. solar panels in cloudy weather) and consumption in different periods of time. Interesting examples involve the use of energy generators during a period of higher demand and, analogously, employing a set of batteries to store energy during off-peak times so as to ease high demand-supply in peak periods.

In this work, we study robust command-and-control strategies to be used by smart control devices within a contract-based collaboration framework, established between two systems, both producers and consumers of the same kind of energy resource. One system is called the *client* and the other one the *partner*. These two systems have to collaborate in order to balance their consumption and production over a given time horizon. Such time horizon is divided into a set $\mathcal{I} = \{I_0, \ldots, I_{\bar{t}-1}\}$ of $\bar{t}$ time periods where $I_t = [T_t, T_{t+1})$, for each $t \in \{0, 1, 2, \ldots, \bar{t} - 1\}$. Typically the time horizon has a length of 24 hours divided into 24 periods of 1 hour.

Client-partner collaboration is established by the use of a set of contracts of consumption and/or production, both offered by the partner, each one having its own functional constraints and gain/cost functions. On each time period, the client is free to enter into a commitment with the partner through any subset of contracts. However, such commitments must be honored. Also, at any time period, the client can consume the energy resource out of any engaged contract but at a very high cost which can vary with the time period.

The client system is composed of subsystems that produce/consume the energy resource. Each subsystem also presents functional constraints and a cost/gain of consuming/producing over the time periods. In particular, the consumption/production can be driven for a subset of these systems (*drivable systems*) while the consumption/production is already planned for the other ones (*non-drivable systems*). Drivable systems are devices that allow being turned on/off or that must be loaded/unloaded from time to time (e.g. batteries, electric car), whereas non-drivable systems (e.g. always-on appliances like refrigerators) must be permanently turned on. Additionally, some of the drivable systems can store the energy resource under a capacity constraint and provide it when needed, thus being called *storage systems*. For a part of the non-drivable systems, only uncertain predictions of the consumption/production are known (*uncertain non-drivable systems*).

From a real-time point of view, the instantaneous production/consumption of each system is measured every Δ time units. It is also at this time scale that drivable systems are driven, i.e, every Δ time units a decision has to be taken for these systems. For the client, an RTCS is a function defined for a period $I_t \in \mathcal{I}$ which associates a set of decisions (i.e. production/consumption/storage actions

*Corresponding authors
Email addresses: mlevorato@ic.uff.br (Mario Levorato), rosa.figueiredo@univ-avignon.fr (Rosa Figueiredo), yuri@ic.uff.br (Yuri Frota), antoine.jouglet@utc.fr (Antoine Jouglet), david.savourey@utc.fr (David Savourey)

for drivable and storage subsystems) to every Δ time units of time period I_t, considering the state of the system.

The optimization problem consists in determining an optimal (according to the cost) contract subscription from the client to the partner in such a way that there exists a robust real-time command strategy which not only satisfies any consumer demands of the client subsystems over the time horizon (even in the worst case scenario) but also in such a way that each commitment taken by the client with the partner is honored. This problem will be called the Robust Contract-based Collaboration Problem (RCCP).

The RCCP can be expressed as a mathematical model, including objective function and constraints. A time decomposition strategy was applied in the solution of the RCCP and two versions of the model were developed. For the deterministic version, uncertain devices consumption/production fluctuation is ignored, and their average power values are assumed. On the other hand, the robust version of the problem is based on a Min-Max Adjustable Robust Counterpart formulation, and a MILP model is obtained by applying Linear Decision Rules (LDR) [1]. An optimal solution of the RCCP model provides the client with a commitment planning for the time horizon: which contracts will the client engage in each period $t \in T$.

Complementing the RCCP model solution, the RTCS gives the client a fine-grained, second level of decision, by defining a set of specific measures to be identified and implemented in real-time according to the state of the client system, at each time unit $d \in \{1, \ldots, \delta^t\}$ of each time period $t \in T$, such as:

- turning on/off a production/consumption drivable system;
- buying/selling a quantity of energy under an engaged contract;
- how much energy will be absorbed/refunded by a storage system;
- how much energy will be bought out of engaged contracts.

Based on the solution of several Robust Optimization models (one for each time period), together with the RTCS, it is possible to reduce energy consumption costs and promote load balance, while dealing with the effects of uncertainty in both production and consumption of energy.

Experimental data were collected from a smart grid with the following elements: 2 drivable systems (one electric car and a group of diesel engine-generators), 1 non-drivable system representing the essential energy consumption of a building, and 2 uncertain non-drivable systems (a photo-voltaic power production system and the uncertain consumption of the same building). The time period is divided into 24 periods of one hour (each period with $\delta^t = 6$). A total of 457 contracts are available for consumption. Preliminary results based on simulations indicate that the robust model coupled with the RTCS outperforms the naïve approach based on the deterministic solution. The obtained improvement is statistically significant in a Wilcoxon signed-rank test. In future work, we will present an extensive empirical study of the behavior of the robust RTCS under a very large set of simulated values for the uncertain parameters.

Acknowledgement

Research conducted during a visiting period at Avignon Université by means of a Doctoral Exchange Program sponsored by CAPES, Ministry of Education, Brazil (Process No.: 88881.187708/2018-01) and by Avignon Université.

References

[1] A. Ben-Tal, A. Goryashko, E. Guslitzer, and A. Nemirovski. 2004. Adjustable robust solutions of uncertain linear programs. *Mathematical Programming* 99, 2 (2004), 351–376.