Mathematical Tools for Smart Grids

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Summary

The purpose of this PhD is to apply analytic tools (like stochastic modeling, game theory, stochastic optimal control, distributed optimization) to address the challenges to deploy future smart grids.

This research action is the opportunity to develop a new collaboration between two researchers in the Labex, but also to start working on a hot research topic, that is currently not represented in Sophia Antipolis' research panorama.

Framework

A number of factors are calling for more intelligence in the electrical power grid, so that the expression “smart grids” has been popularized despite the lack of a common definition. One of the factors is the need to control the increasing input of renewable sources with their high time-variability, unpredictability and distributed generation (often directly at the consumer site). Recent studies [Dro11] show that a naïve replacement of traditional sources with the renewable ones can significantly reduce the reliability of the power grid. Energy production time-variability and the opening up of the market to a large number of competing operators call also for new dynamic pricing features. Another important drive for moving more intelligence inside the network is the potential saving from shifting energy usage to off-peak hours (e.g. to the night). This advantage to reduce peak demand arises from the fact that 1) there is no convenient way at the moment to store energy and 2) energy losses—due to the Joule effect—are quadratic functions of the transmitted power. Future diffusion of electrical vehicles will also require scheduling and control algorithms to efficiently manage their charging.

The economic interest behind smart grids is enormous. This justifies the multiple initiatives from the US governments (see smartgrid.gov) and the EU Technology Platform for electricity networks of the Future, also called SmartGrids ETP. One study sponsored by the US Department of Energy calculated that internal modernization of US grids with smart grid capabilities would save between 75 and 350 billion dollars over the next 20 years [Kan03]. A report from the market research firm Zpryme [Zpr09] valued the Smart Grid industry at roughly $21.4 billion in 2009 and expected it to grow up to at least $42.8 billion by 2014.

Thesis' goal

Smart grids research gains increasing momentum. It spreads over a large set of topics, including monitoring and metering devices, communication infrastructure and protocols, privacy and security issues. Our goal is to apply analytic tools (like stochastic modeling, game theory, stochastic optimal control, distributed optimization) to solve some challenges to deploy future smart grids. In particular the candidate will work on the following two research issues: 1) dynamic pricing and 2) distributed control in smart microgrids.

1. Dynamic pricing

It is very likely that in the future the price of energy for the consumers will change dynamically on short timescales. This is mainly due to the increasing energy contribution from time-varying renewable sources and the economic interest of all the actors: final users, energy producers, power grid operators and appliance producers. While in many cases the smart appliance can simply shift the load to a different moment, heaters and air-conditioners can adapt their power demand with a much finer granularity and the users could specify elastic preferences. These preferences can be easily translated in a utility function that can be used by smart appliances to adapt their power request to dynamic pricing. At the same time the price can be dynamically determined by energy producers and grid operators on

the basis of energy production and demand. In order to scale to a large network with multiple energy producers dislocated on the territory prices should be determined in a distributed way.
The problem is very similar to distributed rate control on the internet, where each transmitter adapts its throughput taking into account a local utility function and a price (a congestion signal) that is determined in a distributed way on the path the flow follows. Our idea is then to use similar approaches for load adaptation to dynamic pricing in smart grids. The main challenge here is how to calculate prices in a distributed way and to obtain a pricing mechanism which is robust to imperfect information on user utilities. We plan to investigate whether recent ideas on probabilistic pricing [Loi11, Loi13] can be used to obtain such "good" prices.
2. Distributed Control in Smart Microgrids
A smart microgrid is a cluster of loads and microsources operating as a single controllable system that provides power to its local area. Although it is usually connected to the tradition transmission grid in one point, a microgrid can also operate autonomously. To this purpose the elements of the microgrid need to be able to autonomously support voltage and frequency references and to manage power flow.
Distributed control approaches have been proposed (see [Mon10] and references there): they usually let each controller operate separately, but their design requires a global model of the overall system. In this PhD research we want to investigate if there is room for an intermediate approach between complex control systems relying on a significant amount of communication and independent controllers relying on a global model of the network. Different approaches, that relies on local computation at each node and information exchanges only among neighbors (e.g. [Ned07,Mas11,Alo10,Kau07]) have been recently proposed and we believe they could be advantageously used in smart grids.

Supervisors
Patrick Loiseau and Giovanni Neglia will share equally the supervision task and will ask to the EDSTIC PhD school an exemption to be officially co-supervisors (they do not have the HDR). If the exemption is not granted, Philippe Nain is interested to work on this topic and could be the official supervisor.
Patrick's research has been recently focusing on network economics, while Giovanni's research on distributed optimization on networks. Their backgrounds complement each other to address the two research topics identified. This project will create a completely new collaboration between two young researchers of two distinct institutions of the labex UCN@Sophia (EURECOM and INRIA).
The research will benefit from some new cooperations the supervisors have already created, in particular with the smart grids research group at the University of Palermo and Applied Mathematics Center of École des Mines ParisTech at Sophia, respectively with a strong backgroung on power grids and energy markets.

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