Decentralized Multiagent Planning for Balance Control in Smart Grids

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Abstract. Integrating large-scale micro-generation in distribution grids is challenging for distribution grid operators, particularly when renewable energy sources (RES) and micro-cogeneration are involved. In this paper we contend that recent developments in multiagent decision making under uncertainty can positively contribute to safe, efficient and cost-effective operation of future distribution grids.

Keywords: Smart Distribution Grids, Decentralized Planning, Agents

1 Introduction

Electric power systems have been undergoing momentous changes over the last decade. In the past, power was supplied predominantly by a limited number of large power plants, mainly nuclear powered or fossil fueled, and then transmitted to the consumers [5]. In the near future, production will increasingly rely on a greater number of decentralized, mostly small-scale production sites [5] based on renewable energy sources (RES), such as solar or wind power, and micro-cogeneration units, such as stirling engines and fuel cells. These will be located closer to the final consumers than traditional power plants, even at the households themselves.

The inclusion of micro-generation enhances the overall system in terms of sustainability. However, we advocate that additional improvement may be achieved through intelligent agent-based decision making. Customers, or agents acting on their behalf, should play an active role in managing the energy produced by the controllable micro-generation units. Additionally, the balance between consumption and supply is required for a proper and stable operation. Thus, agents that control energy consumption can also support the distribution network by matching the timing of their demand to the dynamic availability of the energy supply. As a result, a more efficient operation can be obtained by reducing the peak load while maintaining the power balance.

The massive introduction of small-scale RES-based production and active consumption management introduces significant uncertainty in the normal operation of the distribution grid. Some of the sources behind such uncertainty are [4]: (i) *Operational uncertainty*, usually associated with the demand and the supply of energy (e.g., load pattern predictions, future energy supply of solar cells and windmills); (ii) *Structural uncertainty*, associated with changes in the physical infrastructure (e.g., switches in the power grid may have to be closed or opened to keep voltage and frequency within normal operational limits; a distribution line breaking due to bad weather).

With the introduction of decentralized generation, several important changes regarding the planning, operation and control of power systems have taken place, particularly because of the following differences: decentralized generation units are connected to the distribution network and not to the transmission network; several types of decentralized generation units are connected to the grid by means of power electronic interfaces (whereas large generation plants are coupled to the electricity grid directly); the power generated by micro-generation units is considerably less than power generated from traditional power plants (several orders of magnitude); and renewable energy generators depend on natural and uncontrollable sources, which adds a high level of uncertainty to the system. Given that distribution generation will play an important role at distribution level, power systems are forced to adapt in order to perform control actions at this operating level as well.

In the literature, a large number of the planning and control architectures designed for distribution network and micro-grid applications have two-level hierarchical configurations and only take into account electrical parameters and electrical interactions, even though heat outputs from micro-cogeneration units are also available. For example, in [11] a droop control method is applied on a system that contains renewable energy generators and storage. The control unit optimizes the power output of the generators by communicating new droop settings based on the information collected from the inverters, micro-generation units and battery banks. Another example can be found in [6], where control and power management strategies based on locally measured signals without communication were proposed under various micro-grid operating conditions. The real power of each decentralized generation unit is controlled based on a frequency droop characteristic and a frequency restoration strategy [6].

In contrast to these prior works, we propose addressing the electrical flows, but also the usable heat produced by the micro-generation units, as considered in [8]. Moreover, we defend the incorporation of three aspects of control using an integrated agent-based planning methodology, namely the active power control, voltage control and control with respect to economic considerations. An economic optimization based on forecasts will provide the set-points to the controllable components of the system in which the active power control and voltage control will be applied.

Hence, we envision a distribution grid that is able to self-regulate with little human supervision. We defend the use of new decentralized planning and control techniques for the distribution grid that take into account the dynamics and the topology of the grid and also handle the uncertainty inherent in the production and consumption of electricity. These techniques should allow the grid to preserve its properties as it scales in size and should also accommodate the possibility of massive micro-generation from renewable energy sources and from micro-cogeneration units. Finally, it should facilitate the inclusion of new technologies such as smart heating, ventilation, and air conditioning equipment.

2 Decentralized Planning and Optimization

Consider the distribution grid as a complex system composed of interconnected components, many of which need to be controlled in order to optimize system objectives. Decentralized planning accomplishes this optimization by distributing the control among a team of intelligent agents, each of which operates an individual component. For instance, an agent controlling a particular power substation decides where and when to route power. In planning its decisions, each agent should account for uncertainty in the consequences of its actions, reasoning over, for instance, the likelihoods of different volumes of future energy consumption. Agents may only be able to base their decisions on incomplete and local information, depending on sensory capabilities and on infrastructure supporting information exchange throughout the system. Nevertheless, because the actuation of one component may affect the state of another, the agents should work together to formulate coordinated plans that fulfill quantifiable global objectives.

In the literature, these characteristics serve as the basis for a formal model of multiagent decision-making called a *Decentralized Partially Observable Markov Decision Process* (Dec-POMDP) [1]. The Dec-POMDP model has been hailed as a rich, principled mathematical framework for optimization under uncertainty, and has spawned an increasingly active area of research referred to as multiagent sequential decision making (MSDM) under uncertainty. Power systems research has considered the effects of uncertainty in load predictions [2], the inherent uncertainty in wind forecasts [3] or uncertainty in unit commitment [9]. However, the decentralized optimization techniques for tackling uncertainty that we propose have not yet been exploited in Smart Grids.

3 Discussion

Framing the control problem as one of decentralized planning, one can address the problems of keeping the network under stable operation, performing balance control, and economically optimizing the system, in a single integrated solution, all while accounting for uncertainty. An appealing aspect of this application is the structure in the distribution grid control problem that we expect can be leveraged to improve the efficiency and scalability of decentralized planning [7]. Recent theoretical developments have established that multiagent systems in which the interactions between agents are *weakly coupled* allow for significant computational savings that can result from exploiting such weakly coupled interaction structure [10]. This has resulted in increasing research efforts in the development of better representations of the structure of multiagent systems and better techniques for exploiting it.

Although there is yet little application of MSDM techniques to real problems, control of smart distribution grids provides a well-motivated application domain, and with it a golden opportunity to break free of the status quo and to develop and validate MSDM research on realistic problems. It not only allows the testing of conventional assumptions of existing models and algorithms that have long been taken for granted, but it can also inspire the development of more useful models and methods whose assumptions are more realistic. This would constitute an important step forward in grounding recent MSDM work, and one that is essential for maturing the field.

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References

1. D. S. Bernstein, R. Givan, N. Immerman, and S. Zilberstein. The complexity of decentralized control of Markov decision processes. *Mathematics of Operations Research*, 27(4):819–840, 2002.
2. R. Billinton and D. Huang. Effects of load forecast uncertainty on bulk electric system reliability evaluation. *IEEE Trans. Power Systems*, 23(2):418–425, 2008.
3. E. Constantinescu, V. Zavala, M. Rocklin, S. Lee, and M. Anitescu. A computational framework for uncertainty quantification and stochastic optimization in unit commitment with wind power generation. *IEEE Trans. Power Systems*, 26:431–441, 2011.
4. A. Dominguez-Garcia and P. Grainger. A framework for multi-level reliability evaluation of electrical energy systems. In *Energy 2030 Conference, 2008. ENERGY 2008. IEEE*, pages 1 –6, nov. 2008.
5. J. Kassakian and R. Schmalensee. The future of the electric grid: An interdisciplinary MIT study. Technical report, Massachusetts Institute of Technology, 2011.
6. F. Katiraei and M. R. Iravani. Power management strategies for a microgrid with multiple distributed generation units. *IEEE Trans. Power Systems*, 21(4):1821–1831–, 2006.
7. F. A. Oliehoek, M. T. J. Spaan, S. Whiteson, and N. Vlassis. Exploiting locality of interaction in factored Dec-POMDPs. In *Proc. of Int. Conference on Autonomous Agents and Multi Agent Systems*, pages 517–524, 2008.
8. L. M. Ramirez-Elizondo and G. C. Paap. Unit commitment in multiple energy carrier systems. In *Proceedings of the North American Power Symposium (NAPS), 2009*, pages 1–6, 4-6 2009.
9. P. Ruiz, C. Philbrick, E. Zak, K. Cheung, and P. Sauer. Uncertainty management in the unit commitment problem. *IEEE Trans. Power Systems*, 24:642–651, 2009.
10. S. J. Witwicki and E. H. Durfee. Towards a unifying characterization for quantifying weak coupling in Dec-POMDPs. In *Proc. of Int. Conference on Autonomous Agents and Multi Agent Systems*, 2011.
11. Y. Zilong, W. Chunsheng, L. Hua, and X. Honghua. Design of energy management system in distributed power station. In *Sustainable Power Generation and Supply, 2009. SUPERGEN '09. International Conference on*, pages 1–5–, 2009.