Software Defined Connected Prosumer Communities

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***Abstract*—Electricity generation from renewable sources is radically increasing in an effort to achieve the Sustainable Energy for All objective of doubling the share of renewable energy in the global energy mix by 2030. However, the current grid has difficulty accommodating variable power sources like wind and solar. To accelerate the integration of renewable distributed power generation there is a need for the development of a highly reliable, self-regulating, and efficient grid. To address this challenge, we propose Software Defined Connected Prosumer Communities (SDCPC), a transformative paradigm that leverages IoT-enabled energy infrastructure (i.e., smart metering techniques, digital sensors, and intelligent control systems) that turns the electric power infrastructure into an "Internet of Energy" (IoE) to provide power utilities with digital intelligence to the network of prosumers (i.e., consumers that co-generate electricity as a result of the continuous integration of renewable generation).**

***Keywords*-Big Data; Cyber-Physical Systems; Human-in-the-loop; Adaptive Control; Data-driven Models**

I. Introduction

The continuous integration of renewable generation into the power grid has been transforming passive electricity consumers into electricity Prosumers, i.e., producer-consumers [1]. Intermittent generation from Distributed Energy Resources (DERs) such as rooftop photovoltaic panels and decentralized Energy Storage Systems (ESS) pose fundamental challenges to centralized net-load management practices due to the variability and unpredictability that such Variable Energy Resources (VERs) introduce into the power system [2], [3]. At high deployment levels however, DERs have the potential to collectively become a **synthetic reserve** if coordinated with system needs, due to their proximity to the load. By synthetic reserve, we denote a virtual reserve with desired service timing and magnitude characteristics created by large-scale coordinated control of net-load.

To enable widespread integration of renewable generation at the **distribution network** (unlike projects, such as [4] aiming to integrate renewables into the electric transmission system), we propose to tightly couple the continuous real-time monitoring of the power grid (i.e., physical-to-cyber connection due to acquisition of sensor readings) with adaptive interventions (i.e., cyber-to-physical connection through adaptive control of power generation and distribution). This will lead to the virtualization of connected prosumer communities into a layer, which we denote as Software Defined Connected Prosumer Communities (SDCPC).

SDCPC is a step towards the realization of Smart and Connected Communities by transforming a potentially massive number of connected devices to an Internet of Controllable Things. Our proposed paradigm should not be confused with Software Defined Networking (SDN) [5], that simplifies network management by abstracting higher-level functionality. Instead of simply virtualizing prosumer networks, SDCPC will enable the real-time control and adaptation of connected prosumer communities by leveraging "Big Data" to improve the efficiency, reliability, and economy of the Smart Grid.

II. Challenges

Matching generation and demand becomes particularly challenging with high levels of intermittent, unpredictable, and distributed generation from renewable energy sources [6]. Current approaches for maintaining energy supply-demand balance are supply-side oriented and focus predominantly at the transmission network [4]. Given the increasing penetration of DERs, future efforts at solving the classic net-load management problem need to be studied at various levels of distribution network granularity while meeting real-time performance requirements. Adaptive modeling is the key to cope with the stochastic nature of prosumer networks, optimize its operation in real-time, and develop a transactive grid [7] based on value-added differentiated energy services.

Finally, the greater the penetration of renewable energy, the greater the need to "optimize-on-the-fly" so as to achieve both learning and optimization simultaneously. Solving real-life instances of centralized unit commitment with thousands of DERs, controllable load, and ESS in real-time is prohibitive with existing optimization methods [6].

III. Proposed Approach

We focus on exploiting IoT-enabled power network components for developing novel ancillary services based on

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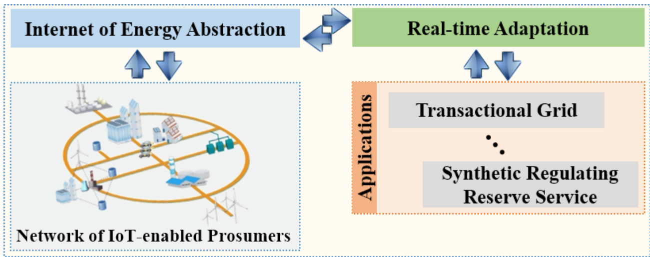

Figure 1. High Level Overview of SDCPC.

distributed resources on the demand side. The need for ancillary services, such as synthetic upward and downward reserves, is proportionally increasing with the level of intermittent renewable generation in the system [8], [9]. Our approach is based on (i) conceptualizing deep interdependencies between the cyber and physical planes at multiple levels of granularity, and (ii) capturing the diverse interactions between and across hierarchies to enable reliable integration of DERs and ESS. Our approach relies on IoT-enabled devices for the collection and exploitation of massive amounts of real-time data, and two way communication between IoT-enabled devices with the utility. This results in an information network that can be used to achieve the synergistic advances among data-driven modeling and sensing, and real-time adaptive optimization required to continuously manage potential imbalances due to short-term variation in both system loads and distributed generation.

A. Software Defined Connected Prosumer Communities

We propose Software Defined Connected Prosumer Communities (SDCPC), a transformative paradigm that abstracts the inter-dependencies between the cyber and physical planes of prosumer networks to enable the creation of virtual reserves with desired service timing and magnitude characteristics close to the load by coordinating the use of DERs and ESS with load at the far edge of the grid. Figure 1 shows a high-level overview of the proposed architecture. The infrastructure layer abstracts the network of distribution stations (DS), distributed generation, and energy storage devices, providing an interface between the IoT-enabled power network components and real-time control and optimization algorithms for providing fast acting synthetic regulating reserve services to the grid. Many other applications can also be enabled using this model.

The proposed SDCPC abstraction enables the smooth coupling between prosumer network data and control planes and abstracts the increased control complexity of net-load balancing in grids with a predominant percentage of renewable energy generators. Our control layer is built on a constrained optimization framework for (i) hierarchical distributed control and management of incentivised prosumers, and (ii) market mechanisms and incentive design for differentiated energy services to help actively manage system load while satisfying global and local operational constraints and objectives.

IV. Conclusion

Since renewable generation and decentralized energy storage are already becoming ubiquitous, realizing the smart grid of the future requires the existing energy infrastructure to be re-imagined. To address this challenge, we are developing SDCPC, a novel approach that decouples sensing, modeling, and control of connected prosumer communities. This is a key step towards enabling the so far untapped synthetic reserve potential of nontraditional energy sources that are changing the very nature of power generation and grid control to become directly controllable. At the same time, SDCPC leads to new modeling, learning, optimization, and computational challenges due to rising requirements for measurement and regulation of distributed system components including renewables, and load.

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