Renewable and Sustainable Energy Reviews 56 (2016) 669–685

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

The need for holistic enterprise control assessment methods for the future electricity grid

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ARTICLE INFO

Article history:
Received 30 July 2014
Received in revised form
1 August 2015
Accepted 12 November 2015

Keywords:
Power grid evolution
Power grid enterprise control
Renewable energy integration studies
Power grid resilience
Smart grid

ABSTRACT

Recently, the academic and industrial literature has coalesced around an enhanced vision of the electric power grid that is responsive, dynamic, adaptive and flexible. As driven by decarbonization, reliability, transportation electrification, consumer participation and deregulation, this future grid will undergo technical, economic and regulatory changes to bring about the incorporation of renewable energy and incentivized demand side management and control. As a result, the power grid will experience fundamental changes in its physical system structure and behavior that will consequently require enhanced and integrated control, automation, and IT-driven management functions in what is called enterprise control. While these requirements will open a plethora of opportunities for new control technologies, many of these solutions are largely overlapping in function. Their overall contribution to holistic techno-economic control objectives and their underlying dynamic properties are less than clear. Piece-meal integration and a lack of coordinated assessment could bring about costly-overbuilt solutions or even worse unintended reliability consequences. This work, thus, reviews these existing trends in the power grid evolution. It then motivates the need for holistic methods of integrated assessment that manage the diversity of control solutions against their many competing objectives and contrasts these requirements to existing variable energy resource integration studies. The work concludes with a holistic framework for "enterprise control" assessment of the future power grid and suggests directions for future work.

Contents

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http://dx.doi.org/10.1016/j.rser.2015.11.007
1364-0321/

1. Introduction

Traditional power systems have often been built on the basis of an electrical energy value chain which consists of a relatively few, centralized and actively controlled thermal power generation facilities which serve a relatively large number of distributed, passive electrical loads [1,2]. Furthermore, the dominant operating paradigm and goal for these operators and utilities was to always serve the consumer demanded load with maximum reliability at whatever the production cost [3]. Over the years, system operators and utilities have improved their methods to achieve this task [4,5]. Generation dispatch, reserve management and automatic control has matured. Load forecasting techniques have advanced significantly to bring forecasts errors to as low as a couple of percent and system securities and their associated standards have evolved equally. It does not appear, however, that this status quo is set to last.

Instead, multiple drivers are set to dramatically change the basic assumptions upon which the electrical power grid was built [6]. The first of these is decarbonization [7]. The European Union, for example, has committed to reduce greenhouse gas emissions in the power sector to 1990 level by 2050 [8]. Such targets create a strong pressure for renewable energy penetration in both the transmission as well as the distribution system [9]. Next, electricity demand continues to grow sometimes as fast as 10% per year in the quickly developing economies [10,11]. Such demands motivate the need for “peak shaving” and load shifting capabilities so as to avoid the installation of new power generation capacity and maximize the capacity factor of already existing units [3,12–16]. Decarbonization drivers also dramatically affect the transportation sector and the emerging consensus is that both public and private transport should be increasingly electrified so as to improve well-to-wheel efficiencies [17–19]. This transportation electrification driver requires the electrical grid to be fit for a new, significant and previously un-envisioned purpose [20–24]. Next, the trends towards electric power deregulation that began at the turn of the century are likely to continue in the hope of achieving greater social welfare and improved electricity price and service [25–34]. Finally, these deregulation trends have inspired and empowered consumers who respond to both physical and economic grid conditions [3,12–16]. In short, these five drivers require the steadily increasing penetration of solar and wind generation as well as evolving capabilities to support demand side management for the tremendous diversity of loads that connect to the electrical grid.

The integration of these three new grid technologies of renewable energy, electric vehicles, and demand side resources ultimately imposes fundamental changes to the grid structure and behavior. As a result, the already existing suite of control technologies and strategies are set to dramatically expand in both number and type. While existing regulatory codes and standards will continue to apply [35–37], it is less than clear how the holistic behavior of the grid will change or how reliability will be assured. Furthermore, it is important to assess the degree to which control, automation, and information technology are truly necessary to achieve the desired level of reliability – if indeed it can be accurately quantified. Thirdly, it is unclear what value for cost these technical integration decisions can bring. From a societal perspective, smart grid initiatives have been priced at several tens of billions of dollars in multiple regions [38,39]. Therefore, there is a need to thoughtfully quantify and evaluate the steps taken in such a large scale technological migration of the existing power grid.

This work, thus, argues that a future electricity grid with a high penetration of renewable energy and demand side management technologies requires holistic assessment methods for the profile of newly adopted energy and control technologies. This argument is fashioned as shown in Fig. 1. On one axis, the electrical power grid is viewed as a *cyber-physical* system. That is, assessing the physical integration of renewable energy and demand side resources *must* be taken in the context of the control, automation, and information technologies that would be added to mitigate and coordinate their effects. On another, it is an energy value chain spanning generation and demand. On the third axis, it contains dispatchable as well as stochastic energy resources. These axes holistically define the scope of the power grid system which must meet competing *techno-economic* objectives. Power grid

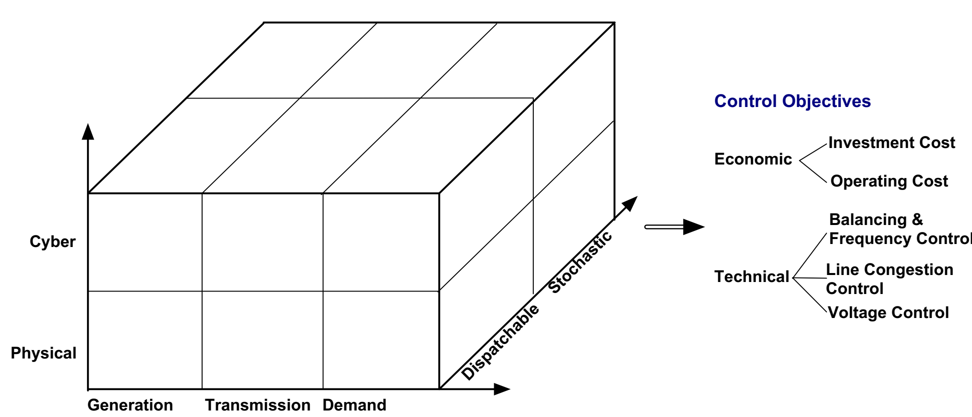

Fig. 1. Guiding Structure of Argument. The power grid is taken as a cyber-physical system composed of an energy value-chain with dispatchable and stochastic elements that must fulfill certain technical and economic control objectives.