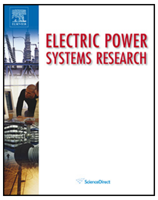
Electric Power Systems Research xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Electric Power Systems Research

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



Modeling study on flexible load's demand response potentials for providing ancillary services at the substation level

Ryan Tulabing[a], Rongxin Yin[a], Nicholas DeForest[a], Yaping Li[b], Ke Wang[b], Taiyou Yong[b], Michael Stadler[a],*

[a] Energy Storage and Distributed Resources Division, Lawrence Berkeley National Laboratory, Berkeley, CA, USA
[b] China Electric Power Research Institute, China

ARTICLE INFO

Article history:
Received 24 February 2016
Received in revised form 8 June 2016
Accepted 9 June 2016
Available online xxx

Keywords:
Demand response
Distributed energy resources
Thermostatically controlled loads
Battery-based Loads
Load prioritization
Load aggregation

ABSTRACT

Demand response (DR) is an important component for the establishment of smart electricity grids. It can decrease the system peaks through load shedding or shifting and optimize the utilization of the existing grid assets, which delays the need for costly upgrades. DR can also enable the integration of intermittent and distributed energy resources (DER) into the existing electricity grid. Fast DR from aggregated flexible loads can provide ancillary services (AS) to absorb grid disruptions and may replace the expensive fast-ramping reserve generation units. This study presents a methodology for load aggregation based on the prioritization of loads according to their flexibility. Different flexible load types are categorized as thermostatically controlled loads (TCL), urgent non-TCL, non-urgent non-TCL, and battery-based loads. Models based on their physical behaviour are developed and simulations performed to apply the proposed aggregation and control algorithm. Results show that the loads during peak hours can be shed off without rebound demand spikes after the DR event commonly seen in other types of DR programs. The algorithm also automatically adjusts the power demand according to the output of the distributed renewable generation, mitigating disruptions due to variations of the DER output. Additionally, the algorithm is able to adjust the load demand dynamically according to the fluctuations of electricity price.

1. Introduction

Grid frequency control and power balancing are traditionally done by ancillary units commonly composed of fast ramping generation units such as gas turbines and diesel generators. However, as new rules to reduce greenhouse gas emissions are implemented, system operators are turning to non-fossil fuel powered resources. Increased penetration of renewable generation from solar and wind, which are intermittent and non-dispatchable, is further driving the need for fast ramping resources. From this point of view, the use of flexibility of demand-side resources and availability of real-time signals communication in the electricity grid enables the interactions between the supply and the demand.

Over the past decades, considering the grid issues of power imbalance and peak demand, demand response (DR) has proven to be a viable option by load shedding and load shifting in response to the need of grid. A number of studies have demonstrated the traditional DR for emergency load relief, peak load management, and price responsive demand [1–4]. However, the use of DR for ancillary service is different from that of traditional DR applications as DR for AS require fast response and high accuracy. Recent studies have demonstrated the use of demand-side resources to provide ancillary service in the electricity market [4–6]. AS can be classified into three categories: regulation, flexibility, and contingency [7]. Ma et al. [5] and Kirby [8] described generalized DR product definitions for load participation in AS, energy, and capacity markets. Those DR product are defined by the response time, the length of the response, the time to fully respond and the event times being called. Regulation service refers to the capacity to respond to random deviations from the scheduled net load. Response time for this type of ancillary service vary between 30 s and 5 min and usually lasts for 15 min. Flexibility ancillary service addresses the large unforeseen deviation of wind or solar output responding as fast as 5–20 min for a duration of 1 h. Meanwhile, contingency service is allocated for immediate response to sudden loss in generation. Contingency services are required to respond as fast as 1–10 min holding for a duration of 30 min or less [7]. In the US electricity market, such as CAISO (California ISO) and PJM region, frequency service requires 4 s response to track automatic generation (AGC) control signals.

---

* Corresponding author at: 1 Cyclotron Road, Berkeley, CA 94760, USA.
E-mail address: mstadler@lbl.gov (M. Stadler).

http://dx.doi.org/10.1016/j.epsr.2016.06.018
0378-7796/© 2016 Elsevier B.V. All rights reserved.

Please cite this article in press as: R. Tulabing, et al., Modeling study on flexible load's demand response potentials for providing ancillary services at the substation level, Electr. Power Syst. Res. (2016), http://dx.doi.org/10.1016/j.epsr.2016.06.018

From the perspective of DR enablement, DR can be considered broadly to fall into two categories: direct control and indirect control. Direct control enables the grid operators to directly turn on or off the customer's loads or change the operating setpoints (e.g. thermostat control) after a short notice. Alternatively, under indirect control, grid operators send requests to reduce load demand to customers, who have the choice to participate or not. In the context of AS described above, demand response has to be fast and automatic (i.e. Auto-DR) [9]. The variability in customer response time makes indirect control less reliable compared to the direct control DR, and unsuited for this application. Different control methodologies for harnessing the DR potential of heating ventilation and air conditioning (HVAC) system were evaluated by [10,11]. Results show that significant demand relief can be taken from temperature reset control and pre-cooling control but with energy and cost penalties. Highest demand relief can be attained by curtailment control but can only be used in shorter duration as the indoor temperature quickly exceeds the comfort level for most humans. For demand response lasting for several hours, pre-cooling control is among the best options [12–14]. However, with regards to DR for AS, battery-based storage and electric vehicle (EV) have proven to be viable options for grid application, ancillary services such as frequency regulation in particular [15–18]. When considered as flexible resources, a number of recent studies have demonstrated the use of EVs for increasing penetration of renewable generation resources. In [19], the authors design three a suitable modeling of electric vehicles with three types of controls (night charge, intelligent charge and vehicle to grid) to analyze the impact of EVs on energy systems. The authors of [16] conduct several simulations to show the adoption of advanced centralized EV charging control strategies and allow the integration of a larger number of EVs in the system. On the other hand, the adoption of a local level of control will allow a better operation performance of increasing penetration of intermittent and variable renewable generation resources installed in isolated power systems. In [20], the authors investigate the use of plug-in EVs (PEVs) to balance the fluctuation of renewable energy sources and study the benefits of fleet EVs in response dynamic price signals. In [21], the authors explore the potential of PEVs to balance variability and uncertainty from wind and solar generation resources. The authors demonstrate the use of a large number of PEVs to provide ancillary services in the regulation (secondary frequency control) time frame by leveraging emerging information and communication technologies, and conclude that roughly 3 million PEVs with a charging rate of 3.3 kW and no V2G capability would suffice to supply a large part of the regulation up and down demand in California.

In the domain of demand response in buildings, recent studies show that using commercial and residential HVAC load control in grid operations can provide power regulation and ancillary services [22–28]. Most research have demonstrated the value of demand-side flexible loads individually at each category of DR product. However, at the substation level, it is quite challenging to aggregate different type of flexible loads at the same order due to different response characteristics (e.g. response availability, depth and duration). There is a need to provide a solution to aggregate, control and optimize each type of flexible load's DR resource in the grid operation.

In this study, we develop a suite of bottom-up physical models to quantify aggregate DR potential from residential sector. Specifically, we propose a general methodology for a DR controller which aggregates common types of residential electrical loads, EV and storage, and predicts their potential to provide demand response resource. The paper is organized as follows: Section 2 describes the methodology for modeling each type of flexible load in residential sector, as well as models for distributed energy resources (DER) like solar and wind. Section 3 introduces the definition of flexibility for each load type, and the power allocation algorithm that prioritizes loads based on their flexibility. Section 4 uses the model detailed in Section 2 and control algorithms detailed in Section 3 to demonstrate the use of aggregated DR resource under several scenarios. Finally, the conclusion and recommendations for future investigations are presented in Section 5.

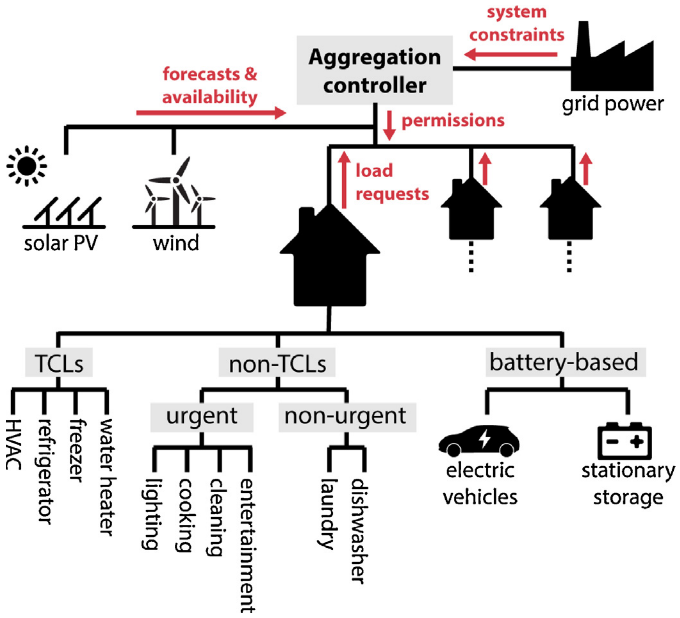


Fig. 1. Aggregation of flexible loads.

2. Methodology

This study uses the bottom-up approach in modeling customer loads and their corresponding DR potential. Individual models of electrical loads are developed based on their physical properties and behavior. The models are then aggregated in a simulation to mimic the load demand at the substation level where the proposed controller should be located. Fig. 1 illustrates the setup of the controller. Loads will send requests to turn on, then the controller will prioritize all requests and grant permission according to available power from the DER and the grid. It is assumed that the communication line between the aggregator and the loads exists and that the central controller has the ability to prohibit a load from starting. Two conditions are required for a load to start: load request trigger, and permission from the central controller. The central controller gathers the load status or simulate the load status, prioritize the loads according to their flexibility, then allocate power by sending a "permission to start" signal to the loads. If a particular load requests to start but no permission has yet been granted from the central controller, it shall wait until the permission to turn on is given – inherently shifting the load demand.

2.1. Load classification

Electrical loads can be classified as: thermostatically controlled loads (TCL); non-thermostatically controlled loads (non-TCL); and battery-based loads. TCLs include HVACs, water heaters, refrigerators, and freezers. Non-TCL loads can further be classified as urgent or non-urgent. Urgent loads are types of load that has to respond to user's request instantaneously after the switch is turned on (e.g. lights, cooking appliances, entertainment appliances). Non-urgent loads are those that can be started after some allowable time delay such as dishwashers, washing machines, and clothes dryers.

Please cite this article in press as: R. Tulabing, et al., Modeling study on flexible load's demand response potentials for providing ancillary services at the substation level, Electr. Power Syst. Res. (2016), http://dx.doi.org/10.1016/j.epsr.2016.06.018