A Model-Predictive Hierarchical-Control Framework for Aggregating Residential DERs to Provide Grid Regulation Services

Kumar Utkarsh, Fei Ding, Changhong Zhao, Harsha Padullaparti, and Xin Jin
National Renewable Energy Laboratory, Golden, CO, 80401, USA

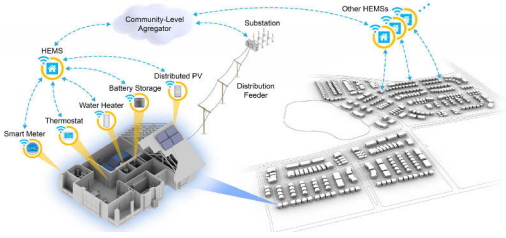
Abstract

This paper develops a hierarchical control framework to aggregate and to manage behind-the-meter distributed energy resources (DERs), which will be ubiquitous in future distribution systems. The proposed framework has following major steps:

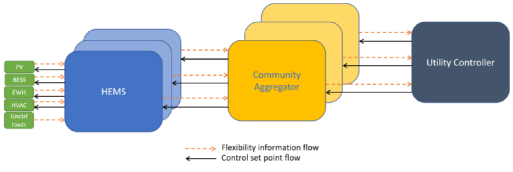
1) Each controller in the hierarchy determines the flexibility of the DERs such that the obtained flexibility is feasible with respect to its operational boundaries.
2) Based on the feasible flexibility, optimal setpoints for the DERs are then determined by the hierarchical controllers to help provide grid services such as voltage regulation to the distribution power network.

Hierarchical Framework

The envisioned framework considers a home energy management system (HEMS), which manage DERs in each home; a community-level aggregator, which manages the HEMS in the community of homes; and a substation-level utility controller, which manages the aggregators of the communities on the distribution feeder.

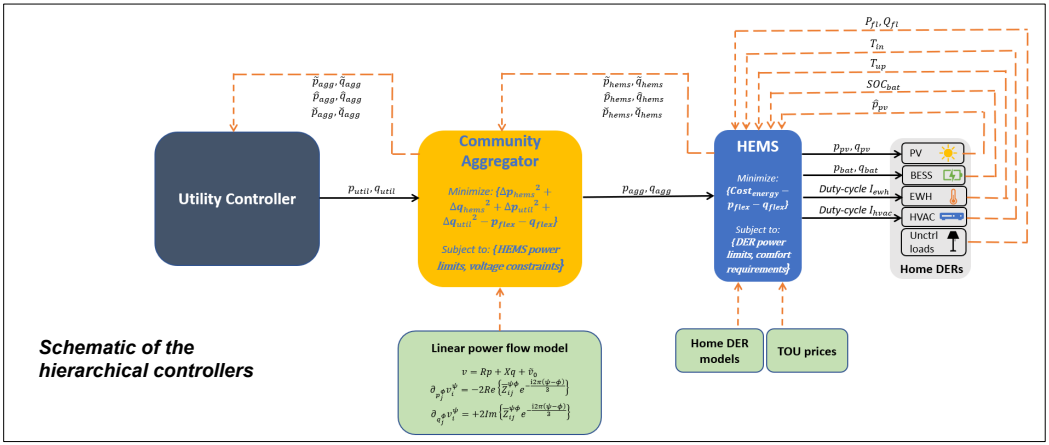


Information and Control Flow



The bidirectional flow of information and control setpoints between the controllers in the hierarchy occurs through the following steps:

1) Given the predictions and the active/reactive power consumptions of uncontrollable loads, every HEMS calculates a trajectory of the upper bound and lower bound for the home active/reactive power consumptions for cost minimization based on user comfort constraints.
2) The community aggregators determine the feasible bounds and nominal powers at their points of common coupling considering their network constraints.
3) The aggregators perform an economic disaggregation of the utility request signal and provide set points to each HEMS.
4) The HEMS perform an economic disaggregation of the aggregator signal and provide setpoints to each DER.

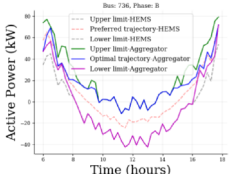


Schematic of the hierarchical controllers

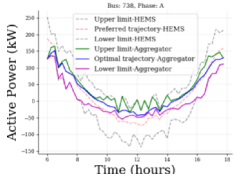
Numerical Results

A. Optimization Modes

The aggregator has a higher preference toward HEMS nominal powers while regulating home node voltages.

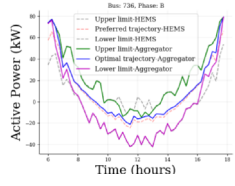


Powers at Bus-736

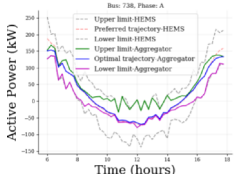


Powers at Bus-738

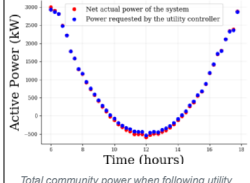
The aggregator has a higher preference toward utility requested powers while regulating home node voltages.



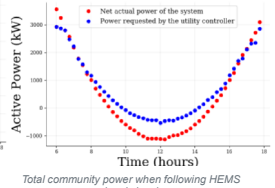
Powers at Bus-736



Powers at Bus-738

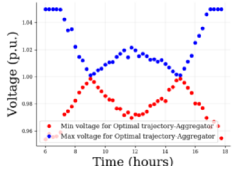


Total community power when following utility signal closely

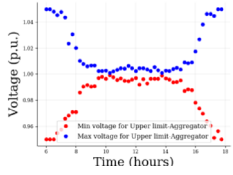


Total community power when following HEMS signal closely

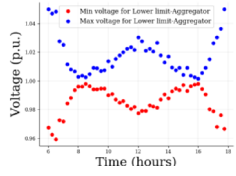
B. Home Voltages



Maximum and minimum voltages for optimal trajectory



Maximum and minimum voltages for upper feasible trajectory



Maximum and minimum voltages for lower feasible trajectory

Conclusions

1) A hierarchical control framework is presented to determine the available power flexibility of the smart homes in a distribution system as well as of the distribution system itself, considering unbalanced power flow formulation and network voltage constraints.
2) The bidirectional flow of information and control ensures that the distribution-level DERs are also able to participate in the grid service markets, thereby helping the power network use the DER flexibility while earning cost savings for the DER owner.
3) The proposed framework is well suited to accommodate other DER types, such as electric vehicles, as well as cost benefit maximization of individual controllers in the hierarchy, which will be studied extensively in our future work.

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technologies Office (SETO) Agreement Number 34236. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes..

Innovative Smart Grid Technologies (ISGT 2020) North America
Washington, D.C.
February 17–20, 2020
NREL/PO-5D00-76093