Economic value of electric vehicle reserve provision in the Nordic countries under driving requirements and charger losses

Electric vehicles can be used for delivering primary frequency control (PFC) and the revenue can compensate for the costs of driving. However, the average system frequency can be biased over the hour, which can lead storage units performing PFC to become either fully charged or depleted. This is also called the energy content of the frequency. Another important role is played by the V2G charger efficiency, which negatively affects the service energy flow. In this paper, the characterisation of the charger and the influence of the losses are detailed. Real frequency and market data are used for calculating the revenue under the Nordic regulatory framework. Earnings are calculated for the best case where the future energy content is known in advance. The results show that, in order to fulfill the service delivery specifications, a crucial role is played by the bid power compared to the size of the energy storage. Recommendations are given in order not to fail regulatory requirements along with considerations on the influence of service provision on the degradation.
Large-scale provision of frequency control via V2G: The Bornholm power system case

This paper assesses the impact of electric vehicles (EVs) providing primary frequency regulation via vehicle-to-grid (V2G) technology. The aim of the work is to define a set of recommendations in order to guarantee a stable large-scale deployment of EV fleets as primary reserve providers. A realistic fleet model is proposed, which emulates the aggregated response of a number of EVs characterized by V2G hardware response times derived in laboratory tests. The effects of primary frequency control via EV fleets replacing conventional generating units are assessed with a sensitivity study in a single-bus power system with growing fleet sizes and response times. Two recommendations are derived to guarantee safe and stable operation: Recommendation 1 requires the share of EVs providing primary reserve to be smaller than the reserve from conventional units; Recommendation 2 requires response times below a given limit value, calculated as a function of the following power system parameters: the system inertia, the total primary reserve over the rotating generation capacity, and the employed droop gain. The full 60 kV power system of the Danish island of Bornholm is then employed to evaluate the validity of the proposed requirements on a real system with complex dynamics, non-linearities and voltage dependencies.

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Web of Science (2014): Impact factor 1.749
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BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 2.92 SJR 1.061 SNIP 1.902
Web of Science (2013): Impact factor 1.595
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Aggregator Operation in the Balancing Market Through Network-Constrained Transactive Energy

The future renewable-based power system will have an increased need for balancing power. Prosumers, having both generation and consumption capabilities, are expected to provide balancing power to the grid, if their flexibility can be appropriately managed. Meanwhile, undesirable line congestion and voltage violations may arise in the distribution network, when flexible resources respond to external control or price signals on a large scale. Hence, the development of an effective framework to coordinate flexibility at the distribution system level is of utmost importance. Such a framework should allow for an optimal provision of prosumer balancing power services within the boundaries of local network security constraints. In this study, a balancing market participation framework is proposed, adopting the concept of network-constrained transactive energy, to facilitate the interactions between the transmission system operator and aggregators who manage prosumer energy profiles. This framework retains user privacy and complies with the current market setup, where flexible energy is traded on the spot and balancing markets; however, it is ensured that the resulting energy profiles do not cause problems in the distribution network.

**General information**

State: Accepted/In press
Contributors: Hu, J., Yang, G., Ziras, C., Kok, K.
A New Method for Handling Lockout Constraints on Controlled TCL Aggregations

Thermal loads are recognized as a valuable source of flexibility in face of the increasing variability caused by the large shares of renewable production. Lockout constraints can significantly reduce the flexibility of thermostatically controlled loads (TCLs). We propose a novel way of modifying the loads' lockout durations to achieve non-intrusive centralized control without relying on local computations and estimations. We derive analytical expressions for the flexibility reduction and validate them via simulations, which show that the proposed method describes the TCLs flexibility accurately. We further show that a simple stochastic centralized controller, which does not rely on local temperature measurements, outperforms the commonly used priority-stack controller in terms of system robustness against infeasible trajectories.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Energy System Management, Lawrence Berkeley National Laboratory
Contributors: Ziras, C., You, S., Bindner, H. W., Vrettos, E.
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Demand side management in urban district heating networks

This paper proposes a realistic demand side management mechanism in an urban district heating network (DHN) to improve system efficiency and manage congestion issues. Comprehensive models including the circulating pump, the distribution network, the building space heating (SH) and domestic hot water (DHW) demand were employed to support day-ahead hourly energy schedule optimization for district heating substations. Flexibility in both SH and DHW were fully exploited and the impacts of both weekly pattern and building type were modelled and identified in detail. The energy consumption scheduling problem was formulated for both the individual substations and the district heating operator. Three main features were considered in the formulation: user comfort, the heat market and network congestion. A case study was performed based on a representative urban DHN with a MW peak thermal load including both residential and commercial buildings. Results show an up to 11% reduction of energy costs. A sensitivity analysis was conducted which provides decision makers with insights into how sensitive the optimum solution is to any changes in energy, user comfort...
or pumping costs.

**General information**

State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Energy System Management, Department of Civil Engineering, Energy and Services, HOFOR A/S
Contributors: Cai, H., Ziras, C., You, S., Li, R., Honoré, K., Bindner, H. W.
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- Scopus rating (2017): CiteScore 8.44 SJR 3.162 SNIP 2.765
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- BFI (2016): BFI-level 2
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- BFI (2015): BFI-level 2
- Scopus rating (2015): CiteScore 6.4 SJR 2.835 SNIP 2.593
- Web of Science (2015): Impact factor 5.746
- Web of Science (2015): Indexed yes
- BFI (2014): BFI-level 2
- Scopus rating (2014): CiteScore 6.93 SJR 3.158 SNIP 3.218
- Web of Science (2014): Impact factor 5.613
- Web of Science (2014): Indexed yes
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- Web of Science (2013): Impact factor 5.261
- ISI indexed (2013): ISI indexed yes
- Web of Science (2013): Indexed yes
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- Scopus rating (2012): CiteScore 5.69 SJR 2.778 SNIP 3.076
- Web of Science (2012): Impact factor 4.781
- ISI indexed (2012): ISI indexed yes
- Web of Science (2012): Indexed yes
- BFI (2011): BFI-level 1
- Scopus rating (2011): CiteScore 5.5 SJR 2.416 SNIP 2.827
- Web of Science (2011): Impact factor 5.106
- ISI indexed (2011): ISI indexed yes
- Web of Science (2011): Indexed yes
- BFI (2010): BFI-level 1
- Scopus rating (2010): SJR 1.531 SNIP 2.259
- Web of Science (2010): Impact factor 3.915
- Web of Science (2010): Indexed yes
Response Accuracy and Tracking Errors with Decentralized Control of Commercial V2G Chargers

There is a growing interest in using the flexibility of electric vehicles (EVs) to provide power system services, such as fast frequency regulation. Decentralized control is advocated due to its reliability and much lower communication requirements. A commonly used linear droop characteristic results in low average efficiencies, whereas controllers with 3 modes (idle, fully charging, fully discharging) result in large reserve errors when the aggregation size is small. To address these issues, we propose a stochastic, decentralized controller with tunable response granularity which minimizes switching actions. The EV fleet operator can optimize the chargers’ performance according to the fleet size, the service error requirements, the average switching rate and the average efficiency. We use real efficiency characteristics from EVs and chargers providing fast frequency regulation and we show that the proposed controller can significantly reduce reserve errors and increase efficiency for a given fleet size, while at the same time minimizing the switching actions.

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Addressing the Conflict of Interest between Aggregators and DSOs in Deregulated Energy Markets
This paper investigates potential conflicts of interest between distribution system operators (DSOs) and aggregators. We propose a method to quantify the allowed operating range of residential flexible loads in a local distribution network. The calculated bounds can be used to formulate DSO services, tradable on a potential DSO service market platform. Aggregators are considered, concentrating thermostatically controlled loads and electric vehicles with vehicle2grid technology in order to perform arbitrage on the power market and to offer ancillary services.

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Contributors: Heinrich, C., Ziras, C., You, S., Bindner, H. W.
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Assessing the Energy Content of System Frequency and Electric Vehicle Charging Efficiency for Ancillary Service Provision
The purpose of this paper is to quantify the effect of biased system frequency deviations and charger losses in order for an aggregation of electric vehicles (EVs) to provide reliable primary frequency control (PFC). A data set consisting of one year of frequency measurements of the Nordic synchronous zone is used for the analysis. The average system frequency can be biased over the hour, which can lead storage units, performing PFC, to become fully charged or depleted. This paper presents statistical bounds on how variable the average system frequency can be on different time scales. Additionally, a method for calculating the expected energy loss caused by continuous charging and discharging is presented together with efficiency measurements of a commercial bidirectional EV charger. It is found that during a year, the energy balance of the service provider, relative to the grid, is within the calculated bounds. The efficiency losses are calculated and validated to have a linear relationship with the reserve capacity and the provision time.

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Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Distributed Energy Resources, Energy System Management
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A Statistical Method for Aggregated Wind Power Plants to Provide Secondary Frequency Control
The increasing penetration of wind power brings significant challenges to power system operators due to the wind’s inherent uncertainty and variability. Traditionally, power plants and more recently demand response have been used to balance the power system. However, the use of wind power as a balancing-power source has also been investigated, especially for wind power dominated power systems such as Denmark. The main drawback is that wind power must be
curtailed by setting a lower operating point, in order to offer upward regulation. We propose a statistical approach to reduce wind power curtailment for aggregated wind power plants providing secondary frequency control (SFC) to the power system. By using historical SFC signals and wind speed data, we calculate metrics for the reserve provision error as a function of the scheduled wind power. We show that wind curtailment can be significantly reduced compared to a robust and conservative scheduling, by appropriately choosing a higher operating point based on the error's expected value and the service error requirement.

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Organisations: Center for Electric Power and Energy, Department of Electrical Engineering, Energy System Management, National Development and Reform Commission
Contributors: Hu, J., Ziras, C., Bindner, H. W., Han, X.
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Controllability and stability of primary frequency control from thermostatic loads with delays
There is an increasing interest in exploiting the flexibility of loads to provide ancillary services to the grid. In this paper we study how response delays and lockout constraints affect the controllability of an aggregation of refrigerators offering primary frequency control (PFC). First we examine the effect of delays in PFC provision from an aggregation of refrigerators, using a two-area power system. We propose a framework to systematically address frequency measurement and response delays and we determine safe values for the total delays via simulations. We introduce a controllability index to evaluate PFC provision under lockout constraints of refrigerators compressors. We conduct extensive simulations to study the effects of measurement delay, ramping times, lockout durations and rotational inertia on the controllability of the aggregation and system stability. Finally, we discuss solutions for offering reliable PFC provision from thermostatically controlled loads under lockout constraints and we propose a supervisory control to enhance the robustness of their controllers.

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Scopus rating (2015): CiteScore 2.45 SNIP 1.478
Web of Science (2015): Impact factor 0.975
Web of Science (2015): Indexed yes
Evaluating the Cost of Line Capacity Limitations in Aggregations of Commercial Buildings

The trend towards electrification of the heating sector in many cases leads to the replacement of fossil-fueled heating systems with electric heat pumps. This may result in significantly higher consumption and potentially violations of the distribution grid operational limits. We propose a day-ahead optimization strategy to assess the cost of imposing capacity limitations in the total consumption of individual buildings, as well as aggregations of buildings. We show that such capacity limitations lead to an increase for the buildings operational costs, which can be interpreted as the value of these limitations. Based on such calculations, the aggregator can value capacity-limitation services to the distribution system operator. Moreover, the value of aggregation is also highlighted, since it leads to lower costs than imposing the same total capacity limitation on individual buildings.

Modelling the Aggregated Dynamic Response of Electric Vehicles

There is an increasing interest in the use of electric vehicles (EVs) for providing fast frequency reserves due to their large installed capacity and their very fast response. Most works focus on scheduling and optimization and usually neglect their aggregated dynamic response, which is particularly important from the power system perspective when EVs offer significant shares of such services. We present a literature review on the aggregated modelling of EVs and derive analytical expressions for the representation of EV populations based on the probability distributions of their parameters. Such approximations can be used in power system studies, in order to capture the dynamics of an EV population more accurately. Finally, we compare our approach to the most widely used in the literature, i.e. the averaging method where all EVs are represented with the population's average values, and discuss the key differences of the two approaches.
An Overview of Modeling Approaches Applied to Aggregation-Based Fleet Management and Integration of Plug-in Electric Vehicles

The design and implementation of management policies for plug-in electric vehicles (PEVs) need to be supported by a holistic understanding of the functional processes, their complex interactions, and their response to various changes. Models developed to represent different functional processes and systems are seen as useful tools to support the related studies for different stakeholders in a tangible way. This paper presents an overview of modeling approaches applied to support aggregation-based management and integration of PEVs from the perspective of fleet operators and grid operators, respectively. We start by explaining a structured modeling approach, i.e., a flexible combination of process models and system models, applied to different management and integration studies. A state-of-the-art overview of modeling approaches applied to represent several key processes, such as charging management, and key systems, such as the PEV fleet, is then presented, along with a detailed description of different approaches. Finally, we discuss several considerations that need to be well understood during the modeling process in order to assist modelers and model users in the appropriate decisions of using existing, or developing their own, solutions for further applications.
Fast and Reliable Primary Frequency Reserves From Refrigerators with Decentralized Stochastic Control

Due to increasing shares of renewable energy sources, more frequency reserves are required to maintain power system stability. In this paper, we present a decentralized control scheme that allows a large aggregation of refrigerators to provide Primary Frequency Control (PFC) reserves to the grid based on local frequency measurements and without communication. The control is based on stochastic switching of refrigerators depending on the frequency deviation. We develop methods to account for typical lockout constraints of compressors and increased power consumption during the startup phase. In addition, we propose a procedure to dynamically reset the thermostat temperature limits in order to provide reliable PFC reserves, as well as a corrective temperature feedback loop to build robustness to biased frequency deviations. Furthermore, we introduce an additional randomization layer in the controller to account for thermostat resolution limitations, and finally, we modify the control design to account for refrigerator door openings. Extensive simulations with actual frequency signal data and with different aggregation sizes, load characteristics, and control parameters, demonstrate that the proposed controller outperforms a relevant state-of-the-art controller.

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Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Energy System Management, Swiss Federal Institute of Technology Zurich
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Web of Science (2017): Impact factor 5.255
Web of Science (2017): Indexed yes
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Scopus rating (2016): CiteScore 8.17 SJR 3.368 SNIP 3.584
Web of Science (2016): Impact factor 5.68
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 6.6 SJR 3.315 SNIP 3.386
Web of Science (2015): Impact factor 3.342
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 5.31 SJR 2.475 SNIP 3.485
Web of Science (2014): Impact factor 2.814
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BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 6.33 SJR 2.523 SNIP 4.243
Web of Science (2013): Impact factor 3.53
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 5.84 SJR 1.941 SNIP 3.387
Web of Science (2012): Impact factor 2.921
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 5.34 SJR 1.586 SNIP 3.205
Web of Science (2011): Impact factor 2.678
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.708 SNIP 2.759
Web of Science (2010): Impact factor 2.355
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.622 SNIP 2.675
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.309 SNIP 2.45
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.12 SNIP 2.48
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.147 SNIP 2.259
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.41 SNIP 2.482
Scopus rating (2004): SJR 0.938 SNIP 2.807
Scopus rating (2003): SJR 2.078 SNIP 2.607
Scopus rating (2002): SJR 1.404 SNIP 2.284
Scopus rating (2001): SJR 1.553 SNIP 1.847
Integrating Large Shares of Heterogeneous Thermal Loads in Power System Frequency Control

Thermal loads can, in principle, provide ancillary services to power systems. In this paper, we propose a new, practical frequency control scheme that allows different types of thermal loads to collaboratively offer reserves in parallel to generators. Primary reserves are provided by residential refrigerators in a decentralized fashion based on local frequency measurements. Secondary reserves come from centralized control of a pool of residential electric water heaters and heating, ventilation, and air conditioning systems of commercial buildings. The scheme accounts for the loads' electrical and thermal dynamics, and allocates the reserves among them using optimization and signal filtering to achieve the desired responses without compromising user comfort. We demonstrate the scheme's performance via dynamic simulations with a linearized two-area power system model and show that load control improves the system's response to sudden losses of generation and fluctuating power in-feeds.

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Contributors: Vrettos, E., Ziras, C., Andersson, G.
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Source: FindIt
Source-ID: 2345884596
Research output: Research - peer-review > Article in proceedings – Annual report year: 2015

Primary Frequency Control with Refrigerators under Startup Dynamics and Lockout Constraints

There is a growing interest in utilizing demand-side flexibility to provide ancillary services. Various methods have been proposed for frequency control with thermostatically controlled loads, yet few consider practical load constraints. In this paper, we develop a fully decentralized method to provide primary frequency control (PFC) with domestic refrigerators taking into account startup compressor dynamics and lockout constraints. The proposed method relies on probabilistic switching to avoid synchronization among loads and large deviations from loads' baseline consumption, and on dynamic resetting of temperature deadbands to provide accurate PFC reserves. We demonstrate the method's performance via simulations with an extract of real frequency data, and via dynamic simulations with a one-area power system model. The results show that the method performs very well in both cases, and allows refrigerator aggregations to mimic conventional generators' droop characteristic and substitute them in PFC. To illustrate the importance of considering startup dynamics and lockout constraints in control design, we show that our approach achieves better results compared to an existing approach that neglects such constraints.

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Organisations: Swiss Federal Institute of Technology Zurich
Contributors: Ziras, C., Vrettos, E., Andersson, G.
Number of pages: 5
Publication date: 2015
Gas-Turbine Stability Improvement through a Compressed-Air Chamber

In this paper a method to improve gas-turbine performance and participation in primary frequency control of autonomous power systems is presented. In particular, a gasturbine model incorporating a compressed-air chamber is developed. It is shown that a significant improvement in primary frequency control can be obtained, as well as a temporary power increase in order to respond to loads above the plant nominal power without overheating.

General information
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Organisations: National Technical University of Athens
Contributors: Ziras, C., Kandiloros, I., Vournas, C.
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Publication date: 2012

Projects:

Toolsets development for DER aggregators providing concurrent services
Ziras, C., PhD Student, Department of Electrical Engineering
Bindner, H. W., Main Supervisor, Department of Electrical Engineering
You, S., Supervisor, Department of Electrical Engineering

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