ECONOMIC POTENTIAL OF LOAD CONTROL IN BALANCING POWER MARKET

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ABSTRACT

This paper analyses economic potential and practical implementation of end-user load control in Nordic power markets. It is found that there is existing infrastructure and remarkably high capacity for load control in Finland. However, the implementation is hindered by number of barriers, such as long data transfer delays and incomplete operation and business models. Still, results of the analysis shows that the balancing market can provide remarkably high economic potential for the load control, many times higher than Elspot market.

INTRODUCTION

The ongoing development of production infrastructure is leading towards scarce of balancing power. In particular, the increasing share of renewables, but also ageing of existing electricity infrastructure and tightening emission reduction goals may enhance this development [1] [2]. Consequently, new tools for maintaining the power balance between production and consumption are needed. Promotion of active demand side participation, not only in the day-ahead markets, but also in more real-time intra-day and balancing (power) markets could provide such tools.

The active demand side participation, which may also be referred to demand side management (DSM), consist of various energy efficiency (EE) and demand response (DR) actions [3]. End-user load control may be seen in many respects as one of the most potential EE / DR action. Main reasons for this include, but are not limited to its potential to enhance DR and EE in a large scale, offer new tools for different market parties business development and profit optimization, and reduce end-users' energy bills.

Prerequisite for large-scale implementation of DR and EE services, such as load control, is a platform that can enable cost-efficient realization. Such platform could be provided by the AMR- and AMI systems. In Finland the penetration level of installed smart meters is close to 100 %. The Finnish Government Decree (66/2009) [4] has been main driver for high penetration of smart meters. It requires DSOs to install remote readable AMR-meters for at least 80 % of all end-users. In addition, it requires that installed meters have to be able to register end-users' hourly electricity consumption, and be capable to receive and execute or put forward load control commands [4].

In addition to proper platform, the large-scale implementation of load control and other DR services require that these provide benefits for the market parties engaged. Basically, this means that the service have to obtain adequate profit-making opportunities. In addition, incentives for electricity end-users are needed.

In general load control applications that are presented in the literature seems to focus mainly on spot-price-based controls, see for instance [5] and [6]. However, according to our initial analyzes the economic potential of load control in spot markets seems to be rather modest compared to the respective potential in balancing market. Hereby, in this paper we focus to the implementation and economic potential of end-user load control in balancing market. The main aims of this paper are to identify incentives and barriers for practical implementation of load control in balancing market, and to evaluate its economic potential.

Rest of the paper is organized as follows. In second chapter the implementation of load control in balancing power market is examined. The existing obstacles and prerequisites for the implementation of load control are introduced. In third chapter we introduce basics of our economic analyses, and fourth chapter presents the results. In final chapter we make conclusions and highlight some key factors related to practical implementation of the considered DR application.

LOAD CONTROL IN BALANCING MARKET

In principle, there is existing platform for large-scale end-user load control as a result of implementation of smart meters in Finland. Still, large-scale implementation is missing in practice with the exception of traditional day-night time control of storing electric heating loads.

Based on the stakeholder workshops and questionnaires, presented in more detail in [7] and [8], approximately 1000 MW heating loads (mainly water boilers) that can be controlled by the time relay, and 800 MW heating loads that that can be controlled by the load reduction, is found in Finland. In addition, there is vast amount other end-user loads such as cooling, ventilation and heat pumps, which can offer considerably high potential for load control. Significant part of these load could be utilized also in balancing markets.

Barriers and incentives

Our analyses show that although existing AMR- and AMI-infrastructure can provide a basic platform, and that there is considerable high capacity for load control in Finland, the practical realization is hindered by number of issues. Rather long time delays in load control by current infrastructure may provide a barrier. In addition, developments in ICT system interfaces as well as in general operational and business models are needed. For instance, the implementation of load control as part of electricity retailers' business may be challenging. As the results of this study will show, an electricity retailer that operates load controls and bids control capacity to the balancing market is exposed to financial risks.

Proper incentives for the market parties engaged to the load control can help to overcome the obstacles hindering the large-scale implementation. The most essential incentive for new DR services, such as different load control applications, is economic potential. If the service offers adequate profit-making potential for the service provider and benefits for the end-users, the needed incentives for the practical realization can be found. Thus, is seems that one of the greatest barriers is that load control does not provide adequate economic potential, at least in the Elspot market where its realization is most commonly considered and piloted. However, the implementation of load control in more real-time markets, such as balancing or reserve markets, could offer considerably higher economic potential as a result of higher prices and price volatility compared to Elspot market.

Although the importance of economic potential cannot be underestimated, also other factors could provide needed incentive for implementation of DR services. For instance, green values and efficient end-use of energy can motivate end-users to obtain DR services. Furthermore, electricity retailer that offers load control services may be better able to attract and commit the customers.

The above mentioned obstacle and incentives are included to most important ones, but may not be the only ones. More information about the barriers and incentive is found in [7] and [8].

Prerequisites for control in balancing market

General incentives and barriers for DR services such as load control was introduced in above. In addition, the market place, in which the service is designed, may provide its own limitations or incentives. Next, the constraints set by the balancing power market for load control are introduced as a base for further analyses.

The regulation of the balancing market obligate that capacity offered to the market have to satisfy 10 MW minimum capacity requirement. The capacity can be aggregated (consist of multiple production/load units). In addition, the capacity have to be controlled to the full power in 15 minutes after the control is subscribed. Furthermore, the power changes of the control must be verified in real-time.

In practice, the above requirements makes the implementation of load control in balancing market through smart meter infrastructure challenging. At least in some cases, rather long time delays in data transfer can make it impossible to put the control in practice in 15 minutes. In addition, reliable and real-time verification of controls require typically load- or load group-specific measurements, which are generally missing.

Despite the above challenges, the implementation of load control in balancing market have to be considered if there can be found adequate economic potential. Alternatively, the existing smart metering infrastructure can be updated, or for instance HEMS (Home Energy Management System) or BACS (Building Automation and Control System) system can be implemented, to enable the load control.

ANALYSES OF ECONOMIC POTENTIAL IN BALANCING POWER MARKET

In this paper we model both theoretical and practical economic potential of load control in balancing power market and compare these. Economic potential is estimated for the example load group that consist of 1388 end-users with direct electric heating and water heating loads. The analyses are based on example customer (end user) group's hourly consumption data (AMR data) and real historical electricity price within the examination interval 1.1.2011 – 31.12.2011. The basic assumption behind the modeling is that an electricity retailer is the market party that implements the load control in practice and uses it as part of its profit optimization.

The analyses of economic potential are made in hour level, respectively as the trading in the Nordic balancing power market takes place, and proceeds as follow. First, theoretical economical potential of load control in balancing power market is computed. Second, the impact of bid price on obtained incomes is evaluated. Third, the theoretical economic potential in Elspot market is estimated for the comparison. Finally, the results are compared and summarized.

Methodology

The analyses of economic potential of load control are based on the methodology that is designed for optimization of use of DER (Distributed Energy Resources) as part of electricity retailer profit optimization. The applied methodology considers the requirements and limitations set by the markets, end-users, technical implementation and retailer operation.

The proposed methodology is first used to evaluate the optimal load control sequence within the set constraints and to calculate the profits from the control. In addition, it is used to define the control sequence for the given bidding strategy, i.e. given hourly bid prices, within the given constraints.

Initial /input data

Our analyses are based on real historical data of electricity prices and example customer group's energy consumption. The load control capacity is estimated based on example customer group's real hourly energy consumption data that is obtained through smart meters (AMR-data). The share of end users' direct electric heating loads and water heating loads is estimated and modeled as a temperature depended load control capacity with the same basic methodology as in [9].

Applied constraints and modeling assumptions

There are various constraints for the considered load control service (application) in practice. For instance, market rules and system operator, end-users, technical realization and retailer's operation sets limitations for the control. As far as it is possible, these constraints are taken into account in the problem modeling. However, detailed consideration of all these constraints is virtually impossible, and thus also some modeling assumptions are applied.

As a base for the problem modeling it is assumed that the electricity retailer is the market party implementing the load control in practice. Hereby, it is also assumed that the retailer have taken into account load control in the planning of the retail business as far it is possible. Still, all impacts of load control cannot be taken into account in advance in the balancing market load control. For instance the payback, which refer to energy and power during the hour when restoration of electric heating storage takes place after the disconnection period [9], may not be forecasted in advance, since the actual volume of load control is known only at the time of delivery. Thus, it disturbs the power balance between retailer's electricity purchases and sales. Hereby, the retailer purchases consumption imbalance power in order to satisfy the power imbalance caused by the payback.

The load control and payback is modeled so that applied control decreases energy consumption within the delivery hour (t) by the volume -E_{Δ}, and payback in the following hour $(t+1)$ increases energy consumption by corresponding volume E_{Δ}. In other words, it is assumed that the total energy consumption does not change as result of load control, but one hour forward load shift will take place. Consequently, when load control takes place the retailer obtains incomes according to controlled energy and up-regulation price in delivery hour (t), and the cost are accumulated according to payback energy and consumption imbalance power price for the following payback hour $(t+1)$.

In order to ensure the end-users comfort and to follow network regulations, the duration of a single load disconnection is limited to one hour. In addition, after the end of each control action there is two hour time period where new controls cannot be applied. Furthermore, at the maximum 5 controls in a day can be put in practice.

Regards to constraints set by the market, it is assumed that controls are put in practice in 15 min. as regulations of balancing power market demands. It is also supposed that controls can be verified according to the market regulations. Furthermore, it assumed that the controlled capacity is part of larger aggregated capacity, and thus the minimum capacity requirements are satisfied.

RESULTS

Results of the simulations are presented in three parts. First, theoretical maximum potential of load control in balancing power market is calculated. Second, the impact of bid price on estimated incomes is estimated. Third, for the comparison, theoretical maximum potential of the considered load control is calculated in the Elspot market.

Theoretical maximum incomes in balancing market

Here we present the theoretical economic potential of load control in balancing market, i.e. maximum incomes within the given control constraints and with the known (not forecast as in practice) electricity prices and consumptions. The results of the simulations are illustrated by Figure 1.

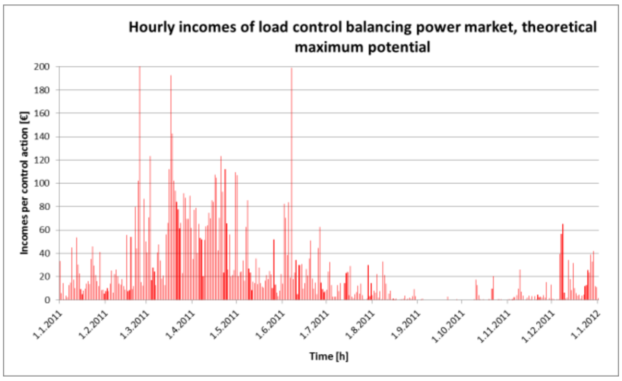

Figure 1. Theoretical maximum income potential of load control for one hour load disconnections in balancing power market.

Figure 1 shows that simulated incomes from load control actions varied significantly within the examination interval. The theoretical maximum are around 23 500 €. Total of 1280 control actions took place in simulations. The average income per control action is thus over 18 €, whereas the highest incomes from single control are around 1500 €.

Impact of bid price on estimated incomes

In order to reach the calculated theoretical economic potential, the retailer should be able to forecast future electricity prices and consumption perfectly, and based on that define the optimal bidding strategy for balancing market. However, in practice, it is not realistic to assume that any retailer would be able to do that. Therefore, the economic potential of load control is examined also through another set of simulations, in which more practical point of view is taken.

In the second part of simulations the impact of bid price on obtained profits is considered. More precisely, the economic potential of load control is calculated assuming that the retailer bids load control capacity to the market with a fixed price that is same for every hour of the examination period. Basically, this is the simplest possible bidding strategy for the retailer, and should thus provide significantly lower incomes that of the theoretical maximum incomes. The results of the simulations are presented in Table 1.

Table 1. Simulated incomes in balancing market with different bid prices.

Bid price [€/MWh]	Income from up-regulation [€]	Cost from consumption imbalance power (payback) [€]	Total income from load control [€]	Total number of applied control actions
10	109 605	-94 723	14 881	1 945
20	109 784	-94 955	14 828	1 938
30	109 661	-95 148	14 513	1 309
40	106 084	-92 583	13 502	1 172
50	98 323	-59 985	11 988	868
60	69 542	-62 120	7 422	616
70	22 839	-19 953	2 885	215
80	6 349	-8 340	-1 991	89
90	5 356	-5 349	6	43
100	4 262	-4 199	63	23
150	3 592	-3 293	300	13
200	3 114	-2 881	233	7
300	2 397	-2 274	123	2

Results of the table shows that in general incomes from the up-regulation, as well as costs from imbalance power purchases, increase when the number of control actions increase. The reason for this is that in general the number of realized control actions increase when the bid price lowers. However, with the lowest bid prices the limitations for control sequences impacts on the timing of controls more, and results in some variation to this trend.

Highest total incomes, close to 15 000 € are obtained when the bid price is 10, 20 or 30 €/MWh. In general, the total incomes decrease when the bid price increases and number of realized control actions decrease. However, within the bid price range 70 to 100 €/MWh total incomes does not follow this trend. Remarkably, the bid price 80 €/MWh provides negative result, which stands for costs from instead of profits from the load control. This is consequence of poor timing of load controls. Hereby, imbalance power costs at the time of payback are higher than incomes from up-regulation at the time of load disconnection in many control actions. The same phenomena decreases total incomes also with other bid prices, but the impact is highest when bid price is 70 to 100 €/MWh.

Theoretical maximum incomes in Elspot market

In the third part of simulations theoretical economic potential of load control in the Elspot market is calculated for the reference level. In other words, the maximum incomes from corresponding load control in the Elspot market are calculated for the example control group, by using the same optimization principles and constraints that was applied to calculation of theoretical economic potential in balancing market in the first part of simulations. The results of the simulation are illustrated by Figure 2.

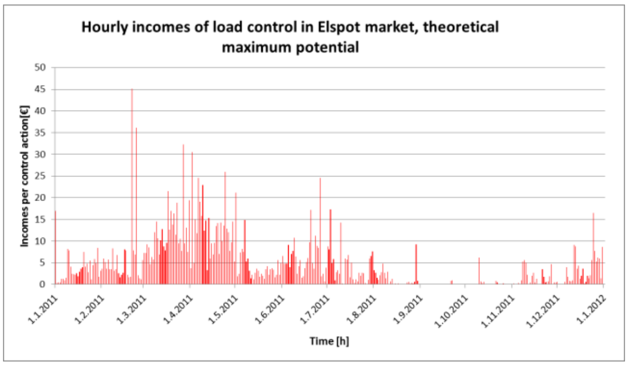

Figure 2. Theoretical maximum income potential of load control for one hour load disconnections in Elspot market.

Figure 2 shows that the simulated incomes from load control actions in the Elspot market varied significantly within the examination interval. The theoretical maximum incomes with the simulated load control capacity, and within the set constraints, are around 3 500 €. Total of 1232 control actions took place within examination interval. Average income per control action is thus approximately 2.8 €, whereas the highest income from single control action is around 45 €.

Summary of simulation results

The results of the simulations shows that the theoretical economic potential of load control is much higher in the balancing power market than in the Elspot market. Calculated theoretical economic potential for the load control of the example control group in balancing power market is around 23 500 €, whereas the respective economic potential in the Elspot market is approximately 3 500 €. Thus, the theoretic economic potential for load control is almost 7 times higher in the balancing market than in the Elspot market.

The result of the second set of simulations showed that if the retailer uses over-simplified bidding strategy, where the bid price is same for every hour, the highest profits are obtained when the bid prices are low (10 , 20 or 30 €/MWh). This is mainly because of the number of realized control actions is high with low bid prices.

The results also shows that the payback effect of load control, which results in power imbalance for the retailer, leads to imbalance power purchases that has high impact to the total profits. With some bid prices, and in particular with the bid price 80 €/MWh, the imbalance power purchase costs resulted by the payback decreased the total incomes of load control remarkably.

When the simplified bidding strategy was used the highest incomes were close to 15 000 €, whereas the theoretical maximum incomes are around 23 500€. Thus, even with the simplified bidding strategy the incomes from the balancing power market are in the best cases over 4 times higher than the theoretical economic potential in the Elspot market.

CONCLUSION

The analyses of this paper shows that there are already remarkable amount of controllable loads, and existing smart meter infrastructure that can provide basic platform for load control. However, there are many barriers that hinders the practical implementation of load control in a large-scale. Moreover, in case of load control in balancing market these barriers are even higher than in case Elspot market. Thus, the implementation of load control in balancing market may not be possible with the existing smart meter infrastructure. This is mainly consequence of high controllability and verification requirements set by the balancing market.

Although the existing infrastructure may not enable load control in balancing market, proper incentives can arise market parties' interest to invest systems that enable it. Basically, this mean high economic potential. Results of the paper shows that economic potential of load control is remarkably higher in the balancing market than in the Elspot market. Even with over-simplified bidding strategy the economic potential can be 4-times higher in the balancing market, and in theory almost 7-times higher. This clearly suggests that although new investments are needed for the implementation of load control in balancing market, it provides much higher incentives for the practical realization.

Finally, it is still pointed out that the implementation of load control require proper operation and business models for the market party, such as an electricity retailer, that implements the load control. Simulation results showed that load control in balancing market may expose the market party significant financial risks. In the worst case, poor bidding strategy combined with the risks caused by payback of heating load control and resulting power imbalance may turn the profits to costs. Hereby, the role of bidding strategy and business process optimization should not be underestimated when considering the market-based load control in balancing market.

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