COORDINATION OF SYSTEM NEEDS AND PROVISION OF SERVICES

Henrik Hansen
Danish Energy Association – Denmark
heh@danskenergi.dk

Lars Henrik Hansen
DONG Energy– Denmark
larha@dongenergy.dk

Hjörtur Jóhannsson
Technical University of Denmark - Denmark
hj@elektro.dtu.dk

Hans-Henrik Holm-Hansen
DONG Energy– Denmark
haheh@dongenergy.dk

Henrik W. Bindner
Technical University of Denmark - Denmark
hwbi@risoe.dtu.dk

Peder Cajar
DONG Energy– Denmark
pedca@dongenergy.dk

Oluf Samuelsson
Lund University – Sweden
Olof.samuelsson@iea.lth.se

ABSTRACT

This paper addresses a challenge associated with large scale deployment of distributed energy resources (DER) to provide system services in future sustainable power systems; namely how to prioritize conflicting interests in a service provided by a DER. For that purpose, different services utilizing the DER in a future system are identified as well as potentially conflicting interests between services. A scheme is suggested for how conflicting interests should be prioritized based on considerations regarding the nature of the service and the system operating state at the time of the service request. Examples are provided for illustrating the functionality of the scheme.

INTRODUCTION

The share of wind power generation in the Danish power system has increased from being negligible in 1980 to represent approximately 20% share of the total domestic electricity supply in 2009 [1]. Danish TSO expects that wind power will cover 50% of Danish electricity consumption in 2025 [2;3] and furthermore, the Danish government has expressed a long term target of achieving a Danish energy supply based on 100% renewable energy by 2050, much of which will be intermittent production.

With the expected development towards a power system based on increasingly distributed, intermittent energy sources, the need for ancillary services is likely to increase, especially for balancing purposes [4]. In [3], the Danish TSO published the results of a survey of methods that could make it possible to meet the goal of 50% wind energy.

For that purpose, distributed energy resources (DER), including demand response, that can be controlled in such a way that it supports the system operation are considered to be an important resource in the future power system. Examples of DER within this project that could contribute to system balancing are mainly focused on household sized micro-CHP units, flexible loads like electric space heating, electric vehicles and other distributed units, all being too small to act in the current market on individual basis.
The main focus is thus on the consumer, and how the consumer can deliver services to grid controllers.

The increased risk of other stability problems, when a fluctuating power production has to be balanced by DER, has motivated research and development of methods able to carry out a real-time assessment of overall system stability and security [5;6] as well as for automatically identifying control actions to avoid instability.

Since the fundamental idea of letting DER respond to instantaneous, electricity prices was presented in 1980 [7], it has become a subject in several research and demonstration projects. The concept of control-by-price is well suited for control of DER due to its transparency and simplicity. It could imply that a price signal is sent in due time that a computer can take appropriate actions that maximize the customer's profit [8]. DER could also be aggregated into Virtual Power Plants (VPPs), which is another way to control and mobilize DER in the market [9-11].

Before a market model can be designed or existing markets be adapted the new DER services, it is of importance to identify the different services utilizing DER in a future system, identify potentially conflicting interests between services and to determine how such conflicting interests should be prioritized. The identification, prioritization and structuring of services provided by flexibility of DER in a future power system cover the aim of this paper.

COORDINATION OF CONFLICTING INTERESTS

The Stakeholders

The possibility of flexibility provided by DER introduces new resources for providing services that support stable, secure and economically efficient operation of power systems. The main stakeholders with interest in these services are:
The TSO as the monopoly responsible for the operation of the transmission system and the overall system stability.
The DSO as the monopoly responsible for the operation of the distribution system and power delivery to customers at all times, without disturbing the transmission system.
The BRP (Balance Responsible Party) as the financially responsible for the balance of energy exchanged through the power markets. In case of deviations, the BRP must pay the

TSO for their imbalance. Other stakeholders affiliated to the BRP are the retailer and the wholesaler. A retailer can also be a wholesaler (the same company), and a wholesaler can be a BRP.

Given the deregulation of the European electricity industry [12] the way to obtain and make use of these services must be on a commercial basis, i.e. through markets. Regulating consumers in order to provide services to the power grid by regulations and paragraphs is not possible in this light. Thus, the main relation between these stakeholders is the BRPs provide services for the markets driven by the monopolies. Today, mainly the TSO, has established markets.

Managing the power grid based on liberalized markets needs to be monitored and governed, to prevent speculation and financial gain from overruling the need for stability [13]. It requires a strong market, with a solid foundation on the technical interworking of the many possible services; to ensure that services cannot be bought in a manner that makes it profitable to cause instability in the power grid.

Identifying system needs with interest in utilization of DER flexibility

Many system needs can be met by DER flexibility. The system needs vary in nature, ranging from solving local problems, to being a small part in addressing system wide problems. Furthermore, the system needs differ in respect to time constraints for the service to be carried out. Some services have a fixed continuous demand (e.g. MW balance), other financial services have to be solved within the hour (e.g. MWh contracted), and even other services are measured across even greater spans of time.

The system needs utilizing DER flexibility are listed below:

TSO need for services:

- Frequency control: Covers the various different reserve power markets today, all the way from primary to tertiary (manual) reserve power.
  - Primary reserves: Respond automatically to changes in frequency. These need to activate without any delays.
  - Other reserves: The remaining reserves for frequency control in order to release the primary reserve again. These can be triggered manually or automatically.
- Voltage support: Services in regards to the voltage stability on the transmission grid.
- Other ancillary services: Includes several things, dominantly the system inertia and short circuit capacity.

In addition to the TSO needs, the TSO can intervene in the system operation in emergencies, in order to avoid a widespread blackout. The system is in an alert state when the system security has fallen below certain limits [14].

DSO need for services:

- Peak-shaving: Aimed at evening out local peaks in power consumption.
- Power Quality: Cover the general power quality. While aspects such as harmonic currents and phase imbalance have some effect on the provision of services, aspects such as flicker have little effect on this.
- Local voltage control: The local voltage level in the distribution grid, while an aspect of the voltage quality, is treated separately. This, as it affects power flow greatly in the distribution grid, among things.
- Mvar bands: In Denmark the TSO has divided the TSO grid in 15 regions as described in [15]. An operational band for the reactive power flow between the TSO and each region is defined This effectively places limits on the reactive exchange with the transmission grid.

Peak-shaving is only attached to the DSO because when clearing the day-ahead market (the Nord Pool Spot), the main constraints on the interconnectors between the control zones are taken into account, and because the Danish TSO has future plans for massive reinforcement of the their grid.

BRP need for services:

- Imbalance issues: Represents the financial issues of a BRP when not maintaining the forecasted consumption and production balance. As flexibility services develops, this service will become more commonly used.
- Work with congestion: The presence of bottlenecks will act as a new type of imbalance. If a bottleneck occurs, the BRP would go into imbalance – unless other costumers can be used as buffer. As such, historical constrictions will become more important in regards to future planning.

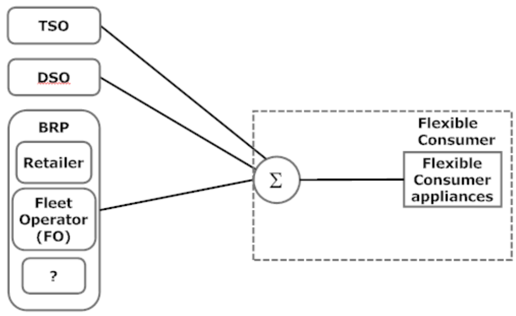

Figure 1: Stakeholder interest in DER flexibility.

A list is illustrated in Figure 1, detailing the interests between the stakeholders and customers with flexible DER. The left side of Figure 1 shows three stakeholders with a need for services. The BRP includes a number of other entities, as the various commercial actors in the electricity market all purchase their power from a BRP. The Fleet Operator would be a commercial entity managing a fleet of flexible consumer appliances, e.g. the charging of electric vehicles, on behalf of the consumer.

The right side is the consumer(s) and all flexible appliances. The two sides are connected by an interface, balancing the requests for services from the three stakeholders.

Commercial stakeholder as flexibility aggregator

Figure 2 shows the BRP as the highest level aggregator, receiving requests from the TSO and DSO, co-ordinating them with its own, and making requests down the supply-chain of commercial entities supplying the end-users.
A 0.4 kV line has up to a few hundred consumers, some of these may have the same supplier, but this is not certain.

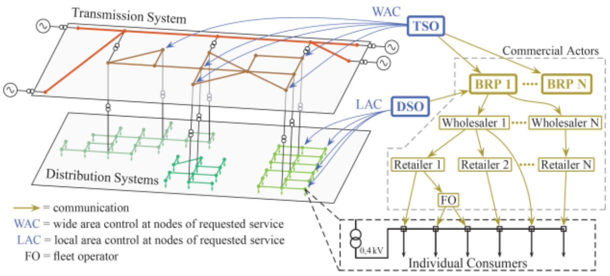

Figure 2: TSO and DSOs request service at different system levels and communicate with a BRP.

Potential Conflicting Interests

The introduction of multiple system needs, which desire to utilize the same asset opens up for potential conflicts between two or more of these stakeholders with contradicting needs, as illustrated by Figure 1. It should be recognized that an activation of a given service can have negative influence on system parameters governed by other services as well. This complex interworking makes the possible conflicts many and difficult to predict at any given time.
It is of the utmost importance that the governing market rules are made in such a way that these conflicts are taken into consideration, to avoid situations where causing imbalance becomes a financial gain.

Prioritizing the needs

In order to handle conflicts when requesting flexibility from DER efficiently, it is useful to categorize the needs:

- Emergency situations: These are actions taken to avoid impending system instability or a blackout. Alert actions are a lesser form of emergency actions.
- Local constraints/requirements: These cover services for resolving constraints in the distribution grid, where a limited number of local resources are available.
- Global constraints/requirements: These cover services for maintaining an adequate level of system security, and for resolving non-emergency issues in transmission networks.
- Planning and financial aspects: These are limitations (non-technical) set by the accuracy of forecasts and financial penalties for not matching contracts.

These four categories enable a priority setup in the same order as listed. In the setup any emergency action is put above all others, in order to prevent potential blackouts.
The services providing solutions for local constraints have the second highest priority in the priority setup.
The services aiming at resolving global constraints have a greater amount of DER to choose from in order to meet its objectives. Therefore, a service resolving local problems should be prioritized before a service resolving global problems in the case of conflicting interest – prompting the global service to be found in another local area. The services categorized under the "Planning and financial aspects" have the lowest priority in the case of conflicting interests, since those do not directly support a more secure system.
Deploying the previously identified services result in the following prioritized list of needs, accounting for how services affect each other and system stability:

1. Emergency actions (TSO)
2. Alert actions (TSO/DSO)
3. Local voltage control (DSO)
4. Peak-shaving (DSO)
5. Voltage support (TSO)
6. Mvar bands (DSO)
7. Frequency control (TSO)
8. Other ancillary services (TSO)
9. Imbalance issues (BRP)
10. Power quality (DSO)

EXAMPLES

General Case

In the following, a simple example is shown to illustrate how the frequency control is obtained in conflict with peak-shaving given the structure in Figure 2.

1. The TSO needs frequency control. Either production must be curtailed, or consumption must increase.
2. The TSO requests an increase of X MW from the BRPs.
3. Each BRP, knowing their capacity from their planning, offer the TSO their capacity and price.
4. The TSO activates the relevant BRPs by cheapest price.
5. As one BRP activates its subjacent partners, an activated 0.4 kV line flags an imminent peak-shaving needed.
6. The DSO informs the BRP of this, to which the BRP shifts the activation of flexible consumers to another area or curtail production.

Had the BRP activated the DER on the line needing peak-shaving they would have had to obtain the consumption elsewhere to counter the peak-shaving – or fail to meet their contract. In extreme cases, the BRP will ignore the peak-shaving; the local area will be overloaded and disconnected. This creates an even larger problem and even more flexible consumers will be needed to control the frequency. It is thus entirely an unwanted scenario for all stakeholders.

Using behaviour descriptions for prioritization

A means to control the end-users DER is behaviour descriptions, as described in [16].
In this example, the electric heaters of a household are controlled by a supervisory controller. The owner of the household has two goals: To participate in frequency control and to reduce his cost of heating

The incentive to participate in frequency control is due to being paid to deliver this service, and the reduction of the cost of heating is to heat the house, at the lowest expense.
The constraint under which the heaters have to operate is that room temperatures should have an acceptable level – a setting that is controllable by the household residents.
The services that heaters provide are frequency control and e.g. price-based, thermostat-controlled heating, the local events that they respond to are: system frequency, measured at the connection point and the price of electricity. The two services can be offered simultaneous because the frequency control algorithm has a deadband. When the measured frequency is within the limits of the deadband, the frequency controller does not have to operate; this gives the thermostat time to control the room temperature. To further reduce the time a heater is subjected to frequency control, it only responds to frequency control part of the time.
The behaviour descriptions for this case are a list of rules for a rule-based system. Rules have the form "if condition - then action". The action activates a certain service, while the condition encodes the constraints the service has to operate under. In this case, the constraints encode the deadband and the time period for the frequency controller, whereas the price-based controller is used whenever the frequency controller is inactive.

CONCLUSION

This paper identifies the three main stakeholders with regards to their individual need for services. Instead of simply forcing compliance and with focus on commercial solutions a scheme for co-ordinating the services are set up at increasingly aggregated levels. The scheme covers the communication and co-ordination of the needs for services. Each need is then considered under normal operations, and a priority list is created for the needs. This priority list is constructed in such a way that in case of a conflict between two services, a service should not be able to be activated, if it would create the need of a higher priority service in the process. With the set-up of the priority list, two examples are given on conflicting services and their activation.
Lastly, the concept of behaviour descriptions is introduced as a means of implementing the control.

REFERENCES

[1] Danish Energy Agency, 2010, "Energy Statistics 2009" Danish Energy Agency.
[2] K. Nørregaard, J. Østergaard, P.-F. Bach, M. Lind, P. Sørensen, B. Tennbakk, M. Togeby, and T. Ackermann, 2008, *Ecogrid.dk Phase 1, Summary Report - Steps towards a Danish Power System with 50 % Wind Energy*, Energinet.dk, Denmark.
[3] P. E. Sørensen, M. Togeby, T. Ackermann, D. K. Chandrashekhara, J. P. F. Horstmann, H. Jóhannsson, A. H. Nielsen, P. Nyeng, T. W. Rasmussen, and Z. Xu, 2008, *Ecogrid.dk Phase 1 WP4 report: New measures for integration of large scale renewable energy*, Risø National Laboratory, Denmark.
[4] Preben Nyeng, 2010, *System Integration of Distributed Energy Resources - ICT, Ancillary Services, and Markets*, PhD thesis, The Technical University of Denmark.
[5] H. Jóhannsson, 2011, *Development of Early Warning Methods for Electric Power Systems*, PhD thesis, The Technical University of Denmark.
[6] H. Jóhannsson, et al., 2011, "Real-Time Stability Assessment based on Synchrophasors", *Proceedings of 2011 IEEE Trondheim PowerTech*.
[7] F. C. Schweppe and et al, 1980, "Homeostatic Utiity Control," *IEEE Trans. Power App. Syst.*, vol. PAS-99, no. 3, pp. 1151-1163.
[8] P. Nyeng and J. Østergaard, 2011, "Information and Communications Systems for Control-by-Price of Distributed Energy Resources and Flexible Demand", *IEEE Transactions on Smart Grid*, vol. 2, no. 2, pp. 334-341.
[9] P. B. Andersen, B. Poulsen, C. Træholt, and J. Østergaard, 2009, "Using Service Oriented Architecture in a Generic Virtual Power Plant", *Proceedings Sixth International Conference on Information Technology*.
[10] S. You, et al., 2009, "Generic Virtual Power Plants: Management of Distributed Energy Resources under Liberalized Electricity Market", *Proceedings 8th International Conference on Advances in Power System Control, Operation and Management*.
[11] S. You, et al., 2009, "A Market-Based Virtual Power Plant", *Proceedings IEEE International Conference on Clean Electrical Power*.
[12] The European Parliament and the Council of the European Union, 2003, *Directive 2003/54/EC of the European Parliament and of the Council of the European Union*.
[13] C. L. DeMarco, 1999, "Strategic behavior in electric generation markets via dynamic governor control design", *Decision support systems*, vol. 24, no. 3-4, pp. 251-258.
[14] P. S. Kundur, 1994, Power System Stability and Control McGraw-Hill, Inc.
[15] Energinet.DK, 2010, *Teknisk Forskrift: TF 2.1.3 Dansk Mvar-ordning* (in Danish).
[16] D. Kullmann, O. Gehrke, and H. W. Bindner, 2011, "Implementation and Test of Demand Response using Behavior Descriptions," *Proceedings 16th International Conference on Intelligent System Application to Power Systems (ISAP)*.

Acknowledgments

This work was a part of the iPower SPIR platform (Strategic Platform for Innovation and Research) and is funded jointly by the Danish Council for Strategic Research and the Danish Council for Technology and Innovation.