BENEFITS AND CHALLENGES OF DEMAND RESPONSE: A CRITICAL REVIEW

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Overview

Advances in IT and modelling capabilities have made demand response a viable, and potentially attractive option to increase the flexibility of power systems. This paper is intended as critical review of the literature in the field of demand response. It provides an overview of the benefits and challenges of demand response as outlined in the current literature. Furthermore, the central assumptions employed for modelling demand response are detailed, with an in depth discussion of the weaknesses of such approaches, and the need for an accurate representation of demand response and the benefits that it can provide at this critical stage in its development.

Methods

A review of the benefits and challenges of demand response is presented, based on the current literature in this field. Demand response (DR) is emerging as an attractive option for increasing the flexibility of power systems. This is a fortunate coincidence with the recent focus on renewable power generation, which typically requires flexibility within the power system. DR can reduce the cost of integrating renewable generation resources in the system and increase their tolerable penetration, through the system security services that it can provide. DR should not be limited to consideration for the support of renewables however, as it facilitates a more efficient use of system resources and assets regardless of the composition of the generation portfolio. Substantial economic efficiency improvements can be brought about by DR, with short run improvements through real time pricing, as the value of electricity and the need for security services can be revealed to customers in real time, avoiding the inefficiencies of flat rate tariffs and allowing consumers to contribute to the provision of system balancing services. Long term improvements are achieved through a more efficient use of system resources, including generation, transmission and interconnection.

Nevertheless, DR is not without its challenges. Current market and regulatory frameworks are ill-suited for DR, and limit its practical abilities, despite its substantial theoretical abilities. Novel market structures are required to allow the full capabilities and value of DR to be accessed. In conjunction with this, viable business cases for DR must be developed, as the significant social welfare increases that can be brought about by DR are spread among many different participants, complicating the task of establishing a viable business. The introduction of the end-user as a direct participant in the power system complicates the task of ensuring that DR is accurately modelled and can provide system balancing services with certainty. The complexity of human behaviour introduces a number irrationalities into the system, and furthers the case for extensive automation of responsive demand. Establishing the value of DR is a central barrier; the value that DR provides to a system is highly system specific, and may provide limited benefits in a system with established flexibility. Key considerations for the evaluation of DR include analysis on multiple time scales, in particular considering the seasonal capacity value of this resource, and consideration of its interaction and complementarities with other system resources, such as generation, storage and interconnection.

Results

An analysis of the literature in this field has revealed that perhaps the greatest challenge for DR is the lack of understanding of its true characteristics. A number of simplifying assumptions are commonly employed to investigate the impact and capabilities of DR. Such assumption belie the complex and uncertain nature of DR, and may result in misleading conclusions. At this critical stage in the development of DR infrastructure and technology, it is imperative that DR is accurately represented so that investment decisions can be made with confidence. One of the most common assumptions is that DR behaves in an economically rational manner, minimising its cost of operation before all other priorities, and that it exhibits a linear demand curve. However, DR is a dynamic, uncertain resource, and both its operating constraints and complex interaction with end-users mean that representation through a linear demand curve is wholly inappropriate. Further assumptions include simplified representation as large centralised units similar to generators, or that DR can be controlled with perfect knowledge of the resource and its environs. The weaknesses and drawbacks of these assumptions are discussed in detail within this paper.

Conclusions

This paper shows that while DR has the potential to bring about a great number of benefits, there are a number of challenges that must be overcome before it can be considered as a valuable contribution to the power system. The overriding issue is the lack of experience and understanding of the nature of demand response. Too much of the work in this field is based upon simplistic models with superficial results. At this crucial stage in the development of demand response it is imperative that a clear and concrete understanding of demand response is established.

Demand is clearly a highly diverse and complex resource, varying according to a multitude of external factors, such as temperature. Despite the limited understanding of the nature of demand response, particularly at the system level where the response of demand from many different sectors and applications is aggregated, it is clear that the resource is highly diverse and dynamic, so using a single model type to represent all of demand is unrealistic. Similarly, it is evident that demand does not fit the conventional model of economic rationality. The interaction of end-users with demand and the operating characteristics of appliances themselves mean that the resulting demand profile exhibits a non-linear, time varying, dynamic and stochastic relationship with price, even in the best-case scenario where the price response is determined through automated control rather than a response from the end-user. It is therefore necessary that novel modelling approaches are adopted. In particular, it is necessary to extend the models to incorporate demand of many different types, and to consider the aggregate behaviour at the system level, and how it interacts with other system resources.

A further aspect of DR that warrants attention is the uncertainty of the response. Demand is affected by a number of stochastic variables, including the weather and the sheer randomness of end-user behaviour, and consequently the response of demand to price or other control signals is uncertain. If the intention is to use DR for the provision of system services, it is imperative to determine the reliability at which the service can be provided. If the reliability of DR cannot be guaranteed to be sufficiently high, it will simply be disregarded in favour of more reliable resources, regardless of the many other benefits that it may bring. The primary concern of the system operator is to maintain system security, and if DR cannot contribute to this, it should be limited to those activities that do not impact on the stability of the system, such as the conventional night-valley filling behaviour that is commonly incentivised today through TOU rates.

DR, where it is currently employed, participates to a limited extent in the power market. Current market structures are poorly suited to DR, and consequently its most beneficial aspects cannot be accessed. Novel market structures should be investigated, and this should be conducted in conjunction with the development of detailed DR models. The financial benefit of DR will be accessed through these market structures, and a poorly structured market could prevent DR from achieving economic viability. Appropriate market structures that consider not only DR, but all other system resources, will ensure system wide economic efficiency, and may further strengthen the economic case for DR.

When evaluating DR, it is imperative that it is considered in the context of the entire energy system. DR alone may offer certain benefits, however when the interaction with other system components is considered DR may become a very attractive option. Integrated resource planning should be employed to consider how the relative benefits of DR, interconnection, storage, conventional and renewable generation can be optimally combined to result in the most efficient use of the system as a whole. Broadening the scope of consideration to encompass previously distinct systems such as natural gas distribution, district heating and biomass may facilitate a truly optimal global solution, revealing opportunities that would not be seen with a narrower focus on the traditional power system. In an operational context this would ensure that the most effective resources are used to maintain total system security on a day-to-day basis, while in a planning context this would ensure that the optimal capacities of each resource are installed on the system. Planning should be considered on a portfolio basis, rather than examining resources in isolation, and on a range of different time scales. As more focus is placed upon renewable resources and DR, the climate will play a greater role in determining the availability of system resources on a seasonal scale. This will have a great impact on portfolio planning, as complementary resources will be important to ensure that system balance can be maintained at all times without requiring excessive redundancy of resources.