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From controllable loads to generalized demand-side resources: A review on developments of demand-side resources

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ABSTRACT

Demand response (DR) is regarded as an important method in the economic and secure operation of the power system, which has attracted great attentions from both industry and academia. With increasing integration of distributed energy resources (DER), demand-side resources become more active and diversified. Moreover, developments of the smart grid (SG) technology provide better environment for DR application. This paper presents an overview of demand-side resource developments from controllable loads to generalized demand-side resources (GDR) including distributed generation (DG) and electric energy storage (EES). Besides, aggregation technologies such as virtual power plant (VPP) and load aggregator (LA) are summarized here. Advantages of GDR application and its development prospects are presented at the end of the paper.

Contents

1. Introduction

In recent years, increasing industrial and residential electricity demand becomes a great challenge to the economic and secure operation of the power system. DR or Demand-side Management (DSM) has proved to be an efficient way to deal with problems like severe peak demand and load fluctuation in such situation. This paper presents an overview of current studies and researches on DR application in different technology and market situations. It also shows the advantages as well as prospects of DR. The paper intends to provide a thorough review of DR developments for researchers interested in this specialized field.

Operation balance of the power system conventionally relies on the adjustments of energy suppliers. Energy utilities expand their generation capacity or purchase reserve capacity in case of emergencies in the system. Such solutions, however, have disadvantages including low response rate, high cost and high carbon emission. New solutions are presented including energy storage

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technologies on the supply side, interconnections with other networks and DSM, among which DSM stands out for its low cost and high reliability [1].

First introduced in the U.S.A in 1984, DSM was originally known as load management and was defined as follows:

"DSM activities are those which involve actions on the demand (i.e. customer) side of the electric meter, either directly or indirectly stimulated by the utility. These activities include those commonly called load management, strategic conservation, electrification, strategic growth or deliberately increased market share" [2].

The core of DSM lies in maintaining the balance of the energy demand and available supply to enhance the stable and economic operation of the system through managements on the demand side. According to previous studies, DSM can be divided into three categories: energy efficiency (using less energy to provide the same services), load management (scheduling the loads to reduce the electric energy consumption or the maximum demand) and DR [3].

As an important branch of DSM, DR (Fig. 1) can be viewed as a new development of DSM with power market and SG technology evolution. According to [4], DR refers to changes in electric use by demand-side resources from their normal consumption patterns in response to electricity price changes, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized. Thus DR programs can be classified into incentive-based ones (DLC, IL, DSB, EDR and CASP) and price-based ones (TOU, RTP and CPP). Both kinds have wide application in the power system and will be discussed later in Section 2.

In DR application, residential, industrial and commercial loads are viewed as available resources in system operation rather than energy consumption simply. Taken distributed generation (DG) and electric energy storage (EES) into consideration, demand-side resources are largely diversified. DG can be further divided into intermittent DG and controllable DG. The actual generation capacity of intermittent DG is uncontrollable, like wind or solar photovoltaic generation. Controllable DGs include diesel or gas generators and small CHPs (Combined Heat and Power Plant), etc. As for EES, besides static energy storage (e.g. electric-based heating and batteries), electric vehicles (EV) are also included for its function of bidirectional energy communication with the power grid.

The developments of SG technologies enhance the real-time information communication between different entities in the power system. With updated market information, end-users can adjust their consumption patterns instantaneously according to their own price preferences or contracts. While DR originally focuses on large consumers, intelligent devices enable small consumers like residential loads to participate in the energy market. These consumers, however, are dispersedly located with small capacity and are hard to control directly by the system operator. To deal with these problems, technologies such as load aggregator (LA) and virtual power plant (VPP) are introduced. Thus both the internal operation of the aggregator and the optimal operation of the whole system become research focuses, which are discussed in Section 3.

The application of DR has expanded from the U.S.A to Europe and finally Asia. Taking full advantage of the activeness of demand-side resources, DR has had a profound influence on the power system. Besides DR operation, its policy is also an important research field.

This review is organized as follows. Section 2 presents the application of DR programs without DER involved. Section 3 addresses the coordination of various demand-side resources and the impacts of aggregation technologies like VPP and LA, etc. Section 4 presents the advantages DR has brought to the power system. Section 5 lays emphasis on the prospects of DR by stating the future work in this specialized field. Section 6 gives the conclusion of this paper.

2. Application of DR without DER involved

The main feature of early developments of DR is the absence of power resources on the energy demand side. Thus demand-side resources mainly include large industrial loads. DR is applied through two kinds of DR programs (DRP) in power system, Incentive-based programs (IBP) and Price-based programs (PBP) [5]. The former is provided through interruptible or curtailment contracts, in which large energy consumers are paid to change their energy consumption patterns by load reduction or shifting [6,7]. The latter is provided through electricity price guidance. All consumers voluntarily adjust their energy consumption to the price fluctuation in the power market [8]. Specific classification of DRPs is shown in Fig. 2. In those listed in Fig. 2, DLC, IL, TOU and RTP are the most common DRPs, among which RTP is the most ideal form of DRP. In [9], the specific definition and application methods of each kind of DRP are provided.

In [10], an economic model is presented for the operator to select the most suitable DRP according to specific system situations. A consumer's demand pattern depends on the electricity price or incentive/penalty values of DRP contracts besides its own load characteristic. Thus several problems need to be considered when DR is applied to a certain power system. These problems include:

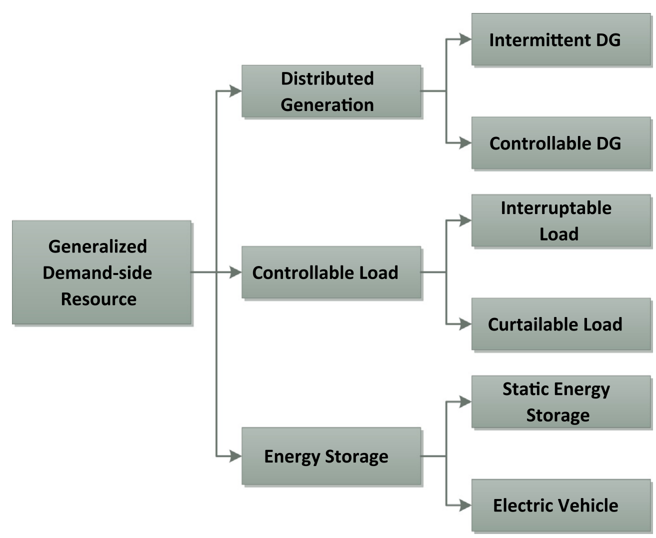

Fig. 1. Classification of generalized demand-side resources.

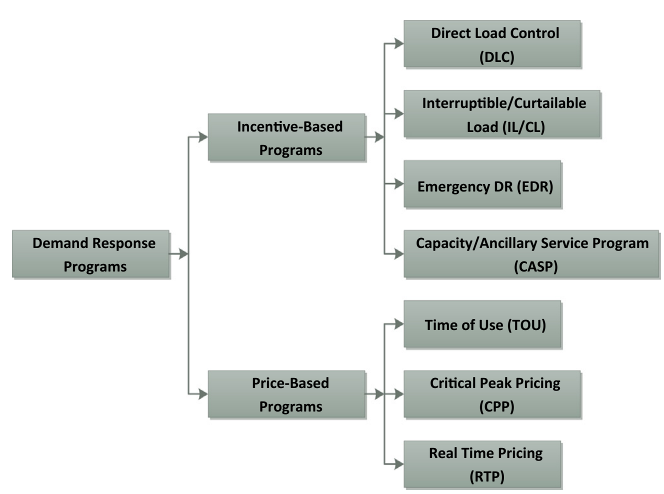

Fig.2. Classification of DRPs.