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The study of Response and renewable energy management using continuous time optimization

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Abstract - Facilities with limited flexibility to schedule their power consumption, such as office buildings or commercial establishments, can be modeled as time-varying non-deferrable loads. In this paper, we propose a demand response strategy for a non-deferrable load facility with renewable energy harvesting and storage capabilities. We assume time-varying electricity prices, and devise a strategy to minimize the expected energy cost incurred by the facility over a finite planning horizon. Unlike existing works, we derive our results by using a generalized model for the energy storage device, which takes into account the non-linear relationship between the discharging rate and the remaining charge. Moreover, we use continuous-time optimization to obtain explicit results, which are meant to reduce the computational complexity of existing strategies. Finally, we use simulations to show that the proposed strategy outperforms the state of the art, especially when the battery discharging model is strictly non-linear.

Keywords: controllable load; load management; renewable energy; microgrid; active distribution system; demand response

1. INTRODUCTION

In recent years, controllable load management has become an active area of new research. Normally, the consumers manage their own loads to reduce their consumption during peak hours. It is possible to shift consumption to optimize the load curve of the system managing "peaks" and "valleys" [1]. By assessing the active participation of distributed energy resources using the questionnaire survey data from Tokyo, Japan during summer 2009, it showed that a controllable load strategy could reduce about 10% of peak demand of a distributed power system [2]. Meanwhile, controllable load management can provide other ancillary services to the grid. For example, the controllable loads, such as heat pump and electric vehicles, are also used to control system frequency and distributed voltage in the power system based on the smart grid [4]. In the distributed power system, the popular controllable loads such as refrigerators, freezers, air conditioners, water heaters, and heat pumps are controlled by the load management programs including direct load control (DLC) [8] and interruptible load management (ILM) [9]. Other controllable loads such as battery storage, Vehicle-to-Grid (V2G), heat storage, *etc.*, are more and more active to take part in the load management programs. Traditionally, the customers sign the interruptible load contracts with the utility companies and then reduce demand at the fixed time when the system is at the peak load period or at any time requested by the power utility. In the smart grid environment, however, these controllable devices can communicate with the upper control system or the distributor operation company, and the bi-level mutual information is communicated in real-time. Measurements from the controllable loads are sent to the management center through a two-way communication network, and the customers provide various ancillary services with demand response management (DSM) With the development of smart grid technologies such as smart meter and smart control technologies, a lot of distributed generation and renewable energy sources (RES) are conveniently connected with the distributed grid. Traditional technologies such as diesel generators are difficult to smooth the distributed grid. It is necessary to develop other flexible solutions to manage the electric distribution network when integrating large amounts of small and dispersed renewable sources. Recently, two types of approaches were studied. One is a micro grid, which provides a solution to manage local generations and loads as a single grid level entity. A micro grid can connect and disconnect from the grid to enable itself to operate in both grid-connected or island mode. The other is the Virtual Power Plant (VPP) which composes various distributed small size generating units and controllable or flexible loads. Unlike the micro grid, the VPP is always connected with the main grid. VPP combines the distributed generation in different geographical sites and mainly focuses on communication and market participation. There are small/medium-scale RES in both micro grid and VPP. However, the impact of RES can be evaluated by considering

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them as a source of demand reduction, instead of a source of generation. From the grid point of view, both the micro grid and VPP are mainly regarded as loads in grid-connected mode. As a result, the micro grid and VPP may be regarded as the new types of loads—"the broad controllable loads".

II. DEFINITION OF CONTROLLABLE LOADS

In this paper, the controllable loads include a wider range than the traditional ones. Various types of controllable loads are defined as follows: Type I of controllable loads: this type of controllable load includes various residential loads, such as fridges, washing machines, air conditioners, space cooling/heating, water heating, These loads are interrupted or shifted by the load's utilities monitor. The load curve can be reshaped by reducing demand. This type of load cannot inject power to the grid at any time. In this paper this type of load is defined as a passive controllable load. Type II of controllable loads: this type of controllable loads includes battery storage, Vehicle-to-Grid, the combined cooling heating, and power (CCHP), *etc.* Compared with the type I of controllable loads, this type of controllable loads can inject power to the grid. These loads can be charged from or discharged to the grid. In addition, this type of load has greater flexibility to be scheduled as controllable loads to accommodate grid needs. In this paper this type of controllable loads is defined as an active controllable load.

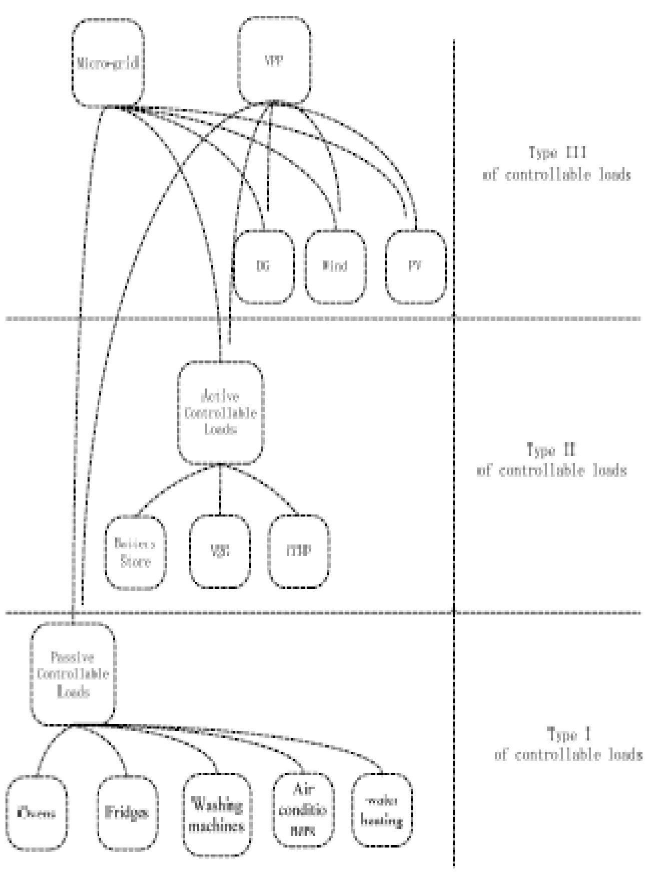

Figure 1. Definition method of controllable loads

III. TYPE II OF CONTROLLABLE LOAD MANAGEMENT APPROACHES

There are other types of controllable loads in the distributed power system, such as battery storage, V2G, CCHP, *etc.* Unlike type I controllable loads, these loads can supply energy. Consequently, they are active controllable loads. There are new characteristics and management approaches with the active controllable loads.

3.1. Loads Characteristics

3.1.1. Battery Storage

Since battery storage can buffer the power output of renewable energy by storing excess energy Throughout times of high availability and inject it to the power system during a power shortage, it is paid great attention as one of the load management components. Due to controllable and flexible charging and discharging operation, battery storage is one of the best ways to reduce the renewable energy fluctuation and enhance system stability. Compared with other controllable loads, battery storage is safe, noiseless, extendible, low maintenance, and of easy operation that does not depend upon landform or physiognomy.

3.1.2. Vehicle-to-Grid (V2G)

Vehicle-to-grid (V2G) describes a system in which plug-in electric vehicles, such as electric cars (PEVs) and plug-in hybrids (PHEVs), can be charged from or discharged to the grid. It can provide power system ancillary services in the form of power balance reserves to support the large-scale integration of variable renewable energy sources like wind power. Unlike traditional demand response schemes, V2G has greater flexibility to be scheduled as a controllable load to accommodate grid needs.

3.1.3. Combined Cooling Heating and Power (CCHP)

Another option for balancing fluctuations of renewable energy is using the CCHP in district heating systems. The stored heat is used in different end users, including space heating and cooling,

IV. TREND DEVELOPMENT OF CONTROLLABLE LOAD APPROACHES

With the development of micro grid control approaches, active loads, and demand response approaches, the new controllable load management approaches are being researched. Firstly, new control strategies may include more controllable loads. A hybrid control model may be popular in practical applications, including the main power system, renewable sources, and many different kinds of controllable loads. The aggregator model, bi-level, and multilayer control models will be studied in detail. Secondly, as more and more meter information is confirmed for the controllable loads and transmission lines in real time, the traditional optimized dispatching model will be

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replaced by the real-time optimized control strategy. The spot price in micro grid and distributed power system would then be realized. Finally, the customer physical behaviors and customer habit formation will attract high attention in the demand response model. The controllable load management approaches will be quickly developed with the research on smart grid and actively distributed.

V. CONCLUSIONS

This paper reviews the controllable load management approaches, including DLC, ILM, V2G, battery storage, and heat storage. The optimal management strategies are reviewed and the control models are discussed. Comparison and development trend of controllable load approaches are also studied in this paper. It is concluded that the controllable loads management approaches are effective to provide fast balancing services to the system in the active distribution system. It is also helpful for future research on renewable energy penetration. Future work will be focused on the penetration level of each controllable load and coordinate the optimal operation of hybrid renewable energy and controllable loads.

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