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A review of demand-side management: Reconsidering theoretical framework

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ABSTRACT

Demand-side management (DSM) has a crucial role in the attainment of sustainable energy that aims to optimize the energy utilization and mitigate emissions. Hence, DSM enhances the flexibility in the power system operation and facilitates low carbon transition in the electricity generation. Recently, the conventional terminology and strategies of DSM have been reformed to match with deregulation of energy environment. Furthermore, the increasing penetration of distributed energy resources (DERs) as well as the advent of smart grids have diversified the techniques and methods of DSM. This paper aggregates the expressions and methodologies about DSM subjects used by the literature and presents explicit definitions of the relevant concepts. In contrast with other review papers in DSM arena, this paper proposes a novel theoretical framework which aims to unify the terminology, concepts, and modalities associated with the literature. A comprehensive categorization of DSM strategies is presented, the scopes are clarified, and the relevant modalities are explicated to attain the unequivocalness in terminology. The evolution of DSM as well as state of the art concepts are considered in the organization of this paper. Moreover, the methods of DSM are reviewed under the paradigms applied in the accomplished classification.

1. Introduction

There are two dissimilar strategies in the power system operation to encounter total predicted load demand: expanding the electricity generation which provides new physical supply-side energy resources, and employing the managerial measures which provides virtual demand-side resources. The first strategy is pursued to provide additional energy quantity to meet the increasing load demand emerged due to modernization or economic development. The second strategy declines the augmentation of energy supply in response to the growth in the load demand and aims to uphold the parsimony in the energy sector through the implementing of appropriate managerial measures and the postponing of generation capacity augmentation. The concept of demand-side management (DSM) has been emerged from the implementing of the managerial measures to produce the resources on the demand-side by influencing the load demand. The term 'demand-side management' was coined by Clark W. Gellings in the 1980's. The basic theoretical frame of DSM has been founded on the concepts addressed in [1–5]. Thus, DSM was encompassed the scheming, implementation, and monitoring of the utility contrivances and programs that can influence the electricity utilization by changing the consumption pattern of the customers to attain the desired changes in the load shape [1]. Ref. [1] has itemized the schemes of DSM including electrical load management, strategic conservation, building loads, and power marketing. The clients and utilities may independently treat to alter the consumption pattern but the concept of DSM entails a utility/client relationship that makes mutually advantageous outcomes [2]. The scope of DSM has been restricted to the scheming and implementation of programs to vigorously shape the electrical load profiles to bring about better energy utilization, lower operation costs and financial stability in [3]. A helpful critical review of DSM implementation on the basis of the concepts embedded in the basic theoretical frame of DSM has been presented in [6]. Since the 1990's, in order to harmonize the basic theoretical frame of DSM with power system restructuring, many concepts, techniques, and terms have been introduced in the literature. Nonetheless, the framework of DSM was retained in the 1990's. For instance [7], and [8] have reviewed the impacts and utility experiences with DSM bidding programs. Moreover, the concept of demand-side response (that had been early introduced by [9]) has been widely employed in the literature (e.g. in [10–13]). Thereafter, price-responsive DSM has become an important subject of DSM. Ref. [14] has comprehensively discussed about the concepts of price-responsive DSM. The fundamentals of DR are clarified in [15]. Moreover, the penetration of distributed generators

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Nomenclature

ADSRCC	Available Demand-Side Resource Capacity Control
ADSRM	Available Demand-Side Reserve Management
AMI	Advanced Metering Infrastructure
CHP	Combined Heat and Power
CILC	Contractual Indirect Load Control
CPP	Critical Peak Pricing
CPP-LC	Critical Peak Pricing with load control
CPR	Critical Peak Rebates
DDSM	Dynamic Demand-Side Management
DELM	Dynamic Electrical Load Management
DENCON	Dynamic Energy Conservation
DER	Distributed Energy Resource
DG	Distributed Generator
DR	Demand Response
DSI	Demand-Side Integration
DSM	Demand-Side Management
ECM	Energy Consumption Management
EEM	Energy Efficiency Management
ELCS	Electric Load Curve Synthesis
ELM	Electrical Load Management
ENCON	Energy Conservation
FP-CPP	Fixed Period Critical Peak Pricing
IRP	Integrated Resource Planning
LF	Load Factor
LFC	Load Factor Correction
LPC	Load Profile Correction
MCP	Market Clearing Price
OPU	Orderly Power Utilization
RTP	Real-time Pricing
SDSM	Static Demand-Side Management
SELM	Static Electrical Load Management
SENCON	Static Energy Conservation
TDLC	Technological Direct Load Control
TOU	Time of use tariff
V-PP	Variable Peak Pricing
VP-CPP	Variable Period Critical Peak Pricing
VSS	Variable Service Subscription

(DGs), the prevalence of competitive electricity markets, the advancement of end-use technologies and control systems, and the advent of smart grids result in the reform of conventional DSM theoretical frame. Main DSM concepts has been itemized in [16] including energy efficiency, energy conservation (ENCON), and demand response (DR). These concepts are the significant facets of reformed DSM theoretical frame in the recent decade. Ref. [17] has provided a review of historical DSM developments in which the DSM has been categorized to energy efficiency, DR, and strategic load growth. As a general classification, DSM is divided into two wide-range concepts including energy efficiency and DR in [18] and [19] based on the impact of technological advances in smart grids and electricity market deregulation. Moreover, some papers have employed the concept of demand-side integration (DSI) to accommodate the concept of DSM with the modern concepts emerged after the deregulation of energy environment [20–27]. According to [17], despite these terminology alterities, the terms of electrical load management originated in the traditional regulated power systems are still used in the restructured power systems.

There are worthwhile papers that have focused on DSM [16,18,28–32]. Ref. [16] has reviewed the DSM programs designed and implemented in several countries. Ref. [28] has presented a historical review of DSM on the basis of the development status of power industry and electricity markets in China with energy conservation and emissions reduction scope. Ref. [29] has regarded DSM as a demand control technique and has overviewed the DSM methods with load management and tariffing scope. According to [29], the main goal of DSM is encouragement of clients to reduce power consumption during peak periods or shift of energy use from peak to off-peak hours to flatten the load curve. Ref. [30] has presented an overview of DSM strategies and technologies for mini-grids with energy efficiency and incentives scope. Peter Warren has proposed a definition for DSM after expressing contested definitions of DSM in [31]: DSM involves the technologies, activities and schemes on the demand-side in order to manage energy consumption or contribute to the attainment of energy policies such as gas emissions mitigation or energy balancing. Ref. [31] has reviewed DSM concept and its role in balancing mechanism as well as electricity market reform in the UK. Ref. [32] has presented a helpful overview on demand-side resources development from controllable loads to generalized demand-side resources which has a comprehensive regard to DSM; however, the classification of DR discussed in [32] follows the previous works. Some review papers published in the recent years, have mostly focused on a certain aspect of DSM. Ref. [33] has presented a helpful literature review about industrial energy saving via managerial schemes, technologies and policies. The DR has been well focused from different perspectives in many surveys and review papers [34–43].

Perusal of the papers published during past three decades exhibits a significant lacuna in theoretical frame of DSM due to the employing of various expressions and methods some of which lack clear definitions. Moreover, in many cases, the main difference between some methods have not been distinguished in the literature and these different methods may be appeared to be alike. Thus, the evolution of DSM's concepts and methods as well as the lack of explicit definitions of some concepts in the literature, imply the necessity of contriving an aggregated theoretical framework for this branch of energy management.

This paper presents a comprehensive review about DSM, clarifies the basic concepts, phrases, general subjects and practical methods of DSM by reconsidering the DSM theoretical framework. The conventional frame of DSM is reformed in this paper with particular standpoint to clearly describe the specific goals of known methods. The structure of the theoretical framework proposed in the present paper, may facilitate the analysis of applicable methods for implementers and participants.

The main novelties and contributions of this paper are listed in the following:

1. Some expressions such as ‘static’ and ‘dynamic’ methods are introduced for the first time.
2. The ENCON is analyzed with an individual and specific way on the basis of explicitness in definitions. In comparison with other papers, this concept is exactly clarified. For instance, the differences between the concepts energy saving, energy auditing, and energy recovery is clearly elucidated in the present paper.
3. The mechanisms, modes, strategies, and methods are separated in the proposed DSM theoretical framework.
4. The energy efficiency management (EEM) and energy consumption management (ECM) are separated and the relevant strategies are clarified.
5. Orderly power utilization (OPU) is separated from DR. These two concepts are comprehensively discussed.
6. In the present paper, the DR is associated with the integration of demand-side resources in power system operation. Thus, the proposed DSM theoretical framework involves the concepts of integrated resource planning (IRP), reliability, security and electricity pricing.

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