Electrical Power and Energy Systems 51 (2013) 153–161

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Integrating commercial demand response resources with unit commitment

H.R. Arasteh [a], M. Parsa Moghaddam [a,*], M.K. Sheikh-El-Eslami [a], A. Abdollahi [b]

[a] Faculty of Electrical and Computer Engineering, Tarbiat Modares University, Tehran, Iran
[b] Department of Electrical Engineering, Shahid Bahonar University of Kerman, Kerman, Iran

A R T I C L E   I N F O

Article history:
Received 31 October 2012
Received in revised form 18 February 2013
Accepted 22 February 2013
Available online 2 April 2013

Keywords:
Commercial exchange
Dynamic participation
Market-based demand response
Power market
Unit commitment

A B S T R A C T

This paper investigates the impact of demand response resources (DRRs) as the consequence of implementing demand response programs (DRPs) on power markets. Indeed, this paper incorporates commercial concept of DRPs with unit commitment (UC) to solve "unit and DR commitment" problem. This mixed problem will decrease the network operation cost by using of DRPs' potential to mitigate some UC constraints and avoiding some highly priced generation of units. Here, employing the proposed DRPs model is considered as a new concept in electricity market. In this paper, a dynamic approach is proposed for participating DR service providers in power markets in order to maximize their profits. This paper also aims to concurrently consider the aforementioned commercial DRPs supply model with the generators supply curves in the unit commitment problem, which is solved to minimize operational costs considering multifarious constraints. Performance of the proposed approach is investigated through numerical studies using a standard IEEE 10-unit test system. The results show the efficiency and advantage of the proposed methodology.

1. Introduction

In the strategic plan of International Energy Agency (IEA), demand side activities are introduced as the first choice in all energy policy decisions, because of their potential benefits both at operation and economic levels [1]. Demand response programs are short-term activities taken by customers to adjust their electricity consumption in order to mitigate the volatility of electricity market's prices; or reliability problems on the electricity network [2]. Cost and emission reduction, decrease of fuel dependency, increase in power system reliability, and an increase in revenues are some of the benefits resulting by implementing demand side management (DSM) programs [1,3,4]. There are three types of demand side management measures based on the overall purpose of the load management (LM) program [5]:

- *Environmental-driven programs*: Achieves environmental and/or social goals by reducing energy usage, deferring commitment of polluted units, leading to increased energy efficiency, and/or reduced greenhouse gas emissions.
- *Network-driven programs*: Deals with challenges in the electricity network by reducing demand in ways that maintain the system reliability in the immediate term and over the longer term, deferring or avoiding the need for distribution and transmission infrastructure enforcements and upgrades.
- *Economic/Market-driven programs*: Provides short term responses to electricity market conditions to reduce the overall costs of energy supply, increase the reserve margin and mitigate the price volatility.

Demand response is established to motivate changes in electricity consumption by end-users. Dramatic increases in electricity demand have made the use of DRPs more attractive to both customers and system operators [2,6–8].

DRPs are divided into three basic categories so-called, Time-Based Rate Programs (TBRPs), Incentive-Based Programs (IBPs) and Market-Based Programs (MBPs) as depicted in Fig. 1.

Each of these categories is consisted of several programs. Time-based programs include: Time of Use (TOU), Real Time Pricing (RTP), Critical Peak Pricing (CPP). These programs expose customers to varying levels of price exposure; the least with TOU and the most with RTP [2]. In TBRPs, the electricity price changes for different periods, so customers should adjust their consumption according to the time and associated tariffs.

IBPs consist of Direct Load Control (DLC), Emergency Demand Response Program (EDRP), Interruptible/Curtailable service (I/C), Capacity market Program (CAP). DLC and EDRP are voluntary programs, and if customers do not curtail consumption, they are not

* Corresponding author. Address: Faculty of Electrical and Computer Engineering, Tarbiat Modares University, P.O. Box 14115-143, Tehran, Iran. Tel.: +98 21 82883369; fax: +98 21 8288432.

E-mail address: parsa@modares.ac.ir (M. Parsa Moghaddam).

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http://dx.doi.org/10.1016/j.ijepes.2013.02.015

Nomenclature

Indices
j number of generators
i index of demand response service providers
k index of generators prohibited zones
t time index

Constants
Ω_i customer type
RD amount of required demand response (MW)
$SUC_{i,t}$ start-up cost of *jth* unit at time t ($/each switching)
$SDC_{i,t}$ shut-down cost of *jth* unit at time t ($/each switching)
N number of generators
T time horizon of unit commitment
N^{DRSP} number of demand response service providers
HSC_j hot start-up cost ($/each hot start-up)
CSC_j cold start-up cost ($/each cold start-up)
MDT_j minimum down-time of *jth* unit (h)
MUT_j minimum up-time of *jth* unit (h)
CST_j cold start time of *jth* unit (h)
D_t demand during hour t (MW)
$\underline{p_{j,t}}$ minimum generation of *jth* unit (MW)
$\overline{p_{j,t}}$ maximum generation of *jth* unit (MW)
$\mathrm{DR}_{i,t}^{\max}$ maximum value for DR service providers enabled DR (MW)

SR_t amount of spinning reserve in hour t (MW)
RUR_j ramp up rate limit of *jth* unit (MW/h)
RDR_j ramp down rate limit of *jth* unit (MW/h)
PZ_j number of prohibited zones of *jth* unit
$p_{j,k}^{Lower}$ lower bound of the *k*th prohibited zone of *jth* unit (MW)
$p_{j,k}^{Upper}$ upper bound of the *k*th prohibited zone of *jth* unit (MW)

Variables
DP demand response clearing price ($/MW h)
a_i, b_i DR service providers' supply curve coefficients
$\mathrm{DR}_{i,t}^{0}$ amount of sold DR by *ith* provider at hour t (MW)
$p_{j,t}^{0}$ power output of *jth* unit at hour t (MW)
$u_{j,t}$ on/off status indicator of unit j at hour t where 1 means on and 0 means off
T_j^U time during which the *jth* unit is continuously on (h)
T_j^D time during which the *jth* unit is continuously off (h)
SUI start-up indicator
SDI shut-down indicator

Functions
$F_{j,t}$ *jth* generator supply function
$F_{i,t}^{\mathrm{DR}}$ supply function of *ith* DR service provider
pf_i *ith* DR service provider profit function

penalized. I/C and CAP are mandatory programs, and enrolled customers are subjected to penalties if they do not curtail when directed. In IBPs, customers are being encouraged with independent system operator (ISO) or local utility to moderate their consumption. Moreover, MBPs include: Demand Bidding (DB) and Ancillary Service (A/S) programs. DB programs encourage large customers to provide load reductions at a price at which they are willing to be curtailed, or to identify how much load they would be willing to curtail at posted prices. A/S programs allow customers to bid load curtailments in electricity markets as operating reserves. In the market-based approach, all players are categorized in two groups: DR Service Users (DRSUs) as well as DR Service Providers (DRSPs). DRSUs need demand response to improve their business and system reliability while, DRSPs are aggregators and customers who provide DR to increase their benefit. This structure creates an efficient market for trading DR. As introduced in [9], DRPs is treated as a tradable commodity in the power market where, the demand response exchange operator (DRXO) collects both the aggregated demand and individualized supply curves. Then, it clears the supply and demand at a common price [9].

DR programs are faced with some important barriers to be successfully implemented in the network. Ref. [10] has raised some important barriers related to DR. One of these common failures of demand response is the inability of customers to continuously participate in DRPs so called "response fatigue". Demand response service providers are considered in this paper as entities to manage

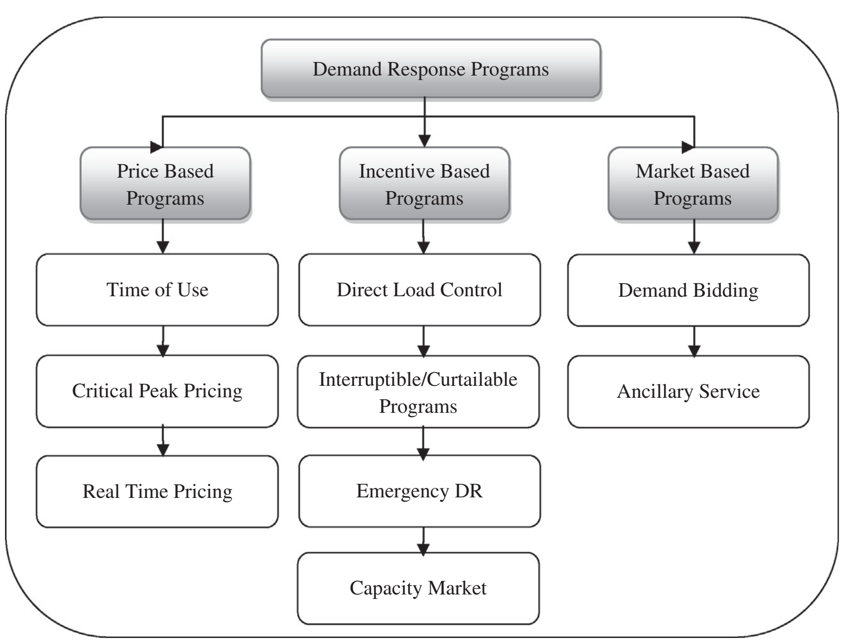

Fig. 1. Classification of DR programs.