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Security-Constrained Unit Commitment Considering Demand Response Resource as Virtual Power Plant

Dongyeon Lee*, Daehyun Park*, Jong-Bae Park*, Kwang-Y. Lee**

*Energy System Lab, Konkuk University, Seoul, Korea,
(e-mails: dongtae55555@naver.com; qkreogus87@naver.com; jbaepark7@konkuk.ac.kr)

** Electrical and computer Engineering, Baylor University, Texas, USA,
(e-mail: Kwang_Y_Lee@baylor.edu)

Abstract: This paper presents a new methodology to security-constrained unit commitment (SCUC) problem with demand response resource (DRR) which is regarded as virtual power plant (VPP). In this paper, based on DRR bids information submitted to Korea Power Exchange (KPX), price elasticity and peak load are calculated and DRR cost function is obtained. The scheduling includes generator characteristics, DRR and reliability constraints Cost functions for generator and DRR are modeled as a piecewise linear function and an Mixed Integer Linear Programming (MILP) based method is applied to solve the optimization problem. Proposed methodology is tested and validated on The IEEE RTS-24 system. Through numerical simulation, DRR has demonstrated the decrease in the total operation cost as well as the curtailment of peak load.

Keywords: Demand response resource(DRR), demand response resource cost function, security-constrained unit commitment (SCUC), virtual power plant (VPP), mixed-integer linear programming.

NOMENCLATURES

A. Indices

B Index of generating unit and DRR cost curve segment, 1 to B

i Index of generating units, 1 to I

l Index of lines, 1 to L

s Index of buses, 1 to S

t Index of hours, 1 to T

i_{dr} Index of demand response resources, 1 to I_{dr}

dr_1 Index of operating type that demand response resource i_{dr} used as load curtailment purpose

dr_2 Index of operating type that demand response resource i_{dr} used as load curtailment purpose

B. Parameters

B_{sm} Admittance of line connecting nodes s-m (S)

$d_s(t)$ Demand at bus s (MW)

$g_{dr1,i_{dr}}^{max}$ Maximum load curtailment capacity of DRR i_{dr}(MW)

$g_{dr1,i_{dr}}^{min}$ Minimum load curtailment capacity of DRR i_{dr}(MW)

$g_{dr2,i_{dr}}^{max}$ Maximum load shift capacity of DRR i_{dr}(MW)

$g_{dr2,i_{dr}}^{min}$ Minimum load shift capacity of DRR i_{dr}(MW)

$g_{dr1,i_{dr},b}^{max}$ Load curtailment capacity of segment b of cost curve of DRR i_{dr}(MW)

$g_{dr2,i_{dr},b}^{max}$ Load shift capacity of segment b of cost curve of DRR i_{dr}(MW)

$k_{i_{dr},b}$ Slope of the segment b of the cost curve DRR i_{dr}($/MW)

C. Variables

$C_i(t)$ Operating cost of generator i at time t ($)

$C_{dr1,i_{dr}}(t)$ Load curtailment cost of DRR i_{dr} at time t($)

$g_i(t)$ Generator I output at time t (MW)

$g_{dr1,i_{dr}}(t)$ Load curtailment capacity of DRR i_{dr} at time t (MW)

$g_{dr2,i_{dr}}(t)$ Load shift capacity of DRR i_{dr} at time t (MW)

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$g_{dr1,i_{dr},b}(t)$ Load curtailment capacity of DRR i_{dr} on segment b at time t (MW)

$g_{dr2,i_{dr},b}(t)$ Load shift capacity of DRR i_{dr} on segment b at time t (MW)

$x_{dr1,i_{dr}}(t)$ Binary variable equal to 1 if DRR i_{dr} is load curtailment at time t, and 0 otherwise

$x_{dr2,i_{dr}}(t)$ Binary variable equal to 1 if DRR i_{dr} is load shift at time t, and 0 otherwise

$y_{dr1,i_{dr}}(t)$ Binary variable equal to 1 if DRR i_{dr} starts the load curtailment at time t, and 0 otherwise

$y_{dr2,i_{dr}}(t)$ Binary variable equal to 1 if DRR i_{dr} starts the load shift at time t, and 0 otherwise

$z_{dr1,i_{dr}}(t)$ Binary variable equal to 1 if DRR i_{dr} stops the load curtailment at time t, and 0 otherwise

$z_{dr2,i_{dr}}(t)$ Binary variable equal to 1 if DRR i_{dr} stops the load shift at time t, and 0 otherwise

$\theta_s(t)$ Voltage angle at bus s (rad)

1. INTRODUCTION

In electricity market with increasing power consumption, attention toward demand response resource (DRR) has been growing because the construction of power plants and transmission lines are becoming increasingly difficult. In the past, supply should follow demand which had been already determined by external factors, such as temperature or socioeconomic activities. However, because technologies to control and measure power consumption are being developed and becoming into wide use, efficiency of power industry has been increasing via demand side market participation. Furthermore, The Department of Energy in Korea announced "2030 Extension Strategies for New Energy Industry" including the plan for environment-friendly processes, dispersion of electric vehicles (EV), and vitalization of energy prosumer market. Among these methodologies, vitalization of energy prosumer is being scheduled in two ways: the plan to increase efficiency of power system and the plan to extend the capacity of demand response market (DRM) to 5% in electricity peak load.

The DRM is new industry where electricity saved from the power saving facilities is being traded. Currently, the domestic DRM has saved 142,557MWh from November 2014 to May 2015, the amount that population in Sejong City of about 170,000 might have used for about 10 months. While high efficiency devices and Time of Use (TOU) was important subject for DRR in the past, only those resources which can improve reliability and economy in the power market are defined as DRRs because it is possible for consumer to respond to the price of wholesale power market. The DRRs can be distributed by its form and by its operation. While load curtailment resources and load shift resources are presented by its form, reliability demand response (DR) and economy DR are done by its operation. Reliability DR is the resource that must be reduced when the system operator commands in emergency situation. On the other hands, economy DR is the resource that can be reduced when consumer reacts to the market price.

Much studies considering DRR in Unit Commitment have been conducted. Hu et al. (2013) and Khodayar et al. (2012) formulated the optimal operating plan by using EV or energy storage system (ESS) as DRR in unit commitment. However, it has limited application to other studies because characteristics of specific resources are used. Wu et al. (2013) showed that DRR can be used as the cost reducing means when daily optimal schedule with generator ramping cost is conducted. Also, Zhao et al. (2013) showed that DRR can be used to accommodate uncertainties from wind power. Furthermore, it indicated that cost per 1MW decreases and social surplus increases as the price elasticity of DRR increases. Chandrasekaran et al. (2011) also showed that demand response maintains its reliability level when it is applied in a hybrid power system. However, this paper only considers time-based DR, not incentive-based DR. Chandrasekaran et al. (2011) quantified effects of DRR in electricity market. Based on market clearing mechanism, Khodaei et al. (2011) established unit commitment (UC) including DRR and system constraints under the objective function maximizing social surplus. However, the study solves the problem by making the bidding price of DRR constant.

Furthermore, some studies describe DRR as Virtual Power Plant, and establish UC. Govardhan et al. (2014) showed that cost function of DRR is made by utilizing incentive and penalty of each demand response program (DRP) and that UC is solved by using genetic algorithm. The study analysed the economics of each DRP, but did not consider system constraints. Focusing on peak shaving and minimization of operating cost, Yang (2015) established UC by particle swarm optimization (PSO) and dynamic programming (DP) after setting DRR cost function cheaper than peak generator. In general, it is difficult to adapt to other studies if DRR is considered as specific resources such as EV and ESS, Also it is difficult to formulate load shift resources if DRR is not considered as virtual power plant (VPP). The studies conducted till now does not take into account all system constraints and generator characteristic constraints. Also it is assumed DRR cost function as constant.

In this paper, based on DRR bids information submitted to Korea Power Exchange (KPX), price elasticity and peak load are calculated, and DRR cost function is made. Finally, the UC is established considering all system constraints and physical and institutional characteristics of DRR, where DRR is divided into load shift resource and load curtailment resource. The rest of the paper is organized as follows: The DRR cost function which is made by peak load and price