Demand Response in an Isolated System with high Wind Integration

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***Abstract*—Growing load factors in winter and summer peaks are a serious problem faced by the Spanish electric energy system. This has led to the extensive use of peak load plants and thus to higher costs for the whole system.**

Wind energy represents a strongly increasing percentage of overall electricity production, but wind normally does not follow the typical demand profile. As generation flexibility is limited due to technical restrictions, and in absence of large energy storages, the other side of the equilibrium generation-demand has to react. Demand Side Management measures intend to adapt the demand profile to the situation in the system.

In this paper, the operation of an electric system with high wind penetration is modeled by means of a unit commitment problem. Demand shifting and peak shaving are introduced to this operation problem. Demand shifting is modeled in two different ways. Firstly the system operator controls the shift of demand; secondly each consumer decides its reaction to prices depending on its elasticity.

The model is applied to the isolated power system of Gran Canaria. The impact of an increased installed wind capacity on operation and the cost savings resulting from the introduction of responsive demand are assessed. Furthermore, results from the different implemented demand response options are compared.

***Index Terms*—Wind power generation, Large-scale integration, Load management, Power system modeling**

NOMENCLATURE

Indices

p	Time periods, hours (alias p')
t	Thermal generators
do	Demand variation downward
up	Demand variation upward

Parametres

β	Relation of marginal price to cost
ε_b	Elasticity
B_{do}	% of maximum demand variation downward
B_{up}	% of maximum demand variation upward
$CFix_t$	No-load cost
$CVar_t$	Variable cost
COn_t	Start-up cost
$CNse$	Cost of non-served energy
COp	Operation cost with DSM
COp_{ante}	Operation cost without DSM
CTr_p	Transaction cost for upward demand variations
$MOff_t$	Minimum Off time
MOn_t	Minimum On time
$PTDo_t$	Ramp for generation unit downward
$PTUp_t$	Ramp for generation unit upward
$PTMax_t$	Maximum generation output
$PTMin_t$	Minimum generation output
$RsDo_p$	Down-reserve
$RsUp_p$	Up-reserve
$Uc0_t$	Initial commitment status
$PenPr_p$	Penalty for price
$PrRef_p$	Reference price
PI_p	Wind energy production
$DRef_p$	Demand without DSM

Variables

d_p	Variable demand with DSM
$dVar_{p,do}$	Demand variation downward
$dVar_{p,up}$	Demand variation upward
nse_p	Non-served energy
$off_{p,t}$	Shutdown decision
$on_{p,t}$	Start-up decision
pr_p	Price with DSM
$pt_{p,t}$	Generation over minimum output
$uc_{p,t}$	Unit commitment decision

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I. INTRODUCTION

RENEWABLE energies have been declared by policy makers as one of the pillars to combat climate change. Different incentive schemes are currently applied resulting in a significant growth of renewable energies. Wind energy can be ranked among the most advanced renewable technologies. This is one of the main reasons why it has become the renewable energy technology with the highest installed capacity in some European countries. With an increasing wind production, the electric energy system has to face new challenging situations. Uncertainty in wind predictions and volatility of wind energy production are among the main concerns of system operators. These are urging issues regarding the growing installed wind generation capacity and its priority use for demand coverage. Thus, investigation of wind prediction has to be increased to make wind predictions more exact. Apart from this, variability of wind electricity production has to be managed in the short-term adjusting both generation and demand. Fast-reacting generation technologies may cause higher system costs. So the best way to save costs is to reduce the amount of energy produced by costly peak plants. This can be done by either of the following ways. First, electricity can be stored in off-peak hours and used later during peak hours. Second, demand can be reduced during peak hours. Third, if consumption is inevitable it could be decreased in peak hours and shifted to off-peak hours. The first option requires using storage facilities. With the second and the third option the demand profile can be changed reacting to system conditions at short notice. This paper focuses on the cost-saving potential of changes in the load shape via demand reduction and load shifting in the short-term in unit commitment decisions. Load shifting objectives can be achieved via different reactions of demand. On the one hand load can be remotely controlled by the System Operator. On the other hand consumers can independently react to price changes. Both approaches will be compared in detail.

The remainder of the paper is structured as follows: Section II gives a literature review. Then, section III explains the modeling approach. A case study is analyzed in section IV and section V concludes.

II. Literature Review

In this section, first demand side management (DSM) will be defined and categorized in the following section. Second, different approaches to model DSM are mentioned. Last, specific studies are commented on.

Activities which aim to influence the demand profile, for example in magnitude and time of electricity usage, are called demand side management (DSM) programs. These programs may comprise six different objectives to change the load shape. Details of each one of them can be found in [1] and [2]. Peak shaving (or clipping), valley filling and load shifting are deemed to be load management objectives. Furthermore, the objective of a flexible load shape requires demand to become responsive to the conditions in the energy system, especially those related to reliability. The energy efficiency or strategic conservation objective aims at reducing the overall energy consumption. The last of the six mentioned objectives is called strategic load growth or electrification, which is interesting if market share is to be increased.

To reach one or more of the above named objectives, DSM programs must be implemented. These programs may have manifold forms. Some classifications can be found in [2]–[4] or [5]. Authors in [4] as well as [5] distinguish between three types of demand response: first dynamic pricing with time-varying prices, second interruptible and voluntary load reductions or economic load response, and third load as ancillary services. Dynamic pricing refers to different types of tariffs faced by customers. Among others, these may include time-of-use prices, critical peak prices or real-time prices. Time-of-use prices change according to different time periods while critical peak prices impose higher prices only in critical situations on a maximum number of times per year (as applied in France). Real time pricing, in contrast, transfers prices and thus system information to customers almost without time loss.

Load reduction programs imply that customers offer to reduce their consumption for a financial payment or a discount. This may include direct load control and interruptible load programs, energy buy-back programs with customers agreeing to reduce consumption and to receive an incentive payment, and demand bidding programs, where demand enters directly the wholesale market and offers load decrements.

Load may provide certain ancillary services as regulation reserves. There are many more possible measures like educational programs and subsidies on loans which will not be commented on here. Another concept on the notion of demand side management can be found in the literature: demand response. This term is used when the focus is on price responsiveness of demands. Demand response programs include mainly load curtailment and dynamic pricing programs [2].

In the following, specific studies of interest are resumed. Many specific studies have been carried out especially in the USA as there DSM programs were initiated already in the 70ies. An overview of the beginnings and experiences of Demand Side Management programs, especially in the USA, can be found in [2]. For descriptions of currently applied DSM schemes in other countries in Europe, Asia and Latin America the work of [6] may be of interest. The potential of DSM activities and other parameters such as price-demand elasticities, are assessed in [7]–[15] using empirical data. Models to express the reaction of demand to price are developed in [16]–[22].

An online database about the potential application and use of DSM in eighteen countries including Spain is presented in [7]. Authors in [8] evaluate and monitor a multi-country study about energy efficiency in the new member countries as well as the EU25, while [9] estimates the behavior of the demand system focusing on Spanish households. An extensive study about elasticities in different works and regions is carried out in [10]. This article provides a quantification of the real-time relationship between total peak demand and spot market prices. The ”Demand for Wind” project described by [11] shows results of field trials in UK of demand side management for domestic consumption. The work in [12] shows the benefits of applying different tariffs (time-of-use and real-time-pricing) in a small domestic test system in Ireland, where wind generation is becoming more important. Authors in [13] simulate a methodology of demand-side bid generation to a real university customer in Spain. The work of [14] presents customer-level demand for electricity by industrial and commercial customers purchasing electricity in the England and Wales electricity market. While former studies focused mainly on domestic electricity consumption the authors in [15] apply peak clipping and valley filling to different industries and analyze their cost saving potential.

The impact of demand side management in newly liberalized and deregulated electricity markets is issued by many authors such as those in [16] and [17]. Other authors measure different impacts on markets. Authors in [18] assess the impact of market structures on the elasticity of demand. They model the consumer behavior using a matrix with self- and cross-elasticities. In [19] the effect that more demand response would have on various market participants is investigated. Authors in [20] look at the ISO level and present a model for demand response programs assessing these programs, their goals and implementation. In the work of [21] price responsive distributed resources are simulated in a bottom-up approach via probability density function curve. In [22] it is argued that many demand management schemes do not take into account demand shifting, which they call rebound effect. They implement demand shifting for a small bus system and find great cost savings.