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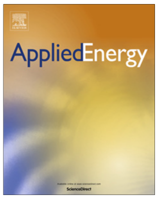

Demand flexibility versus physical network expansions in distribution grids

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HIGHLIGHTS

- Algorithm for optimal congestion management minimizing the DSO's total costs.
- Demand flexibility can be used to defer physical network expansions.
- Consumers offer their flexibility for a fixed, riskless benefit via our mechanism.
- Reduce DSO costs by using demand flexibility as a mean for congestion management.
- Regulation may be a catalyzer for demand flexibility to become a success story.

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ABSTRACT

The volumes of intermittent renewable energy sources (RES) and electric vehicles (EVs) are increasing in grids across Europe. Undoubtedly, the distribution networks cope with congestion issues much more often due to distributed generation and increased network use. Such issues are often handled by unit re-dispatching in short term and grid expansion in long term. Re-dispatching is, however, not always an appropriate solution for local distribution networks since the limited generation units are mostly RES of uncontrollable volatility. Recovering the incurred investment costs on the other hand would trigger an increase of the network tariffs. A possible solution is to defer such an investment by utilizing the demand side resources. The FlexMart model, developed and suggested in this paper, provides the ability for the Distribution System Operator (DSO) to purchase demand flexibility offered by residential consumers. Two feeders with different topologies are tested and the ability of the suggested mechanism to provide benefits for the involved stakeholders, both the DSO and the consumers, is demonstrated. The developed empirical model, works as a long-term planning tool and has the ability to provide an optimal combination of physical expansions and flexibility dispatch to reassure the stable and secure operation of the grid.

1. Introduction

Flexibility can be defined as the ability of a power system to utilize its resources to respond to changes in net load [1]. Demand side flexibility refers to the part of the load which is shiftable without violating comfort standards of the consumers [2]. Flexibility can be part of efficient strategies, such as to facilitate the integration of intermittent RES to the grids [3,4]. Moreover, the need to integrate more RES to the grids is continuously increasing, in an attempt to transition to a sustainable, cleaner power system. From a European point of view, the commonly adopted 20-20-20 goals described on the 3rd package [5], foresee a turn towards renewable resources in order to minimize CO2 and emissions of greenhouse gasses (GHG). The intermittent nature of these resources causes several issues, not only from a technical perspective but from an economic one likewise.

For the sake of consumers' comfort, the grid must have adequate capacity to provide the connected users with high-quality, uninterrupted power under any circumstances. However, the

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Nomenclature

n	node
t	time
l	line
c_{tot}	total cost [€]
c_{exp}	expansion costs [€]
c_{curt}	curtailment costs [€]
c_{flex}	flexibility costs [€]
c_{line}	expansion costs per unit [€/kW]
k_{exp_l}	volume of expansion [kW]
b_n	price benefit [€]
$curt_{n,t}$	volume of curtailed power [kW]
p_{imp_t}	volume of power imported through the feeder [kW]
$q_t^{D_n}$	optimal demand after flexibility dispatch [kW]
$q_t^{D_{down_n}}$	volume of down-regulated demand [kW]
$q_t^{D_{up_n}}$	volume of up-regulated demand [kW]
$f_{l.t}$	power flow [kW]
P_t	energy price [€/kW h]
$Q_t^{D_n}$	power demand [kW]
$C_{flex_{inv_n}}$	investment cost for flexibility [€]
ROI	return on investment rate [.00]
$PV_{n,t}$	output power of PV systems [kW]
CAP_l	initial line capacity [kW]
BP	base apparent power [kVA]
Θ_{n_i}	power angle [°]
Z_l	line impedance [Ω]
$COEF_{flex}$	flexibility coefficient [.00]

Abbreviations

RES	Renewable Energy Sources
DSO	Distribution System Operator
EV	Electric Vehicle
ROI	Return On Investment
GHG	Green House Gas
SO	System Operator
CAPEX	Capital Expenditure
OPEX	Operational Expenditure
LV/MV/HV	Low/Medium/High Voltage
NPV	Net Present Value
MP	Market Power
TSO	Transmission System Operator
IB	Incentive-Based
PB	Price-Based
DR	Demand Response
LINEAR	Local Intelligent Networks and Energy Active Regions
FLECH	FLExibility Clearing House
BRP	Balancing Responsible Party
GRASP	Greedy Randomized Adaptive Search Procedure
CHA	Constructive Heuristic Algorithm
MILP	Mixed Integer Linear Programming
AU	Aggregating Unit
PV	Photovoltaic
KPI	Key Performance Indicator

uncontrollability of the output level of RES increases the occurrences of congestion problems in the distribution grids. Investing in grid facilities, i.e. power lines, feeders and substations, is capital intensive. Moreover, considering the fact that these additional investments are utilized when load is peaked and hence only for some hours per year, the question which arises is if such an approach is actually efficient. The implementation of such a solution, however, becomes more difficult due to the increasing share of intermittent RES integrating to the grids. Another option would be to use a market-oriented approach instead of physical expansions or re-dispatching. Traditionally, flexibility has been provided by the generation side through a re-dispatching of units and starting-up of auxiliary units. Existing technologies allow a smart communication between the different actors of the power system. A solution which utilizes the available demand side flexibility could possibly provide an alternative to physical expansions [6].

This paper assesses the possibility of mobilizing residential demand side resources in order to defer physical expansions in local distribution networks. In order to empower consumers to offer their demand resources to the grid, specifically here to the DSO, the designation of an appropriate incentivizing mechanism is proposed. The incentives for the consumers come from either savings from price differences, i.e. shifting consumption from peak hours with high prices to lower priced hours; or by providing an adjusted fixed benefit. In this paper, flexibility is dispatched according to the needs of the DSO in order to minimize its required investments, while the flexibility remuneration mechanism is a combination of both approaches in order to limit the risks for consumers. The choice for such a regulated approach is motivated. A small local market can have a lot of capabilities and potential, however, it is assumed that it has limited liquidity. Consequently, market power can easily be concentrated and potentially exploited, exposing the market participants to risk. More details on the proposed mechanism are provided in Section 3.

The main contribution of this paper is the provision of a mechanism that valorizes fairly the demand flexibility resources, considering DSOs and consumers' best interests alike. The methodology used consists of two directions. First, the development of a conceptual market model and second, the development of an empirical planning model using mixed integer linear programming (MILP) on the GAMS software system. The selection of this twofold methodology, conceptual and empirical, is justified by the intention of the authors to conduct both qualitative and quantitative research on the topic. Following this introductory section, Section 2 contains the literature review in the context of flexibility markets and recent projects. The proposed pricing structure and modeling are analyzed in Section 3. Section 4 hosts the results obtained from the empirical model and a brief discussion on them, whilst Section 5 serves a conclusive purpose.

2. Literature review

Following the recent evolutions, distribution networks face various challenges. The continuously increasing penetration of the intermittent RES, the rising EV market and the fact that distribution grids were not designed to accommodate distributed generation add a lot of stress to the grid [7–9]. Despite its various benefits, distributed generation, RES and EVs might result in congestion issues [10–12] as well as policy implications [13]. Such issues hinder the stability of the system due to over-loading of the lines and may lead to involuntary load shedding, having hence a negative impact towards the security and reliability of the system [14,15]. Common approaches to relieve transmission networks include, among others, re-dispatching of generators and making use of control devices [16,17]. Unit re-dispatching is not applicable to a distribution grid since its generating units are primarily RES, whose output level is not controllable. Hence, one of the problems