



Assessing low voltage network constraints in distributed energy resources planning



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ABSTRACT

Many efforts are being devoted towards achieving optimal planning and operation of DER (Distributed Energy Resources). However, during the planning process, not all relevant thermal constraints of the distribution network are considered; some works claim that they must be taken into account, while others follow the single-node approach.

This paper assesses the effects of the distribution network thermal constraints in DER planning, using a deterministic linear programming problem to find the optimal DER planning and operation. Three case studies with different network topologies under several DER implementation scenarios are analyzed. A DC load flow is used to estimate the required network reinforcements to accommodate optimal DER investments, if any. Reinforcement costs are then calculated to assess the net benefit compared to limiting DER investments and operation, according to the network thermal limits. Results suggest that there is no significant economic advantage in limiting DER investments and line flows, compared to reinforcing the low voltage network to allow the larger flows that result from an unconstrained network problem.

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1. Introduction

Energy is one of the most demanding issues in current and future urban centers, especially considering the increasing complexity of its systems and sustainability requirements [1]. In this setting, DER (Distributed Energy Resources) stand as a promising alternative to contribute to sustainability, security of supply, and energy efficiency [2]. DER commonly refers to distributed generation (essentially based on renewable energy sources), but also in addition to distributed energy storage, and demand response strategies as well.

The benefits and requirements of these decentralized schemes have been widely studied. DER systems are presented in Ref. [3] as promising energy solutions, describing how their expected massive deployment would result in important changes in current power systems. In Ref. [4] it is pointed out how DER eases the integration of renewable energy and how, by using storage systems, the stability problems related with their intermittency and lack of dispatchability can be lessened.

Two main approaches have been adopted for DER planning: one from the perspective of the distribution system operators, and another from the perspective of retailers acting as aggregators. On the one hand, DSOs (distribution system operators) can better control the total aggregated resources, in theory providing more stability, quality of service [6] and energy efficiency to the grid (minimizing losses and network investments) [5]. This approach normally deals with high-to-medium voltage levels. On the other hand, aggregators can manage many DER owners, also known as *prosumers* (producer-consumers, [23]), optimizing the operation and planning of their systems in a coordinated way while partaking in the electricity and ancillary services markets [7]. Individual *prosumers* are not usually big enough to directly participate in the markets due to its entry barriers [8], hence the advantage of aggregating them to profit from wholesale market benefits [9]. In this sense aggregators concentrate more on consumers than on the network, maximizing individual and aggregated benefits, thus deal mainly with medium-to-low voltage levels.

When the DSO approach is applied, many studies focus on the impact of DER planning on the network operation and its expansion. A model planning the expansion of the distribution network considering sizing, placement and timing of DER investments and/or network reinforcements is proposed in Refs. [8]; [10], a

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Nomenclature

Sets

h	hour = 1–24
m	month = 1–12
y	years = 1 – <i>lifespan</i>
c	houses = 1 – <i>numHouses</i>
l	power lines on the network = 1 – <i>numLines</i>

Parameters

<i>lifespan</i>	expected lifespan for PV (photovoltaic) and HP (heat pump) systems in the study (years)
<i>numHouses</i>	number of houses (nodes) in the district
<i>numLines</i>	number of power lines in the district
<i>demandElec_{c,m,h}</i>	base electric demand curve for 12 representative days (kWh) in each house
<i>demandTherm_{c,m}</i>	total thermal demand for 12 representative days (kWh)
<i>hourlyPrice_{m,h}</i>	normalized electric hourly prices referred to the base price <i>costE_y</i> (%)
<i>costE_y</i>	electric energy base buying price at year <i>y</i> (USD/kWh)
<i>sellE_y</i>	electric energy base selling price at year <i>y</i> (USD/kWh)
<i>costT_y</i>	thermal energy base buying price at year <i>y</i> (USD/kWh)
<i>fixEpow</i>	access tariff for electric power (USD/kW)
<i>fixTpov</i>	access tariff for thermal power (USD/client)
<i>DNI_{m,h}</i>	direct normal irradiance at month <i>m</i> , hour <i>h</i> (W)
<i>lossesPV</i>	total electric losses in the PV system (%)
<i>lossesHP</i>	total thermal losses in the HP system (%)
<i>costPV</i>	total cost per installed watt of PV (USD/W)
<i>costHP</i>	total cost per installed watt of HP (electric power input) (USD/W)
<i>costBat</i>	total upfront cost of batteries, considering a replacement every 8 years (USD/Wh)
<i>OMfixPV</i>	fixed annual operation and maintenance costs per installed watt of PV (USD/W)
<i>OMfixHP</i>	fixed annual operation and maintenance costs per installed watt of HP (USD/W)
<i>COP</i>	coefficient of performance for the HP
<i>demandShift</i>	maximum allowed load to be shifted per day of the base electric demand (%)
<i>DRequipCost</i>	costs of equipment required in each house to do load shifting (USD/house)

<i>daysInMonth_m</i>	number of days in month <i>m</i>
<i>effBat</i>	battery charge/discharge efficiency ratio (%)
<i>lineCap</i>	maximum power line capacity

Variables

<i>powerPV_c</i>	installed capacity of PV in house <i>c</i> (kW)
<i>powerHP_c</i>	installed capacity of HP in house <i>c</i> (kW)
<i>elecEnergyInput_{c,m,h}</i>	electricity for thermal production with HP in house <i>c</i> at month <i>m</i> , hour <i>h</i> (kWh)
<i>gridEnergyBought_{c,m,h}</i>	electricity bought in house <i>c</i> from the grid to meet the demand at month <i>m</i> , hour <i>h</i> (kWh)
<i>boughtEnergyT_{c,m}</i>	thermal energy bought (natural gas) in house <i>c</i> from the grid to meet the daily demand in month <i>m</i> (kWh)
<i>ProdPV_{c,m,h}</i>	electric PV production in house <i>c</i> at month <i>m</i> , hour <i>h</i> (kWh)
<i>batCapacity_c</i>	installed capacity of the battery system in house <i>c</i> (kWh)
<i>SOC_{c,m,h}</i>	battery state-of-charge in house <i>c</i> at month <i>m</i> , hour <i>h</i> (kWh)
<i>disBat_{c,m,h}</i>	energy discharged from battery in house <i>c</i> at month <i>m</i> , hour <i>h</i> (kWh)
<i>chBat_{c,m,h}</i>	energy charged to the battery in house <i>c</i> at month <i>m</i> , hour <i>h</i> (kWh)
<i>gridEnergySold_{c,m,h}</i>	electricity sold in house <i>c</i> to the grid at month <i>m</i> , hour <i>h</i> (kWh)
<i>transferredEnergy_{c,m,h}</i>	electricity transmitted (surplus) from house <i>c</i> at month <i>m</i> , hour <i>h</i> (kWh)
<i>receivedEnergy_{c,m,h}</i>	electricity received (shortage) in house <i>c</i> at month <i>m</i> , hour <i>h</i> (kWh)
<i>decDemand_{c,m,h}</i>	decrease in base demand from <i>demandElec</i> of house <i>c</i> at month <i>m</i> , hour <i>h</i> (kWh)
<i>incDemand_{c,m,h}</i>	increase in base demand from <i>demandElec</i> of house <i>c</i> at month <i>m</i> , hour <i>h</i> (kWh)
<i>demandNew_{c,m,h}</i>	new consumption curve after changing the base profile of <i>demandElec</i>
<i>powElect_c</i>	contracted annual electric power in house <i>c</i> (kW)
<i>load_{c,m,h}</i>	total load (electric demand + <i>transferredEnergy</i> – electric production – <i>receivedEnergy</i>) at each house <i>c</i> at month <i>m</i> , hour <i>h</i> (kW)
<i>lineFlow_{l,m,h}</i>	total energy flow at each power line <i>l</i> at month <i>m</i> , hour <i>h</i> (kWh)

quantification of the impact of different penetration levels of distributed generation on distribution network costs is presented, analyzing three actual geographical distribution areas. Another relevant example is the Reference Network Model presented in Ref. [11] which is a large-scale distribution planning tool used to plan distribution networks from scratch or incrementally from an existing grid. This Reference Network Model is also used in Ref. [12] in combination with an algorithm that optimizes the location, size, and supply area of the medium-to-low voltage transformer substations with the objective of minimizing costs.

Unlike the above-mentioned models where the network is of prime importance, DER planning models from the aggregator perspective follow a very different approach. For instance, in Ref. [13] it is described as a commercial tool for optimal sizing and operation of DER in microgrids, with many applications in different research projects, such as those described in Ref. [9]. There are numerous examples of EV (Electric Vehicle) aggregation,

considered an interesting type of DER, given their energy storage capabilities. For instance, a mixed-integer linear programming model is proposed in Ref. [4], where an aggregator schedules the charge and discharge of EVs, maximizing the profit of the concerned agents while also taking into account energy markets, customer preferences and battery degradation. Similarly, two business models for aggregating EVs are comprehensively described in Ref. [7], including all the relationships between the different stakeholders that take part on the energy system. In this work, the capabilities of the EV as a DER system, and the potential benefits of aggregation are remarked upon. Nevertheless, these works commonly focus on the optimization and management of energy consumption, considering individual benefits only, and due to the small size of the applications, paying little attention to their impact on the grid.

For large DER penetration, the aggregator perspective could cause problems to the distribution power system producing

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