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Financial and environmental benefits of active distribution networks

Beneficios financieros y medioambientales de los sistemas de distribución activos

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Abstract

To identify the role and importance of local renewable energy resource integration on power distribution systems, this work presents a survey on how Active Distribution Systems capture benefits from this kind of energy resources. Also, this paper introduces the basic concepts of two economic tools that can help in the environmental valuation of local renewable energy projects, along with a discussion on the role of energy currencies in the development of renewable energy. As a conclusion, thanks to the advent of concepts such as “prosumer” and emergent technologies such as digital currencies, it is possible to achieve financial and economic viability for local renewable energy projects with the aid of Active Distribution Networks.

Keywords: active distribution networks benefits; energy currencies; energy management systems; environmental valuation; renewable generation.

Resumen

Con el fin de identificar el rol y la importancia de la integración de fuentes locales de energía renovable en sistemas de distribución, se presenta una revisión sobre las formas en las que los Sistemas de Distribución Activos pueden capturar beneficios provenientes de este tipo de fuentes. Además, se introducen los conceptos básicos de dos herramientas del área de la economía que pueden ayudar en la valoración medioambiental de proyectos de generación renovable local; y se presenta una discusión sobre el papel de las monedas basadas en energía para el desarrollo de las energías renovables. Como conclusión se tiene que gracias a la aparición de conceptos como el “prosumer” y tecnologías emergentes como las monedas digitales, es posible darle viabilidad financiera y económica a la generación local de energías renovables con ayuda de los Sistemas Activos de Distribución.

Palabras clave: sistemas de administración de la energía; beneficios de los sistemas de distribución activos; valoración medioambiental; generación renovable; monedas basadas en energía.

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1. Introduction

The microgrid concept evolved from a convenient backup system for power distribution [1] to a new paradigm for energy distribution systems in which generation (from a local energy source or storage device) is coordinated to supply local energy needs while behaving as a sole system [2]. Thus, microgrids appear as one of the enabling technologies for the inclusion of Distributed Energy Resources (DERs) into power distribution networks.

For low DER penetration, microgrids can optimally schedule their local generation. However, as the DERs penetration or the number of microgrids in a distribution network increase, the problem's complexity increases, since the independent local optimization of all DERs might lead to a suboptimal operation point from a system wide perspective. Therefore, to optimally coordinate multiple DERs in a power distribution system, there is a need to change the focus towards a more general approach: Active Distribution Networks (ADN) [3, 4, 5, 6].

Accordingly, in the same way a microgrid can yield to higher efficiency and reliability for a distribution network with low DER penetration, an ADN can be used to increase reliability and assure the efficiency of the operation of a distribution network in presence of higher DER penetrations. It is worth noting that the ADN objectives are accomplished through the coordination of the microgrid(s) and DER(s) connected to the distribution network, akin to how microgrids coordinate all its local DERs given a suitable communication protocol [7].

It is expected that such coordination schemes of DERs help to solve some of the problems that prevents local renewable generation to take a bigger share in energy consumption, namely, there are four main problems [8]: (1) generation cost is still too high, (2) there is not a common methodology to evaluate benefits, (3) intangible benefits (like social or environmental benefits) are usually reduced to emission mitigation, and (4) benefits are analyzed only in local scenarios. To those problems one should add the lack of an "adaptation process of the state-of-the-art technologies to local and regional scenarios" [9] which inhibit massification of needed technologies – this is why Gazoni *et al.*[9] recognize this element as a relevant goal for researches on non-conventional renewable energy sources.

Overall, it is expected that implementing active network management leads to a lower environmental impact and a higher benefit for every agent in the power distribution system. This is thanks to two main factors: (1) As presented in [8], in this very moment social benefits of local renewable generation compensates any cost disadvantage, (2) because ADN can translate economic and energetic efficiency to short/medium term benefits, hence, opening a way to increase renewable penetration in power distribution systems. Consequently, ADN are the enabling technology for the viability of high renewable energy penetration in future distribution networks.

Even more, a macroeconomic analysis can estimate the impact of such renewable penetration in primary energy consumption, allowing decision makers to find another way to account the value of the environmental and social benefits of local renewable generation.

This work presents the benefits that can be captured by introducing an ADN operation scheme into a power distribution network in addition to some methodologies to assess environmental benefits of renewable energy implementations. Some of the conclusions can be applied to the case of a microgrid or a distribution network with low DER penetration, but it will mainly depend on the specific conditions in which they might appear.

The paper content is organized as follows: Section 2 describes the types of benefits depending on the system participant (section 2.1) and some tangible benefits (i.e. associated with higher profits and savings for agents in the network) that can be captured in the short/medium term (section 2.2). Then, this paper introduces the basic concepts of two tools for environmental valuation of renewable energy projects (section 2.3). Section 3 have a discussion on energy-backed currencies, and finally, Section 4 presents some concluding remarks.

2. Benefits

Direct benefits of Active Distribution Networks are usually associated with bill reduction and system loss reduction. Consumers benefit from bill reduction and distribution system operator benefits from loss reduction, but, by taking advantage of those benefits, they can indirectly capture benefits such as enhanced reliability (for the consumer) and congestion mitigation (for the system operator). With the adequate incentives and property rights, these benefits can yield other benefits by allowing investment deferral, peak shaving and demand bids. Rigorous analysis must be done to avoid speculators overvalue these benefits and to avoid risk adverse stakeholders undervalue them, thus it is important an objective characterization of such benefits.

Note that benefits here presented are a general overview and not an exhaustive list of all possible price or economic signals that might support Active Distribution System deployment. Further readings on the topic include: A survey on economic signals for power distribution system in [10]; A survey on microgrid benefits that may serve as an introduction [11]; And the studies in [12, 13] which offers an extended insight on social-economic microgrid benefits. Further details of some of the benefits here presented can be found in [14, 15, 16].

2.1. Types

Types of benefits are described according to the agents involved. Like [14] proposes, here are treated four kinds of agents:

1. The customer is an agent that consumes energy from the system. Its benefits are associated to reduction in energy cost and constant supply of energy.

2. The independent power producer is an agent that generates energy in the system. Its benefits are associated to selling energy or services based on energy supply through contractual agreements.

3. The distribution network operator is an agent that assures the energy delivery service for all agents connected to the distribution network. Its benefits are associated to low cost and efficient operation over time.

4. The external agent is an agent who is outside or partially inside the system. It can be concrete entities like adjacent distribution systems and the power system operator; or it can be abstract entities like society and economy. Its benefits are associated to positive externalities due to efficient operation of the power distribution system.

In [17] the authors suggest that profit optimization for the independent power producer may lead to an overall optimization. To explore that concept, the independent power producer benefits will be described in the first place, to then explain how they may influence other agent benefits. This also will help to show the complexity of the benefits available in an Active Distribution Network [14].

2.1.1. Independent power producer benefits

There are two ways an independent power producer (IPP) could benefit in a microgrid: energy sales and service provision. The energy sales can provide some benefits by local production to a price higher than wholesale/spot market and lower than distribution system tariff; this is called the *local benefit* [14]. On the other hand, the IPP could set its strategy to sell when energy price is high and buy from the main grid to satisfy its demand when energy price is low; this is called the *selectivity benefit* [14]. Service provision consists of three services:

- *Balancing services*, which consist on selling active power support to keep system frequency under required limits. This kind of service also includes the reserve provision, which consists on an instant support of active power anytime the distribution system or the power system operator needs it [18]. In the latter case, the IPP sells its service through the reserve market [19, 15].

- *Power quality services*, which consist on selling reactive and distortion power support to keep system voltage and harmonic distortion under required limits [20, 21, 14].

- *Service quality services*, which consist on energy sales during an outage. This kind of service includes black-start support, system restoration support and reliability support [22, 19]. Both kinds can be transacted inside or outside the power distribution network.

2.1.2. Customer benefits

The customers can benefit from an energy cost reduction due to the local benefit or due to a downward pressure on electricity prices caused by an increase in the penetration of low cost local generation [15, 14]. Therefore, this benefit can be obtained if customer plays also as IPP or if the energy consumed is from an IPP.

Note that if the customer and the IPP are the same players, the IPP profit maximization yields to energy cost minimization, because the greater the difference between local and central energy costs, the greater the benefits obtained.

The same can be expected with the selectivity benefit, although it may have different minimum energy cost: In the local benefit case, the minimum energy cost is constrained to the operation cost of the local generator; in the selectivity benefit case, the minimum energy cost is constrained to the minimum price between central and local generation.

On the other hand, since energy cost savings depends on the load type [23], it is key to consider the consumption type and level of the demand to precisely estimate the expected reduction on energy costs.

Additionally, if continuity of energy service has value to the customer, the reliability service from an IPP could be used to increase the IPP benefits. Nevertheless, in a deregulated environment, efficient operation of this continuity energy service is possible only if the customer and the IPP are the same players and the IPP is allowed only to supply the load associated to its customer. Otherwise, there is a need to regulate the maximum outage energy price, since in a contingency the few local generators constitute an oligopoly inside the microgrid [6]. As a conclusion, unless the perfect competition conditions are met, *not* in all cases profit optimization of the IPP leads to an overall microgrid optimization.

2.1.3. Distribution network operator benefits

This kind of benefits can be summarized as actions that lead to a lower operational cost. Operation cost could be diminished by technical loss and congestion mitigation, thanks to in-site generation and consumption. This rises automatically the overall system efficiency. Also, the maintenance cost of equipment could be reduced by implementing controls with smoother transitions between operational states [15].

The distribution network operator (DNO) could also reduce the reliability compensations associated to service quality problems [22]. If reactive and harmonic active filtering is implemented within power electronic interfaces, also a better power quality could be achieved [20, 21, 14]. The DNO can encourage Independent Power Producer (IPP) to prefer a selectivity benefit strategy (see IPP benefits on section 2.1.1), by observing that price reactivity from the IPP could alleviate distribution system congestion, thus, reducing the amount of energy purchased in the wholesale market and/or deferring infrastructure updates [19, 14, 16]. System congestion reduction can also be translated to the power system operator to reduce the transmission costs due to constraints.

2.1.4. External benefits

So far, the benefits of the main participants were reviewed. Customers care about low cost and reliable energy service, IPPs care about big sales at high prices and DNO cares about low cost and efficient operation. None of the agents presented attempts to affect other participants, but, because of the complexity of ADNs and power transmission and delivery systems, they cannot avoid external impacts [14]. Here the focus is towards the positive impacts. On [6] is presented a full review of the pros and cons of ADN.

Until this moment, two positive external consequences have been presented: downward pressure due to high local generation penetration and power system congestion reduction by selling local energy at strategic time slots. Because local generation can take advantage of the natural resources, also a general reduction in pollutants can be achieved. State policies like pollutant vouchers (See [24] and [25] for a technical description) or pollution penalties can translate pollution decrease to/into benefit increase. Intangible positive consequences are lower infrastructure footprint, overall reduction of non-renewable source consumption and even an increase in employment [14].

After identifying all the important external factors, one can formulate what is call a social welfare maximization problem to correctly allocate the energy resources in the network. Depending on the available information and on the problem's complexity, this can be formulated as a multi-objective optimization, which in turn, might help to determine the set of benefits to be maximized to achieve a desired operation point. Other approach is to use *Mechanism Design Theory* to understand the circumstances needed to achieve such maximization, if possible.

2.2. Financial benefits accounting

As a matter of scope, this subsection presents the most promising tangible benefits. Because of their low regulation requirements, short-term/medium-term nature, ease of implementation and ease of gross benefit calculation, they are suitable for investment funding and business case developing. The following benefits were left out of this review:

- *Balance services*, which includes active power support and reserve support for the power system operator. References to start are [26] for an overview; and [15] and [14] for an introduction to possible applications.

- *System restoration support*, which implies system reconfiguration and coordination rules (not related with the steady state operation) that must consider adjacent systems (other power distribution systems or power transmission systems).

- *Harmonic power mitigation*, which consist in controlling total harmonic distortion within the system. An approach that does not require additional active filters to compensate the harmonic power is presented in [21]; there, Kang *et al*. attempts to solve the physical compensation problem from a technical point of view, but their approach has a clear impact on total harmonic compensation costs. A harmonic pricing based on a pollution market mechanism (see section 2.1.4) is presented in [27, 28] and a harmonic pricing based on harmonic losses is presented in [29].

- *Reduced maintenance*, which bases its results on analysis of equipment's failure times. Although without formal analysis of the failures times, in [30, 31] the authors present an initial approach focused in an expected longer battery life due to the smooth operation strategy.

- *Lower electricity prices*, which are a long-term effect of high penetration of microgeneration with competitive price. An introductory analysis is presented in [15].

- *Adjacent system benefits*, which can be counted as indirect benefits because of the existence of the Active Distribution Network (a positive externality). This topic was left out of the present review because it is the following step once the power distribution network with local renewable generation is efficiently operated. Hence, there exists a methodological gap that must be filled before moving forward. Those benefits are usually intangible at the short-term and rely on estate intervention for efficient allocation.

Tangible benefits described below are those related to price selectivity, reactive support, system reliability, loss reduction and investment deferral. Keep in mind that a second analysis stage with tools like Input-Output Analysis and General Equilibrium methods (see [32]) is needed to capture interactions and impacts of such tangible benefits on variables that behave like *public bads* (in contrast to *public goods* [32]), e.g., pollution.

2.2.1. Selectivity benefit

Energy purchases are made by utilities mostly through long-term bilateral contracts, however, a portion of them is through the short-term spot market. Covering those short-term purchases for the Distribution Network Operator in critical hours is a way to increase the benefits from a local microgeneration installation. Those kinds of benefits are constrained to the following conditions [15]: (a) The price per energy delivered must be lower than the spot market price, (b) the price per energy delivered has to be higher than the final customer price if the Independent Power Producer and final customer are different agents, (c) local generation has to be flexible and dispatchable. One may use the market price-duration curve (a curve that shows the time that lasted a specific spot price over the observation time window) to calculate the selectivity benefit potential [15]. If the Independent Power Producer (IPP) and the customer are different agents, the benefits might be reduced when there is no interest from the Distribution Network Operator (DNO) to avoid wholesale market purchases. If the DNO is interested, it could reduce the cost of spot market purchases by contracting the IPP.

Gil *et. al* in [15] present a selectivity benefit study with «four-year historic of the Ontario electricity market price» where the Independent Power Producer and the customer were the same agent. The price-duration curves were approximated by a power function ($f(x) = ax^b$) for the top 1000 hours of the year. The benefit calculated with this price-duration curves range between 3.52¢/kWh and 7.05¢/kWh for the data analyzed. The average (over the 11 most important cities) of residential electricity price in 2008 was 10.44¢/kWh --This information is available on line in the Canadian Electricity Association website: http://www.electricity.ca/media/Electricity101/Electricity101.pdf, page 54.

2.2.2. Reactive power support

An adaptation of harmonic compensation pricing presented in [29] could be implemented to reactive power pricing into Active Distribution Networks. Also, reactive power could be valued for minimum power losses by calculating how active flow changes affect the reactive flow within the network. In [20], this change ratios are measured with an index called *Lost of Opportunity Cost*. Albeit in that work only the methodology is established, future studies may try to evaluate its pros and cons as a real-time or market-based pricing mechanism. The idea behind this index is that if a decrease in active power increases the reactive power flow, then less active power could be transacted into the microgrid. Hence, the reactive power is priced by how much active power is no longer transacted into the network. In [14], there are some other mechanisms to reactive power pricing that follows the idea behind the LOC and the idea of standard reactive power regulation. Finally, Morris *et al.* in [14] highlight the feasibility conditions of reactive support into a microgrid. This kind of service depends on the actual characteristics of the network and the absence of a mandatory reactive power support, so the Independent Power Producer has a margin of active power increase by reactive compensation.

2.2.3. Reliability support

There are some benefits associated to service continuity (reliability); greater benefits come from power distribution systems with low reliability and high load density. However, today major applications lie on rural areas, where the service quality and load densities are low [13]. Thus, before any real implementation the investor must carefully estimate interruption rates and local generation installation costs. Such studies cannot be generalized (except for the methodology) because the success highly depends on regulation and utility characteristics.

In [33] it is presented the “hosting capacity” index as a way to measure the maximum allowable local generation a network can withstand without violating a given minimum performance criteria. Such criteria can be voltage magnitude limits on steady state operation as well as energy service quality index.

A simple accounting method of the reliability support benefit is presented in [16, 22] and [13] and annex 4 of [12] can be also consulted for further information. In [16], Costa *et al*. present the benefit based on typical reliability indexes without concerning the value of reliability itself. For a guide to outage valuation see [34]; moreover [35] analyzes problems of usual practices for reliability improvement valuation. Further information can be found in [14].

For a Distribution Network Operator (DNO), the reliability support benefits come from compensation reduction, and thus depend on current regulation. For an incentive mechanism based on Non-Delivered Energy (NDE), a high improvement for a low reference not only decreases the compensations but turns them into a reward [16]. Although the reward level is temporal for a moving reference, still this could be an important extra revenue stream.

2.2.4. Power loss reduction

Again, the price-duration curve could be used to calculate power loss benefits due to a local generation at each bus of the system [15]. The study in [15] reveals that the benefit is between 0.25¢/kWh and 8¢/kWh for a (reasonable) load reduction of 2%. The same 10.44¢/kWh for residential electricity customers can be applied as a comparison point.

One interesting result stated in [13] is that, for the same installed capacity, the higher the density of local generation, the lower the impact on system losses. This is reaffirmed in [36], where it is also asserted that three local generation units strategically located have the same effect on losses that an ideal case with more than three microgenerators. Quezada *et al.* in [36] highlight the impact of microgeneration with reactive power control, since a better voltage profile will reduce reactive power flow and, therefore, system losses. They also clarify, that although those results can be reproduced qualitatively, numerical value of the system losses depends on power distribution topology and load pattern.

2.2.5. Investment deferral

It consists on in-site generation for strategic loads, especially in peak hours to shift in time a feeder improvement [15]. In essence, this is the same approach of the selectivity benefit, but with a different set of rules, dictated this time directly by the Distribution Network Operator (in the selectivity benefit previously presented the rules were dictated by the power market prices and the customer). Therefore, if the investment deferral benefit does not overlap with the selectivity benefit, there are two possible revenue streams to be exploited. If there exists overlapping, the estate must develop regulations for fairly benefit allocation. It is worth noticing that the benefits for the investment deferral consist on the difference between the actual value of the investment and the present value of the future investment if the cost of the investment would not change [15]. There, future value does not consider changes in time, except those due to the money value.

In the study presented in [15], this benefit reveals a potential of 20¢/kWh (compare it with 10.44¢/kWh for residential customers) for covering near to six peak hours per week. However, that study assumes that the distribution utility does not incurs in costs for the local generation project. It is worth that this benefit has a strong dependence on the utility's cost structure, planning projects and infrastructure. In [37], it is shown that low density of microgeneration has a greater positive impact on this benefit. This is thanks to the complementarity between production patterns, which increase energy availability.

This benefit is akin to a short-term, low budget planning benefit, so for a more complete planning picture the reader could see [38] and [5]. Both treat reliability improvements as important criteria for benefit maximization: In [38] the reliability analysis is based on Expected Loss of Load and in [5] the reliability analysis is based on the number of curtailments. Finally, two expressions to investment deferral, one as a function of the load growth and other as a function of the installed capacity of the local generation can be found in [16].

2.3. Environmental benefits accounting

2.3.1. Local assessment

Valuation methods based on *stated value* (ask people about its value perception of an environmental service) or *revealed value* (correlate observations to valuate indirectly an environmental service) could be implemented to measure the value of an environmental service in a project, but as long as the first one has a strong subjective basis; and the latter needs some indirect value measure, its application in environmental valuation of renewable generation is difficult. As an alternative to those kinds of valuation methods Kuosmanen *et. al* in [39] use a Cost-Benefit analysis approach using *Data Envelopment Analysis* (DEA) to value the environmental impact of projects based on a measure of efficiency. Since this kind of analysis gives a price to each environmental factor, it is important to clarify that such prices assigned by DEA do not have real meaning, i.e. if an intangible cost equal zero does not mean that it is negligible. DEA prices serves as a qualitative comparison index between projects.

2.3.2. Global assessment

Input-Output Analysis (IOA) is a macroeconomic tool suitable for estimating whole economy behavior in the short term, since it ignores supply or price impacts on resulting demand or production. It can measure the environmental impact of Active Distribution Systems in terms of avoided non-renewable primary input energy consumption, while considering inter-industry relationships. Such avoided consumption clearly can be translated to pollution mitigation but also in costly generation replacement [32]. The IOA uses *transaction table*s as an input for accounting all the money an economic sector must pay to another. Such tables come from the national economy accounting system of a country and they give a standard unit to compare each sector. Moreover, interactions could be measured in physical units or in a combination of physical units and value.

3. Energy currencies

As an alternative to Feed-In tariff for renewable energy generation [40], some countries have begun to consider the energy credit concept [41]. The latter can lead to an even more disruptive kind of technology: energy currencies. This kind of technology allows to exchange injected energy not only with energy at another time –like the energy credit does– but also with other currencies [42]. In contrast to other «alternative coins» (*altcoins*) [43], energy currencies creation depends on the amount of renewable energy being supplied, and akin to those kind of currencies, all the transactions are managed in a decentralized fashion through a peer-to-peer validation using a transaction (and creation) database (e.g. «BlockChain» in the case of Bitcoins). Other common characteristics with *altcoins* are the protection against inflation and the reduced transactions fees [44]. However, using as starting point the analysis done in [42] and [45], there are two major advantages over such currencies: (1) Since renewable sources are inherently distributed and scarce, the economy effects of energy currencies can be designed to only affect local economy, without negatively impacting the macroeconomic stability, (2) Since energy currency creation depends on renewable energy injections, there is no a deflationary behavior. Furthermore, consumed and injected energy balance can be used to properly adjust the total amount of energy money, similarly to the proposed mechanism in [45], where it is suggested that *altcoin* creation must be ideally linked to nominal gross domestic product to have positive macroeconomic effects. Therefore, the value of energy money will be higher where there are low energy injections and will be lower where there are plenty of local generation, thus acting as a market signal for renewable projects. With this in mind, and despite the early stage of the development of energy currencies, they might be the proper tool to incentive renewable energy in a mature green energy market.

4. Conclusions

A review on benefits of Active Distribution Networks was presented. In this context, Active Distribution Networks appears as tool to capture as many benefits as possible from the local renewable energy. All this thanks to well known concepts like «prosumers» and demand response, and hopefully to the future inclusion of disruptive technologies like energy currencies.

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