DC Power in Buildings: Separating the Hype from Reality

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SUBJECT MATTER EXPERTS FOR QUESTIONS ON THIS TOPIC

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ARTICLE SNAPSHOT:

What has changed in our industry?
A groundswell of distributed energy deployments will usher in new possibilities for distributing power in buildings. The growth of direct current (DC) generation and storage resources has set the stage for a future in which power could be efficiently transferred between distributed energy resources (DERs) and loads within a building as DC. Firms such as Bosch and Cisco have begun embracing and commercializing the technology, but its future is still uncertain due to a lack of awareness and standardization, as well as other practical barriers.

What is the issue facing cooperatives?
Should it take hold, DC power in buildings would bring new challenges and opportunities for co-ops. It could serve as an enabling technology for DERs that may accelerate and amplify many of the challenges posed by distributed energy. For co-ops embracing the new products and services that DERs provide, however, it could also offer significant benefit by simplifying DER installations and reducing costs. DC could one day be a powerful ally for innovative co-ops shifting toward more consumer-centric, service-based business models.

What do co-ops need to know and do?
Co-ops that experience high member interest in DERs should monitor the standardization and commercialization of DC. Innovative co-ops are encouraged to start experimenting with the technology in micro-grid and commercial building DER pilots.

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THE EVOLUTION OF DC

A century ago, Thomas Edison and Nicola Tesla touted competing visions for the electric grid, Edison's based on direct current (DC) and Tesla's based on alternating current (AC). Even though some of the earliest power plants and distribution utilized DC, such as Edison's Pearl Street generating station in New York City, Tesla's vision for a centrally managed AC grid ultimately triumphed. But DC power still saw widespread use in select applications, including telecommunications networks, marine, and vehicles. Today, a growing community of researchers, energy efficiency advocates, manufacturers, and some utilities have been resurrecting Edison's DC concept for power distribution in microgrids and buildings.

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You may have heard buzz around DC before. In the past, supplanting ubiquitous, dominant AC power did not yield enough benefits to warrant a change to DC. Several recent trends and potential benefits are driving renewed interest in DC, including a continued shift toward local and distributed energy resources (DER). Plug-in electric vehicles (PEVs), batteries, solar photovoltaics (PV), wind generation, and fuel cells all produce, store, or consume energy as DC, requiring inverters to interconnect and synchronize with the grid. This step lowers efficiency, adds complexity, and increases equipment and installation costs. Eliminating this step by maintaining power as DC between generation, storage, and end loads in a building is a solution that simplifies installations, reduces part counts and costs, and improves power delivery efficiency. These gains may allow buildings and districts to eke more energy out of DERs — as much as 10 to 15 percent (CLASP 2016).

WHAT ABOUT DC ON THE GRID?

DC power is used today at two very different endpoints of the grid: high-voltage transmission and, increasingly, on the customer side of the meter. This article focuses on the latter development. High-voltage DC (HVDC) can transmit power long distances at lower capital cost and with fewer losses than comparable AC transmission and is particularly useful in tying disparate, unsynchronized AC grids together. It is increasingly common to see HVDC transmission to interconnect with large wind or hydro generation.

DC technology in buildings presents both risks and rewards for electric co-ops. It could amplify and accelerate emerging challenges that co-ops already face, but for those embracing the broader adoption of distributed energy and a shift toward a customer-centric services model, DC could also be a powerful enabling technology.

DERs are some of the fastest growing and most disruptive technologies entering the power system today, rapidly increasing the penetration of DC technology. In 2016 alone, PV installed costs dropped 20 percent, while U.S. installed capacity doubled (SEIA 2017). Though less mature, battery technology has declined in cost to the point that PV + battery systems are expected to reach grid parity in certain markets within a decade (RMI 2015), and storage mandates in jurisdictions such as California are helping to accelerate that pace. PEVs will continue to expand as battery prices decline and states, municipalities, and utilities invest in charging infrastructure. Though they only represent about 1 percent of U.S. passenger vehicle sales, PEVs saw over 35 percent growth in 2016 alone (Rapier 2017).

Energy production and storage through DERs represent just one side of the DC equation; DC also opens opportunities to optimize power delivery to today's electrical *loads*. When the grid first evolved, incandescent lamps and AC motor appliances dominated building load, but with the advent of solid-state electronics and controls, about a third of today's loads — lighting, office equipment, consumer products, and many

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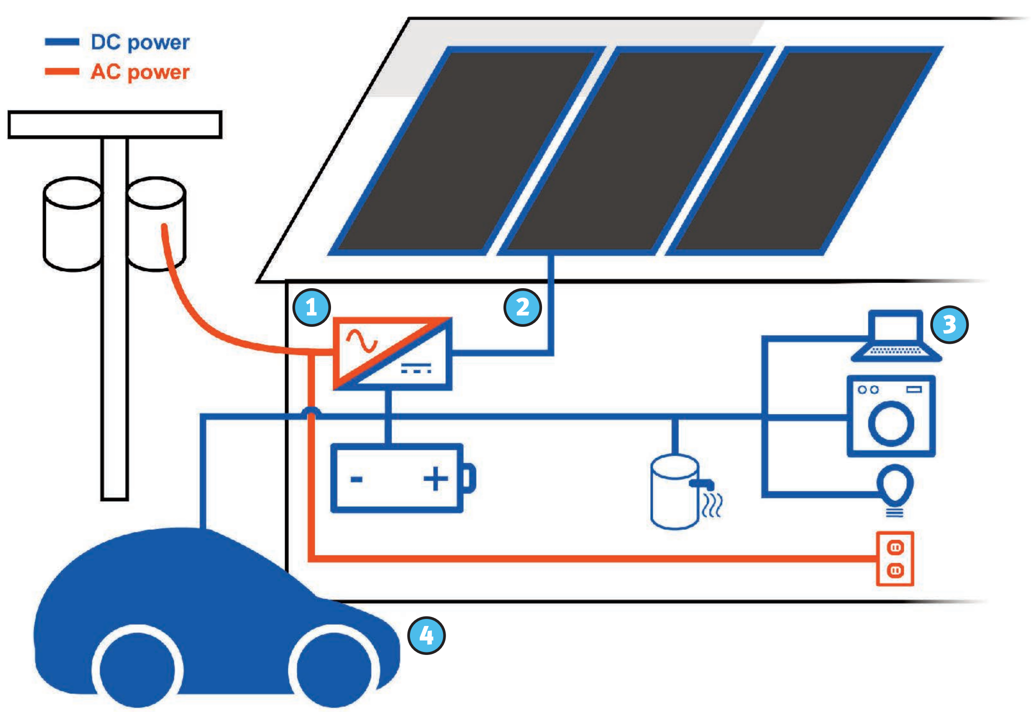
motorized appliances — requires DC power (CLASP 2016). The rectification and voltage conversion stages required to deliver DC power leave less power available to provide useful energy services. If those loads are being served by DERs, the losses compound as power may travel through several redundant conversion steps.

Despite the proliferation of DC endpoints on the grid and in buildings and the compelling benefits of DC systems, barriers to distributing DC power in buildings are still manifold. DC power systems lack the broad standardization and acceptance of AC technologies, even in areas as fundamental as voltage levels (although, as noted in the next section, stakeholders are making strides in this area). Outside of PV installations and a few niche applications, DC technologies like the ones described in this paper are not generally known or understood by building electrical designers and tradespeople, leading to increased project costs. Given the lack of field experience with the technology, there is no consensus on whether the approach is feasible in retrofit applications or merely new construction. Finally, given the billions of dollars invested in well-standardized AC infrastructure, it may be difficult to convince manufacturers and consumers alike to migrate to a new paradigm for energy savings alone.[1]

Although a move to 100 percent DC buildings is difficult to imagine, hybrid buildings with both AC and DC components may be possible, at least in greenfield applications. A bi-directional power converter provides a two-way bridge to the AC grid. Legacy AC loads or non-essential loads could still run on the AC side of the building's wiring (Figure 1). A home might one day tie refrigeration, communications equipment, and a PEV charger into a single DC system, using rooftop PV or the PEV's battery to power critical loads during emergencies. A commercial office building might use a similar system to power lighting and office electronics, for convenience, cost savings, and power resiliency.



1. Buildings remain grid-tied using a hybrid AC-DC system and a two-way converter.
2. Members generate and store energy on site using PV and batteries.
3. Loads like electronics and LED lighting operate directly on site-produced DC electricity.
4. Consumers who adopt PEVs charge (and discharge) their vehicles on the building's DC distribution system. Image adapted with permission by Collaborative Labeling and Appliance Standards Project.

FIGURE 1: A hybrid AC-DC building. *Image adapted with permission by the Collaborative Labeling and Appliance Standards Project.*

1 It may be possible and relatively easy to convert existing AC branch circuits, such as those used for overhead lighting, to DC using existing wiring. In commercial facilities, retrofits to occupied spaces may be facilitated by access to drop ceiling plenums.

TECHNOLOGY SNAPSHOT

Standardization

Industry-led standards currently provide a number of different DC “formats” suitable for use in buildings. Table 1 summarizes several of the most prominent standards.

Commercialization

DC power is used in buildings today where power and data must be simultaneously delivered on the same cable, such as with USB and Ethernet. Power-over-Ethernet (PoE) applications are limited to enterprise IT products, such as wireless access points and Voice-over-IP phones. USB-powered mobile devices are ubiquitous, and USB Power Delivery could expand coverage to other small electronics.

Several vendors have introduced DC power distribution and energy management systems designed for more general purpose power delivery, including Nextek and VoltServer. Tech giant Cisco introduced its Digital Ceiling platform in 2016 to enable smart lighting applications over DC-based infrastructure using standard Cat 5/Ethernet cabling. Bosch also now offers engineered DC microgrid systems aimed at the large commercial and industrial sectors.

Pilots

A variety of projects around the nation are currently piloting DC building technologies.

- **NextHome** – The NextHome, located in Detroit and run by NextEnergy, serves as a proving ground for residential DC technologies. It currently incorporates a variety of DC devices, including a PEV charger, PV system, battery storage system, appliances, HVAC, and lighting.
- **Colorado Sustainability Alliance DC Project** – The goal of the Alliance Center DC project is to demonstrate and quantify the benefits of retrofitting existing commercial office buildings to utilize DC. It will provide DC power to lighting, office electronics, and eventually HVAC, coupled to a rooftop PV + battery storage system. Early stage results are expected in late 2017.
- **Bosch EPIC project** – Bosch recently joined forces with the California Energy Commission and a Honda parts distribution plant to demonstrate and highlight the effectiveness of transforming large commercial warehouse buildings into renewable-based DC micro-grids.

TABLE 1: Examples of DC Power Delivery Standards

Standard	Application	Status
EMerge Commercial Buildings v1.0	First commercial building and campus requirements.	Pending
EMerge Occupied Space v2.0	Power distribution requirements for commercial interiors (tenant spaces).	Available
EMerge Residential v1.0	First residential building requirements.	Pending
NFPA 70, U.S. National Electrical Code	Various low-voltage DC (<1000V) requirements, including batteries, PV, grounding and bonding, and safety in the workplace.	Available
Power over Ethernet	Power delivery over Cat 5 Ethernet cabling at up to 25.5W (updates may allow up to 100W)	Available, with updates pending for early 2018
USB Power Delivery	Low voltage DC through USB cabling for small electronics at up to 20V and 100W	Available

AMPLIFYING CHALLENGES, CREATING OPPORTUNITIES

Whether DC succeeds in the marketplace or not, co-ops already face a host of rapidly evolving challenges in managing the future of their grid and the expectations of their members. PV is growing at its fastest rate ever (SEIA 2016), creating multiple planning, interconnection, and power quality challenges for co-ops. Third parties continue to present a dizzying array of new, connected DER opportunities, such as smart thermostats, battery storage systems, and electric vehicles, piquing member interest but straining already overburdened co-op staff resources. Meanwhile, long-term load growth is stagnant or declining in many regions (Fox 2017), forcing co-ops to simultaneously confront a host of technological demands from members alongside flat revenue. (See Table 2)

> **Just as it could amplify challenges for co-ops, DC could be a powerful asset to proactively address them.**

Would the adoption of DC fundamentally alter this picture? The simple answer is no. DC itself is just a platform for delivering power and data. However, the broader adoption of DC in buildings could amplify many imminent grid challenges by lowering the barrier to entry for DERs. DC could simplify and reduce the cost of DER installations, making the technology more "plug-and-play" through standardization. This would do for DERs what USB or HDMI standards have done for computers and entertainment. In addition, the efficiencies gained with DC and increased self-consumption of locally produced energy would put further downward pressure on energy sales.

TABLE 2: Emerging Grid Challenges and DC Impacts

	Trends	Additional Impact of DC
Distributed Energy Resources (DER)	• Strained capacity • Intermittency • Bi-directional flow	• Simplifies installations through standardized voltage busses, connectors, and protocols
Grid Management	• Intermittent local generation • Variable loads	• Enables dispatchable DERs and loads at grid edge and behind the meter
Energy Sales	• Increased load variability • Stagnant or declining energy sales	• Increased efficiency and self-consumption • Efficiently integrate DC-based loads for beneficial electrification

But co-ops can use DC for organizational and member benefit. Just as it could amplify challenges for co-ops, DC could be a powerful asset to proactively address them. By integrating power delivery and communications, DC can enable improved real-time monitoring and control of DERs, helping to mitigate several DER grid challenges described above. Such applications are possible without DC, but the technology could make integration simpler and more efficient. DC could similarly serve as an ally in beneficial electrification efforts by coupling to large, controllable loads such as PEVs, water heaters, and large appliances, many of which contain DC motors and controls.

ENABLING NEW OPPORTUNITIES

DC power use in buildings could offer a variety of benefits to members, while opening possibilities for new products, services, and revenue streams. A few potential use cases are described below.

Simplified DER Installations

Implementing DERs for homes, businesses, and larger campuses today is anything but a turnkey process. With DC power such installations will become significantly more "plug-and-play" through standardized voltage buses, connectors, and communications protocols. For co-ops working with local partners to integrate DERs on behalf of members, the technology could simplify the installation process, lowering overall program costs.

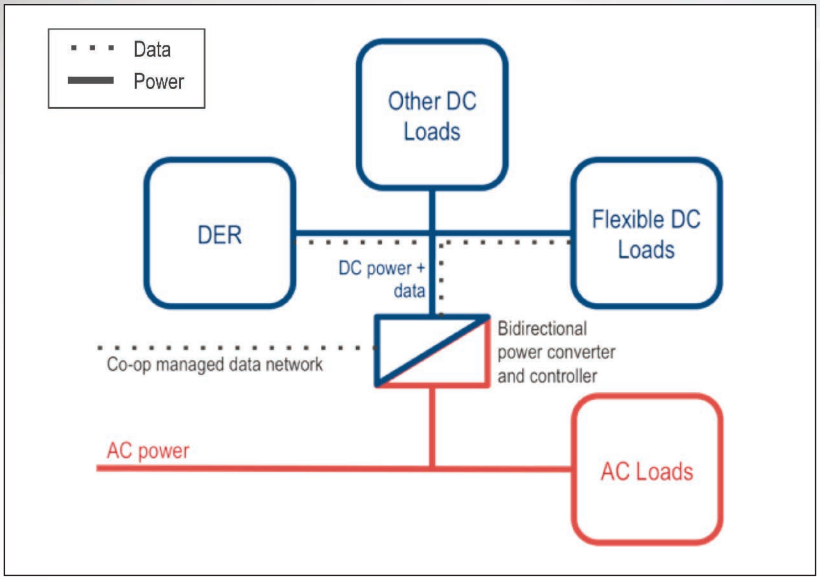


FIGURE 2: DC can deliver both power and data, allowing for better insight and dispatch of DERs and flexible loads. A bidirectional power converter or grid edge device would provide a critical integration point.

NRECA EVALUATES GRID EDGE DEVICES

Over the past four years, NRECA has provided support to develop and pilot a grid edge device that could provide significant grid management services to distribution co-ops. The GridBridge Grid Energy Router (GER) is a power electronic device installed at the distribution transformer with the ability to monitor power quality parameters and control power flow. Future iterations will also allow the direct integration of DERs like PV over a DC bus. By allowing for the direct integration of DER systems, it would eliminate inverters and allow the utility to more actively manage power quality and capacity constraints around DER installations. NRECA is currently piloting GER's monitoring and control capabilities in cooperation with Brunswick Electric Membership Corporation (BEMC) in North Carolina and plans to pilot DC DER integration capabilities in 2018.

FIGURE 3: GridBridge Grid Energy Router mounted on power pole

DC-enabled Grid Management Benefits

At this early stage, utilities are in a position to influence the DC roll-out in their favor. Unlike many smart home technologies, which often rely on third-party routers and broadband service for connectivity, DC technology could evolve as a natural extension of co-op data networks. Co-ops could own the bidirectional conversion equipment, perhaps eventually integrating this function into billing meters or transformers (see Figure 2). Coupling the DC system to utility-owned data networks would enable highly reliable insight and control of distributed services, such as "dispatchable" PV and battery storage systems (see NRECA's **Technology Advisory on dispatchable solar power**). DC-powered smart or flexible loads could later be placed on the DC bus to provide grid services, such as frequency regulation and demand response (see NRECA and partners' **Community Storage Initiative** for examples of these applications).

Advantages include:

- Critical dispatchable services would use a reliable, co-op owned and controlled communications system rather than third-party, member-controlled broadband.
- Dispatchable, DC-connected services could be placed on special incentivized rate structures.
- DERs and DC loads would be coupled using standardized communication protocols and data models, further simplifying data integration.
- Co-op assets could integrate other valuable services, such as power factor correction or voltage regulation, to manage power quality issues at the edge of the grid.

NRECA is already piloting a precursor to this concept using grid edge devices from GridBridge (see sidebar to the left), but the concept could also be adapted to behind-the-meter cases as well.

Selling DC as a Value-Added Resiliency Service for Members

As DER costs decrease, DC in buildings presents a value-added service that co-ops can provide for members interested in resiliency and self-generation. For example, members would pay an additional fee for locally generated, resilient power that is clean and 100 percent available to critical loads such as refrigeration, medical devices, and communications/IT equipment. A member's home, business, or even small campus would be outfitted with solar PV, generators, or other local DC generation sources. These would be coupled via DC to battery storage and tied to the grid through a co-op owned AC-DC bi-directional converter with islanding capability. Although resiliency can be achieved with an AC system, increased efficiencies of a DC mini-grid increases run time through an outage.

Highly innovative utilities are piloting very similar ideas today, and could do so more easily and cost-effectively in the future with DC. For example, Vermont-based Green Mountain Power (GMP) currently offers customers a program that combines energy efficiency retrofits, energy management controls like smart thermostats, rooftop PV, generators, and battery storage, for a fixed monthly fee. In GMP's case, the utility is actually disconnecting some customers from the grid who live at the end of problematic circuits to save on long-term equipment upgrades and maintenance.

PLANNING FOR THE FUTURE

Admittedly, widespread adoption of DC in buildings is not expected at any point in the near future. Still, with exponential growth in DERs, DC standards may increasingly enable some of the newest and most disruptive energy technologies on the grid. Given the uncertainties and the long timeframes involved, what should co-ops be doing to prepare themselves? Below we outline potential activities that co-ops can undertake around this topic over the coming decade based on their level of engagement (see Table 3).

Co-ops with a strong interest in shaping the future of DER deployment are advised to closely monitor and even participate in the DC standards-setting process. There is still ample opportunity to influence these standards for co-op and member benefit.

TABLE 3: Co-Op Participation Options Over Time

	Desired Level of Engagement in Behind-the-Meter DC	
	Low	High
Near Term (0-3 Years)	• Monitor DC research and standards developments process	• Participate actively in DC standards-setting
Medium Term (3-7 Years)	• Monitor DC standards and technologies that could impact DER deployments	• Actively pilot emerging DC technologies to enhance DER deployments
Long Term (7+ Years)	• Begin deploying proven DC technologies in DER deployments • Monitor utility and co-op pilots for new DC-enhanced services to incorporate into portfolio	• Actively pilot innovative services enabled by DC technologies

ADDITIONAL RESOURCES

EMerge Alliance: an industry coalition to promote and develop DC standards.

DC Nexus: an information clearing house for the DC microgrid community.

LBNL DC Project: a research project, funded by California's Electric Program Investment Charge (EPIC) grant program, to investigate design options for the integration of DC systems in residential and commercial buildings.

Demand DC: a white paper, funded by the Collaborative Labeling and Appliance Standards Project (CLASP), that explores use cases for DC power in the home.

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Dr. May-Ostendorp has been investigating emerging energy savings and distributed energy opportunities at the building-grid interface since 2004. He has authored dozens of publications on product efficiency, building controls, and smart systems, and his research has led to mandatory efficiency standards, voluntary labeling programs, and utility efficiency programs. He utilizes his expertise in building systems, building energy modeling, controls, and energy data science to research, develop, and evaluate new clean energy technologies on behalf of diverse clients from the public and private sectors. He lives in the foothills of the San Juan Mountains with his wife and three children in Durango, CO and is a member of La Plata Electric Association.

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