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Berkeley Lab's Comments - RFI DC Power System (23-ERDD-01)

Please see attached.

Additional submitted attachment is included below.

August 7th, 2023

California Energy Commission
Docket Unit, MS-4
Re: Docket No. 23-ERDD-01
715 P Street
Sacramento, CA 95814-5512

Re: Lawrence Berkeley National Laboratory Response to Request for Information - Direct Current Power Systems

Berkeley Lab is pleased to present our response to the CEC's Request for Information - Direct Current Power Systems. See response below:

DC Components, Equipment, End-Use Devices, and Technologies

1) *What DC components and equipment are needed to enable more efficient integration of DC devices with other DC devices? What is the current TRL of these devices? What specific research is needed to advance the TRL (e.g., design work, laboratory testing, pilot and/or commercial demonstration)?*

DC works very well today in motor vehicles (conventional and electric), inside of most consumer devices, and with digitally managed technology such as USB and Ethernet. What inhibits it today is a lack of power distribution standards for power-centric applications (rather than data-centric as with USB and Ethernet). Without standards, integration is completely cost-prohibitive. Technology standards don't map perfectly to the TRL construct; the related standards would need design research in order to move relatively quickly through to higher TRL stages.

The most impactful DC equipment would be a set of DC-ready loads and appliances. Nearly all types of loads are internally DC, and DC-input versions of AC loads are almost always simpler and cost less. Buildings today are AC, thus the market for DC-input loads is limited. However, due to the lack of DC loads, developers will continue to make AC buildings. This is the chicken-and-egg problem of the DC industry. With a standardized bus voltage, standardized connectors, and several options for DC loads, developers can confidently switch to DC.

2) *What are the TRL, cost effectiveness, efficiency, and availability of the following technologies?*

a. *DC-DC converters that provide high voltage and high current to enable high power transfer or bi-directional transfer between various DC equipment.*

This depends on the definition of high voltage. For the 380-1000 V range (technically low voltage, but high in a buildings context), bidirectional DC-DC converters can be found, but not easily. Many companies have developed application-specific converters, e.g. DC-coupled EV chargers, etc. DC microgrid design may be facilitated by upcoming tools like DEP's DCIDE tool.

b. *Solid-state transformers for integration of renewables, EV, and energy storage.*

Today, these are mostly custom parts.

c. *DC revenue-grade meters to measure, collect, and store real-time data for DC power systems.*

The Emerge Alliance led the development of an ANSI standard for revenue grade meters. That sets the stage for commercial DC meters.

d. DC power systems for buildings that can be directly coupled withDERs to reduce energy losses with fewer redundant stages of power conversions.

An increasing number of companies are offering this with proprietary integrations between PV, storage, and (sometimes) EV charging, but the real need is standards-based DC-coupled systems. This would greatly increase the value of such systems and drive cost reductions.

There are also several small companies that offer 48V DC power distribution, often with the options to add solar panels or battery storage.

e. DC-based end-use equipment (e.g., refrigeration, cooktops, lighting, motor-driven loads) that can be integrated into an efficient DC-based power system.

These all exist but suffer from relatively high prices from low sales volumes (not from any reason tied to DC itself).

They also face a lack of standards for DC power networks that they can connect to (in terms of voltages, wiring, connectors, and digital power management protocols).

DC Adoption Pathways and Use Cases

3) What are the most likely commercial applications for DC-based power systems in the short (3-5 years) and long terms (5+ years)?

It is important to recognize where DC distribution is already successful, which is with USB and Ethernet; technologies which provide a communications path along with the power, and, separately, digitally manage the power flow across the link. The interoperability enabled by standardization and the features that are enabled by digital management are reasons why companies use these technologies. Critically, these technologies are global.

Two very different areas are likely the soonest adopters. One is highly engineered systems, such as in data centers, inside of motor vehicles (this is a reality today), tightly coupled PV/batteries/EVs, and new construction for fixed devices (e.g. lights, fans, etc). The second is highly un-engineered systems, e.g. convenience wiring as with USB-like outlets, and running power where the relative safety and small wire size of DC is a benefit. These are not building-type specific, but rather derived from the characteristics of the power distribution context.

LBNL published an analysis of likely near-term applications for DC power in a conference paper (Vossos, Vagelis, Melanie Gaillet-Tournier, Daniel Gerber, Bruce Nordman, Richard Brown, Willy Bernal, Omkar Ghatpande, Avijit Saha, Michael Deru, Stephen Frank. 2020. *Direct-DC Power in Buildings: Identifying the Best Applications Today for Tomorrow's Building Sector*. Proceedings of the 2020 ACEEE Summer Study on Energy Efficiency in Buildings in Asilomar, CA. Washington, DC: American Council for an Energy Efficient Economy. August. https://escholarship.org/uc/item/1cm0s5nw.), and a journal article (Vossos, Vagelis, Daniel L. Gerber, Melanie Gaillet-Tournier, Bruce Nordman, Richard Brown, Willy Bernal Heredia, Omkar Ghatpande, Avijit Saha, Gabe Arnold, and Stephen M. Frank. 2022. "Adoption Pathways for DC Power Distribution in Buildings." Energies vol. 15, no. 3: 786. https://doi.org/10.3390/en15030786).

While it may still be difficult to develop or retrofit fully DC buildings in the next 5 years, there are reasons for a hybrid AC + DC building. In general, plug loads will be difficult to transition to DC, but hardwired, lighting, and appliance loads could easily be transitioned to an internal DC microgrid. This can have advantages in efficiency, cost, and resilience, particularly in buildings with DC-coupled solar and storage. However, the greatest advantage is that it can serve to reduce the utility interconnection requirements. Consider a home with a 100A panel and natural gas space heating, water heating, cooking, and vehicles. If this home intends to electrify, it would need a panel upgrade, which could be up to $20k and take more than a year. The home could instead use a DC microgrid with electric versions of these loads coupled directly to solar and storage. The DC microgrid would connect with the rest of the home through a low-capacity bidirectional inverter, usually eliminating the need for a panel upgrade. One example is the dcbel, which combines solar, storage, and 2 EV fast chargers in a DC microgrid with a low-capacity grid connection.

The panel upgrade problem is considerably worse for EV charging depots. The utility interconnection agreement for EV fast chargers can add hundreds of thousands to the cost of a project, and often takes 3 years to execute. An amazing application for DC today is an off-grid solar/storage/EVSE depot microgrid.

4) *What are the recommended ideal locations (e.g., where on the distribution grid, geographically, or at particular facility types like EV supply equipment stations) to deploy DC-based power related demonstrations and what technology(ies) would ideally be demonstrated?*

To avoid extra AC/DC conversions, DC is best used within generation facilities, or within customer sites. Any site that can integrate PV, storage, and EVs is a good candidate. Loads will be added once we get appropriate standards.

5) *What kind of buildings/facilities are the best fit for early DC-based implementation and why?*

Per the answer to Q3, the context of the individual devices is much more important than the building type.

6) *What are potential DC adoption pathways for residential and commercial buildings, and how could we structure a solicitation to best inform that transition to greater adoption?*

DC today has been successful in engineered systems (e.g. internal to a vehicle), where the integral data or convenience are valuable (e.g. powering a camera), or where the ease of running DC wiring reduces costs (e.g. low-voltage DC or fault-managed power).

Per Q3, another great adoption pathway is to use an internal DC microgrid to avoid the need for a panel upgrade. Often this is relevant to adding new EV charging (e.g. dcbel), and quite nice for V2B applications.

7) *What research is required to directly connect an EV via a DC bus to a residential/commercial building allowing for a more flexible and efficient bi-directional power flow? What components/equipment and research are required to accelerate the adoption of DC bi-directional power flow equipment in residential/commercial buildings and improve the overall system efficiency?*

A “DC bus” is a construct from the pre-digital era with little or no utilization of power electronics. While that may well have use in the future, alternative architectures may become even more important. USB and Ethernet, for example, do not use a bus model. Technology standards are essential for progress; research into how to form those standards is a much needed first step.

To connect an EV battery with the microgrid DC bus, we simply need a galvanically isolated bidirectional DC/DC converter. These are simpler and require fewer components than their AC/DC counterparts. Today it is difficult to find such products with built-in communications and EVSE software, but early adopters have instead programmed generic isolated DC/DC converters.

8) *What are the research opportunities to demonstrate DC building blocks for a local DC microgrid that increase the overall system efficiency and reliability when compared to a similar AC system?*

Such DC systems exist today. The central research questions are about what system architecture(s) to support and what technology standards are needed.

Near-Term (3-5 Years) Opportunities

9) *What are the high priority DC-related technologies and/or research needs to successfully integrate or transition to DC-based power distribution networks?*

The question needs to be clearly disaggregated into three domains: High Voltage DC transmission, DC for neighborhood-scale distribution, and DC internal to individual customer sites. The latter needs to be divided into high-voltage (e.g. 350/380V and multiples thereof) and 48V.

In addition to developing bus voltage standards, we will have to develop and standardize a DC plug-load connector and receptacle format. Ideally it will be a global standard that is as permanent as NEMA 5-15. Right now, the Anderson Power Safe-D-Grid is a popular choice, but such will have to become an open standard if it is to be globally accepted.

10) *What specific DC equipment (e.g., DC-DC converters) and components are required to serve as an enabling device for the integration of DERs with a microgrid or DC-related infrastructure?*

A DC microgrid can be developed entirely with three types of equipment. (a) DC-DC converters are the basic building blocks to integrate solar, storage, and loads. A DC microgrid will contain many such converters of various sizes. They are almost always more efficient and lower cost than their AC/DC or DC/AC counterparts. These converters must achieve sufficient market penetration such that they can replace AC/DC. Some loads, such as motor loads, do not require a DC-DC interface. EVSE DC-DC converters must be galvanically isolated. (b) DC protection must be standardized and trusted. There are a number of candidate technologies/methods such as arc extinguishers, solid state breakers, hybrid breakers, and converter blocking. We just need to write into code which is allowable/applicable for what type of protection stage. (c) DC microgrids perform best with a controller, whether it be centralized or distributed. A controller is not necessary, but with one, the DC microgrid can perform demand response and manage a fleet of attached distributed energy resource assets.

a. *What are the research opportunities to advance the TRL to simplify the interconnection of microgrids to the grid in one package using only DC-DC related components and equipment and eliminating DC-to-AC followed by AC-to-DC conversion?*

We need (a) a greater market for DC/DC converters, and (b) design tools such as DCIDE, which make it easier for designers to select and place components in their system, and (c) standards and codes for what types of components can be placed where.

11) What advancements are required in power electronics to enable DC and mixed DC/AC microgrid topologies that can reduce power conversion, increase efficiency, and improve reliability?

Better GaN and SiC integration will help in the power electronics world of tomorrow. More affordable fabrication processes are necessary.

13) What are the enabling or emerging technologies that can:

b. Accelerate DC-based power distribution networks for efficient DC-DC integration of DERs?

For resiliency and to facilitate electrification of end uses, people are looking at integrating energy storage into end-use devices (e.g., Channing St Copper's induction range). These storage-integrated appliances are more cost-effective than traditional centralized storage, and are easier to implement with a DC power network. Research is needed on methods to coordinate the operation of storage distributed throughout buildings (within appliances, powering individual circuits, or integrated with generation). LBNL has conducted a techno-economic analysis of distributed storage here: Gerber, Daniel L., Bruce Nordman, Richard Brown, Jason Poon. 2023. "Cost analysis of distributed storage in AC and DC microgrids." Applied Energy. vol. 344, 121218, https://doi.org/10.1016/j.apenergy.2023.121218.

14) What are the opportunities for EVs to directly support a residential/commercial building directly via a DC bus that eliminates the requirement of an inverter and increases system efficiency and reliability?

Perhaps the greatest advantage of such systems is that by being only loosely coupled (through a small electrical connection) to the AC power domain in a building, permitting from the utility grid can be eliminated.

Longer-Term (5+ Years) Opportunities

15) What are the opportunities for standardizing DC voltages and system design across various DERs, end uses, and DC plug-in electric vehicle chargers? How can research help to accelerate this process?

The issue is not picking a voltage, but rather defining an entire technology standard that covers voltages, current levels, cabling connectors, power distribution communication, general data communication, etc. At 48V there is no point in pursuing non-digital approaches. For 350/380, there may be merit to both analog and digital technologies; this is a research question. For analog, the U.S. should collaborate with the Current/OS effort in Europe. The goal would be to develop DC distribution standards that can power a wider range of equipment in buildings, are lower cost, and offer more features than today's standards (such as PoE and USB).

16) What areas of research are required to potentially accelerate adoption of DC buildings and related technologies by residential and commercial developers and customers?

- Very little can be done without technology standards.
- After standards are available, load manufacturers will have to start research and development of DC loads.

17) What pertinent data (e.g., performance and cost) are required to accelerate large-scale commercialization and deployment of DC-based end-use equipment?

There is a need to develop energy and power quality metrics and methodologies for assessing power distribution systems in buildings, and to develop these into industry standards. Beyond energy and power quality, additional M&V procedures must be established to study and compare the cost, safety, and reliability between DC and AC buildings. In addition, further research should assess the value of features specific to DC microgrids, including managed power distribution, distributed storage, and combined data and power. (Gerber, Daniel L., Omkar A. Ghatpande, Moazzam Nazir, Willy G. Bernal Heredia, Wei Feng, Richard E. Brown, "Energy and power quality measurement for electrical distribution in AC and DC microgrid buildings", Applied Energy, vol. 308, 2022, 118308, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2021.118308).

18) What current or upcoming communication standards or protocols should be demonstrated and/or developed to ensure successful DC-DC integration and interoperability?

DOE is currently funding work to develop a 48V DC digitally managed distribution standard, to address the complexity and cost of existing standards such as PoE and USB. This should be foundational and the CEC could help with research, standardization, and market transformation. For 350/380V, the Current/OS (https://currentos.foundation) effort should be built on. A digitally managed technology standard for 350V and up is also needed, but not currently in development. It may be able to leverage principles and technologies from the 48V standard in development.

19) What specific codes and standards will the deployment of a DC-based power system help inform?

Once the technology standards are in place, the NEC should be updated to clarify how they are to be treated. It is too early to tell if any CA building codes or titles will need to be updated.

Safety and Protection

20) What power electronic solutions are needed and required to enhance the safety of a DC microgrid?

Protection for DC microgrids is complicated due to the lack of a natural arc extinguishing feature present with the zero voltage crossing in an AC waveform. Candidate topologies have been developed and researched, including arc extinguishers, solid state breakers, hybrid breakers, and converter blocking. We will need to develop guidelines on which can be used in place of what types of protection.

21) What protection equipment is needed to interface with a DC/AC microgrid that will enable the reliable operation of the microgrid during disaster events?

AC microgrids require an ATS. DC microgrids do not. Their bidirectional gateway DC/AC converter is sufficient for this role. In fact it performs better; there need not be any down time between a grid interruption and system islanding.

22) What are the opportunities to advance DC components/equipment to improve the protection and coordination and increase the resiliency and interoperability of multiple connected DERs?

Each microgrid company has its own proprietary software for how it handles microgrids with multiple DERs. However connecting new equipment is not easy; these companies need to attach controllers for each DER to be connected. The ideal eventual solution is to have a unified standard like Matter or a mandated set of registers such as Sunspec. Something like Rule 21 would eventually be useful to standardize registers for monitoring and control of DERs and loads. In particular, loads may start to contain batteries.

23) For DC-DC converters, what are the safety mechanisms (e.g., NFPA 79) that are required in manufacturing, and how can research help address issues related to fire protection and health and safety?

Nationally recognized testing labs such as UL should be sufficient to test for safety. UL is extremely expensive and is a huge barrier for small companies; it would be nice for them to have more competition. DC equipment may be increasingly installed within walls with greatly limited thermal coupling, making it difficult to vent heat due to electrical loss. It’s important to specify what can be installed in a wall and put specifications on its allowable losses.

24) What emerging technologies can be demonstrated to reduce the safety and electric shock risks associated with higher DC voltage operations?

With digitally-managed power, connected devices can communicate before a high voltage line is energized, rather than leaving circuits energized continuously. This can address arcing and some safety issues. The same can be done for when cables are removed from a connector.

“Fault-managed power” (e.g., VoltServer) has emerged as a way to safely distribute high voltage power without costly safety requirements such as wiring in conduit. The solutions available in this area are all proprietary and no standard exists. They also tend to have high energy losses and the components are expensive. CEC could consider funding the development of an open standard for fault-managed power systems, and explore ways to decrease the cost and energy losses of these systems.

25) What further research and/or analyses are required to ensure DC components/equipment protection is developed and proper guidelines are established?

It will require extensive lab testing to determine what protection technologies are applicable and acceptable in which scenarios. Then these results will have to be written into standards and building codes.

EPIC Program Area and Funding

27) For each suggested area of research above, what is the recommended CEC funding amount? What percentage of the funds should be provided by the recipient in terms of match?

The DC industry today is small and most companies active in the area do not have the deep pockets available to contribute match funds as cash - only as in-kind work.

Berkeley Lab appreciates the opportunity to provide this information regarding Direct Current Power Systems. The following individuals contributed to this request for information: Rich Brown, Daniel Gerber, and Bruce Nordman.

Sincerely,

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