

The Need for Communications to Enable DC Power to be Successful

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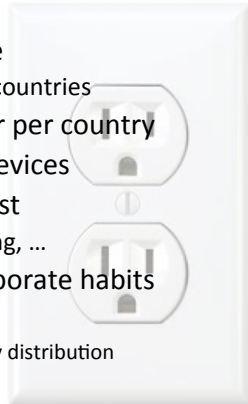


DC power use today

- Major end uses powered by DC
 - Rail transport
 - Vehicles (and in-vehicle appliances)
 - Niche industrial applications; 48V (telecom)
 - Recent: USB, Ethernet; 380V (datacenters)
 - Off-grid locations
 - Likely very small percent of global electricity use
 - Much less is "Direct DC"
 - DC from generation to end use
- DC today: "Not successful"

Challenges of AC's incumbency*

- Available nearly everywhere
 - In buildings in industrialized countries
- One dominant physical layer per country
- Plug-and-play for end-use devices
- Wide availability and low cost
 - Parts, labor, design, permitting, ...
- Inertia in individual and corporate habits



*Excepting high-voltage or high-capacity distribution

How to get to success?

- Reasons for DC adoption to date
 - Capital cost, installation cost, convenience, reliability, historical inertia, lack of AC
 - Energy savings rarely compelling; never alone
- Need package of benefits that together form "compelling value proposition"
- DC needs capabilities not (easily) available from AC

Communication about power

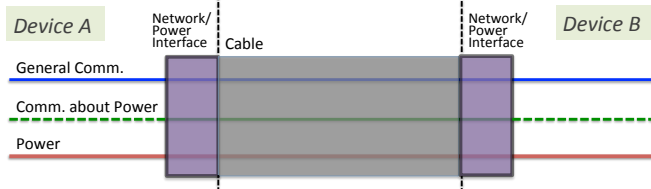
"Standard DC"

A method for transmitting DC power defined by a well-known technology standard, enabling plug-and-play interoperability

"Managed DC"

Standard DC technologies that include communications for managing power distribution within the power cable

- Over the power wires or over adjacent wires
- Examples: USB and PoE (and UPAMD and HDBaseT)

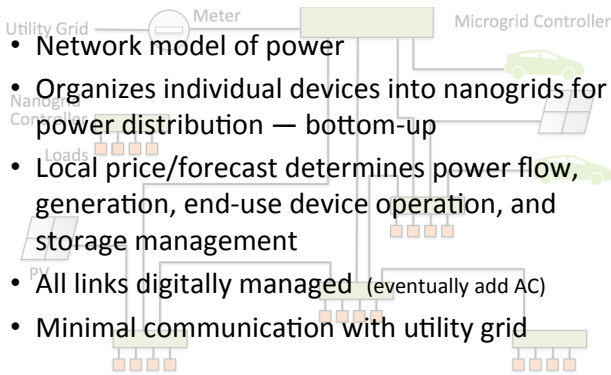


Benefits of Managed DC

- "Plug-and-play" operation
 - End-use devices
 - Local generation
 - Local storage
- Improved safety
- Fine-grained management of constrained supply
- Enabling optimal operation with a local price
- Greater efficiency with Direct DC
- New powering models
 - Networks; bi-directional; multiple power inlets; ...

Local Power Distribution is required for some of these

Local Power Distribution (LPD)



- Network model of power
- Organizes individual devices into nanogrids for power distribution — bottom-up
- Local price/forecast determines power flow, generation, end-use device operation, and storage management
- All links digitally managed (eventually add AC)
- Minimal communication with utility grid

Managed 380V DC

- 380V DC power currently lacks communications
- Inventing something new would be time-consuming and expensive

Proposal

- Have an Ethernet port adjacent to each 380V inlet and outlet
- String Cat-6 cable along each 380V cable
- Use Ethernet path to negotiate 380V characteristics **before** energizing power line
- Use PoE to power end device for communications in absence of 380V DC power
- Create local price with LPD



Communications for DC

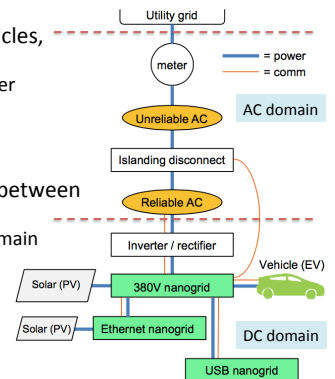
Three approaches to implement

- Scale-down utility technologies
 - e.g. SCADA, MODBUS, etc.
 - Expensive; AC-oriented
- Use existing Managed DC technology as-is
 - Only covers individual links
- Local Power Distribution (LPD)
 - Creates network model of power

Only LPD can enable DC to be widely successful

Proposed deployment path

- Use DC as integrator of local generation, local storage, vehicles, reliability
 - Storage integral to nG controller
 - Enables “Direct DC”
- Enable modest reliable AC
 - e.g. refrigerator
- Amount of power exchanged between DC, AC small
 - Most DC power stays in DC domain
- Can add DC capability incrementally and organically
- Can exchange power with neighboring buildings
 - Useful in disaster scenarios



Summary

- DC needs compelling value proposition to gain interest for manufacturers, consumers
- Communications enables benefits AC systems can't deliver at all or at comparable cost
 - Efficiency, cost, flexibility, convenience