Design and Specification of Building Integrated DC Electricity Networks

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***Abstract*— Adoption of millions of small energy efficient, low power digital and DC appliances at home and at work is resulting in a significant and fast growing fraction of a building's electricity actually consumed in low voltage DC form. Building integrated energy systems featuring renewable photovoltaics are also increasingly attractive as part of an overall electricity and emissions reduction strategy. This paper details design and specification of a novel system level method of matching building integrated photovoltaic electricity generation with local low voltage DC appliances in office and other ICT intensive environments such as schools. The chosen scenario considers load components consisting of a diverse range of modern low power ICT and DC appliances, networked and powered by industry certified smart DC distribution technologies. Energy supply to the converged DC, IT and ICT network is described as featuring a roof-mounted or other on-site photovoltaic array in combination with conventional supply from the local grid infrastructure. The direct and strategic benefits of smart DC infrastructures are highlighted as the enabling technology for optimal demand reduction through fully integrated energy management of DC systems in buildings.**

Keywords—Green Computing, low carbon ICT, building integrated photovoltaics, smart DC, power over Ethernet, appliance energy management, advanced system control

I. INTRODUCTION

The potential for building integrated PV to actively mitigate electricity consumption and carbon emissions at point of demand is highly significant. With the UK installing 5GWp non-dispatchable solar PV capacity in 5 years to end 2014 and predictions indicating an installed base upwards of 10GWp by 2020, representing 12% of total grid capacity, there is concern that present deployment mechanisms, integration and utilization strategies are becoming a considerable network management liability and quality of service risk particularly at local levels [1]. This scenario results in a negative effect on energy policy and loss of support for PV as a valuable contributor to the UK's low carbon energy strategies.

State of the art Demand Side Management methods aim to reduce risk and increase confidence in locally utilizing renewable energy by employing local energy storage to improve the supply demand match and re-structure the overall demand profile [2]. However, the control strategies used to achieve this restructuring are typically sensitive to deviations away from design expectations [3]. This then poses a question of compatibility and relevance of this general approach to DSM systems design in modern and future building scenarios which include an increasingly uncertain local demand dominated by a vast and diverse array of small appliances.

More than in any other sector, ownership of and dependence on communications-enabled equipment; computers, media devices in commercial buildings is growing fastest. Cumulative energy consumption of ICT and small DC appliances in commercial and other buildings already forms a significant proportion of the total electrical demand [4]. The continuing and rapid shift to LED lighting, ever increasing adoption of mobile appliances and ICT, and future innovations and networked services such as internet of things (IoT) are expected to put proportion of DC consumption on a par with AC consumption in office and other building segments by 2020 [5]. A high LVDC device density not only results in potential for greater cumulative energy waste through increased numbers of devices being left switched on but can be detrimental to thermal comfort of occupied zones and may even affect reachability of environmental plant in the workplace [6]. In response to this threat at a worldwide scale, and at a rate reflecting the fast turnover of the industry, appliance manufacturers are driving a revolution in energy efficiency across many categories of low voltage digital appliances [7]. State of the art DC distribution technologies such as IEEE and IET ratified Power over Ethernet are also evolving to service low voltage low power DC appliance market segments, integrating high speed data and extensive control capabilities with DC power distribution in a single suite of interoperable industry standard technologies [8] [9].

Recent research investigating scope for integration of PV, battery storage and demand management in modern PoE powered office and other ICT dense working environments proposed a PV powered LVDC PoE distribution to ICT environment [10]. The network design detailed in this paper uses and supports IEEE data standards and new IET codes of practice for DC distribution in buildings as system design and deployment guides to realize a smart-enabled and highly flexible

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low voltage DC infrastructure suited to PV integration and modern ICT appliance fleets. Trials of this system highlights the value of an industry standards approach to smart LVDC and concludes that full integration of a dedicated PV source with an IT-based DC infrastructure serving local appliance demand is both cost-effective and complementary to wider energy management activities.

II. SCENARIO

The demand scenario in this paper consists of a typical range of DC, IT and ICT appliances in a modern commercial building. The supply scenario is a notional connection of this demand network to a roof or building integrated PV array.

III. DC APPLIANCES IN BUILDINGS

Convergence of low power appliances and mobile working is resulting in a dramatic drop in individual device power demand as recent market analysis summarized in Table [1] shows. Transition to low wattage solid state LED lighting fixtures also adds to the DC appliance portfolio in buildings and potential convergence with the IT network. Relevant to this paper is that low power laptop and tablet devices are becoming more common in workplaces as replacements for traditional desktop PC's and shift away from traditional modes of working. Individually, these devices feature a relatively modest battery capacity commensurate with a few hours untethered use for the appliance. This capacity becomes valuable for demand management when aggregated across hundreds or thousands of such devices in a building. The integration and demand management challenge is therefore to cost-effectively engage with highly distributed and intermittent small appliance energy storage resources in a building.

IV. DC DISTRIBUTION IN BUILDINGS

Alternative power distribution technologies in buildings is a large and growing area of research and development [11]. The amount of Ethernet cabling in a medium sized office can often be hundreds of kilometres, inter-connecting and internet-enabling thousands of appliances and representing major capital and on-going investment. These essential data networks are also being utilized to distribute electrical power in DC form using amendments to the ubiquitous IEEE802.3 suite of protocols; termed Power over Ethernet (PoE).

TABLE [1]

DC Appliance Voltages and Power Ratings		
Device	***Input Voltage***	***Rated Watts***
Laptop	19 VDC	45
Tablet	5 VDC	10
Lite PC	7-14 VDC	10
Thin Client	12 VDC	15
Large Monitor	12-14 VDC	22
Wi-Fi Access Point	5-12 VDC	10
Inkjet Printer/ MFD	12-24 VDC	30
LED Lighting Fixture**	18-37 VDC	40

Ratified by IEEE in 2005, 802.3af allows up to 12.95W at a user safe low voltage of between 52-57VDC, to be delivered to a device and provides the method by which hundreds of millions of legacy IP telephones, security cameras and wireless access points in almost all modern buildings worldwide are already powered [12]. 802.3at, ratified by IEEE in 2009, allows up to 25W per Ethernet channel to be delivered to low power DC appliances over CAT5e and above cables. 802.3af/at Power over Ethernet was adopted by the IET in its recent code of practice for Low and Extra Low Voltage DC Power Distribution in Buildings, providing design and installation guidance and assurance that the technology is both safe and fit for purpose in UK buildings.

As PoE converged data and power standards in non-domestic settings evolve to increase DC power capacity towards 50W (P802.3bt working group) and as power demand of individual appliances continues to fall within these levels, industry standard smart DC distribution could hold an increasing advantage over traditionally separate mains AC power and data infrastructures and provide the catalyst for fundamental change in design and how appliance electricity in buildings is supplied, distributed and managed.

A timeline of industry wide global convergence on LVDC appliances is summarised in Figure 1 showing market analysis and trends of representative individual appliance class power ratings against past, present and likely near future PoE power capacity from recent research.

V. ENERGY MANAGEMENT OF POE NETWORKS

Primary asset management of PoE equipment is defined by IETF in RFC3621 [13]. The RFC defines mechanisms to allow the power state of a PoE channel (appliance plus cable) to be monitored by the DC power sourcing equipment (PSE) and exposed as data to developers [14] [15]. These energy management features are also complementary to 3rd party development of integrated PV and smart DC control using standard internet protocols and web technologies. A new standard relevant to LVDC and PoE, RFC7460, extends energy management capability further by formalizing query and reporting of power state of the networked device itself to a central manager [16].

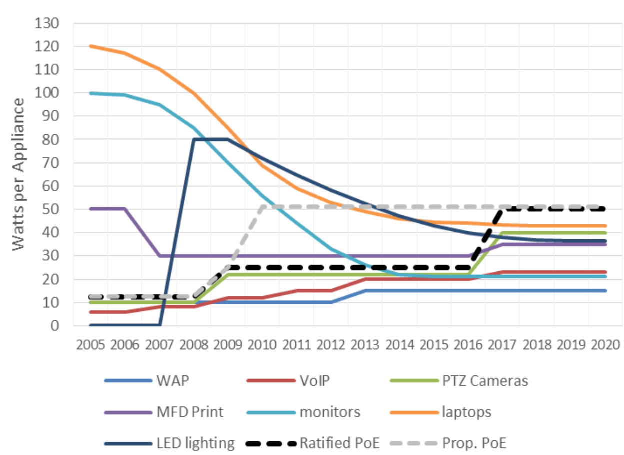

Fig. 1 Trends in PoE power Capacity and Appliance Demand

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Significantly for future integrated demand management purposes, this RFC also incorporates reporting protocols for device and other networked energy storage assets. For purposes of system control design, it is relevant to note that modern IP/ PoE networks are radial from a central switch to each device.

VI. System Topology

The integrated system topology aggregates PV and grid electricity supplies to a central LVDC hub such as a PoE midspan for radial distribution to devices as shown in Figure 2.

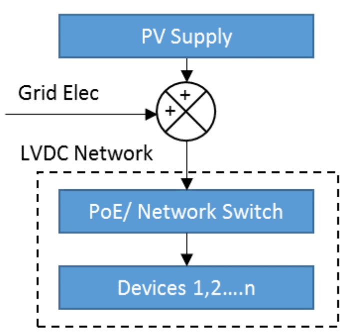
VII. System Trials

The appliances and systems discussed above were successively developed and tested in live deployment trials in a high profile government building in Wales, in University of Strathclyde and recently in BRE's Innovation Park at Ravenscraig where initial assumptions regarding PoE component compatibility in retro-fit applications, ICT functionality and behaviour were verified with a view to full system control. Progression in trial structure at these three locations also allowed testing Endspan and Midspan PoE supply configurations as well as demonstrating retro-fit of PoE to non-PoE enabled thin client, fixed desktop and mobile computing appliances.

IEEE/ IET compliant PoE powered ICT appliances tested as fully functional and demonstrated by the trials included a 1GHz solid state 'lite' PC and 19" screen on a single CAT5e channel. A second computing configuration retro-fitted to the PoE enabled IT network during the trials included a business class laptop. Of note is that 50W capacity PoE was used to provide power to the laptop appliance using only a single CAT cable and splitter, as shown in Photo 1.

VIII. Conclusions

Contribution of ICT to electricity demand from a building is increasingly significant. A fully integrated renewable supply has the potential to optimize reduction in ICT demand if combined with management and control of local battery storage. Power over Ethernet was identified and demonstrated in this paper as a standards backed low cost high value combined smart DC infrastructure for growing volumes of networked digital and low power ICT devices. The LVDC network presented is flexible in accepting any and all low voltage low power DC appliances capable of a PoE connection as was demonstrated by inclusion of thin clients, lite PC's,



mobile PC's, screens, MFD printing and an industrial PLC unit.

Fig. 2 Integrated System Block Diagram

Photograph 1 LVDC Network and Appliances

The continuing support of international standards bodies will be critical in the transition to DC dominated buildings. Ratification by IEEE and the IET of 802.3af and 802.3at PoE provides essential market assurance that the technology is safe and fit for purpose for all DC appliances below 25W. This power level maintains the already established security camera, VoIP and wireless access point markets but a significant portion of demand such as laptops and LED lighting will struggle to reduce peak consumption to this level in the near future. Already well underway as P802.3bt, future IEEE ratification of this amendment will very likely provide 50W DC and is massively significant as the point at which the IT industry can cost-effectively compete to replace conventional 240VAC distribution to wall sockets and outlets to the vast majority of appliances in buildings including laptops and mobile devices with their battery storage capacities, and LED luminaires.

IX. Future Work

Future work will include further design and development of a demand management control suited to both the highly stochastic nature of PV and compatible with mobile laptop and other battery-enabled appliance fleets. This control intends to demonstrate full integration of an IT network dedicated renewable PV energy supply.

Acknowledgments

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References

[1] National Grid Solar PV Briefing Note, online resource viewed 05/16, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/66609/7335-national-grid-solar-pv-briefing-note-for-decc.pdf

[2] Palensky P, Deitrich D, Demand Side Management, Demand Response, Intelligent Energy Systems and Smart Loads, IEEE Transactions on Industrial Informatics, Vol 7, No 3, 2011

[3] Kirschen et al, A Model of PV Generation Suitable for Stability Analysis, IEEE Transactions on Energy Conversion, Vol 19, No.4, 2004

[4] International Energy Agency publication note, More Data-Less Energy, http://www.iea.org/publications/freepublications/publication/MoreData_LessEnergy.pdf

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[5] DC Power for Commercial Buildings, Navigant Market Research Summary, 2013, retrieved 2015, http://www.navigantresearch.com/research/dc-power-for-commercial-buildings

[6] Jenkins, Liu, Peacock, Climatic and Internal Factors Affecting Future UK Office Heating and Cooling Energy Consumption, Energy and Buildings, Vol 40, Issue 5, pp 874-881, 2008.

[7] Energy Star 6 Program Requirements for Computers, retrieved 2015, http://www.energystar.gov/ia/partners/product_specs/program_reqs/Final_Version_6_Computers_Program_Requirements.pdf

[8] ANSI/ IEEE802.3-2009, Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications, Amendment 3: Data Terminal Equipment (DTE) Power via the Media Dependant Interface (MDI) Enhancements. ISBN: 9780738160436

[9] Institution of engineering and Technology, Code of Practice for Low and Extra Low Voltage Direct Current Power Distribution in Buildings, ISBN: 978-1-84919-835-6, 2015

[10] Counsell J, Stewart M, A novel DSM philosophy for building integrated renewable systems, Paper presented at 2nd International Conference in Microgeneration and Related Technologies, Glasgow April 4-6 2011.

[11] E-Merge Alliance, standards for DC Systems, http://www.emergealliance.org/

[12] Venture Development Corporation, 2008. Power over Ethernet (PoE): Global Market Demand Analysis. Retrieved 2009

[13] Berger A, RFC 3621 Power Ethernet MIB, IETF standard, 2003, https://tools.ietf.org/html/rfc3621

[14] CISCO EnergyWise http://www.cisco.com/cisco/web/UK/solutions/network_systems/energywise.html

[15] Microsemi PowerviewPro, http://www.microsemi.com/products/poe-systems/midspan-power-manager-module-powerview-pro

[16] Quittek J, RFC7460 Monitoring and Control MIB for Power and Energy, https://tools.ietf.org/html/rfc7460

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