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Household DC networks: State of the art and future prospects

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Executive summary

This study investigates the potential benefits and feasibility of household DC networks. Unlike the case of AC systems, a well-established set of standards for household DC networks is currently lacking. However, several recommended standards and configurations have been discussed in previous studies. This work reviews some of the most promising suggestions and further analyses those that are most suitable to be implemented. In addition, a comparative study is carried out between a hybrid AC-DC system and a proposed DC configuration, for different selected geographical conditions in the EU. Specifically, the comparative study focuses on energy savings from avoiding conversion losses, and economic payback.

The choice of transitioning to DC networks in households is found to dependent on the evolution of electricity consumption of household devices, residential solar PV penetration, and the cost of DC power converters. It is most likely that DC household networks will be taken up in parallel to the current AC system; a hybrid configuration with installations of parallel networks of AC and LVDC distribution systems is a possible "transition solution". Some recent developments in favour of a transition of DC networks include the launch of USB 3.1 (capable of power delivery of up to 100 W), dramatic fall in costs of solar PV since 2008, and growing support at the EU-level for residential electricity storage through batteries. In addition, both the International Electrotechnical Commission (IEC) and the Institute of Electrical and Electronics Engineers (IEEE) are actively engaged in developing DC network standards. This is critical for the large-scale adoption of low voltage DC networks.

Over a century ago George Westinghouse, with the support of Nikola Tesla, defeated Thomas Edison in the 'War of Currents'[1], thereby successfully establishing alternating current (AC) as the primary mode of electricity transmission and distribution. Large power plants such as coal, nuclear and hydro, are often located far from consumption centres. With transformers, the voltage level of AC power is easily increased to very high voltages, which is preferable for long distance transmission, before being stepped down again to levels that are safe for consumers to use. Today, however, there is a revival of direct current (DC) for high voltage transmission, particularly for long distances, and integrating large-scale renewables such as hydro and wind parks.

The past decade has also seen a rapid increase in local electricity generation from renewable sources, such as solar photovoltaics (PV), both globally and in the EU. Solar PV panels generate DC power that is either used to charge batteries or fed into the electricity grid after being converted to AC, with associated losses[2]. Batteries play a crucial role in balancing the variability of solar PV, and are especially well suited to households.

Furthermore, there has also been a shift towards the use of DC power on the demand side. Several household appliances, such as computers, mobile phones and LED lighting use DC power, requiring the electricity from the grid to be converted from AC to DC. One important technical development is that

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[1] http://energy.gov/articles/war-currents-ac-vs-dc-power (Accessed: 16th July, 2015)

[2] http://www.solarpowerworldonline.com/2013/04/how-do-solar-inverters-work/ (Accessed: 16th July, 2015)

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household appliances are increasingly using power converters to convert unregulated AC to constant DC, for speed control for increased efficiency. These modern appliances are therefore well suited for direct DC supply.

This paper investigates the current developments related to DC networks and their feasibility at the household level. By distributing DC rather than AC power, the number of transformations can be reduced, and associated losses. Several studies show that cumulative losses of the DC-AC-DC conversion when powering DC appliances through local PV systems were in the range of 5-7%[3,4]. The losses across the EU from avoiding this conversion could be approximately 120-170 million €/year across the EU (Table 4 in Annex B).

DC networks

Market for DC networks

Due to their high DC demand, the first real market where low voltage DC (LVDC) is expected to be employed are data centres. At present, several pilot installations are testing and demonstrating the value of such LVDC networks[5]. Some of these data centre projects have reported that the benefits of DC include a 10% to 30% reduction in energy consumption, about 15% lower capital costs, potential increases in reliability, a smaller carbon footprint, simpler design, less physical area requirements and less cooling demand[6,7,8]. With the very large and growing energy consumption of these data centres, up to 10% of global electricity consumption in 2013[9], even relatively minor gains in efficiency can have a significant impact.

In addition to data centres, other potential markets are expected to be non-residential (tertiary) buildings such as office buildings and supermarkets. These buildings are typically characterised by large electrical DC loads from computers, screens, and possibly lighting (with a shift from fluorescent lamps to LED lighting).

Depending on the success of LVDC networks in these markets, the residential sector may also follow. The main reasons for this potentially delayed market uptake are:

- The benefits of LVDC networks for households has not been clearly evident due to prevalence of large AC loads and relative lack of low-cost appropriate power converters.
- There is a large stock of households, which are not renovated or refurbished as frequently as data centres and tertiary buildings.

In this respect, the rollout of the latest USB technologies and standards may play a significant role in accelerating the deployment of LVDC in households. With a capacity to deliver up to 100W of power at a voltage rating of 5-20V, USB 3.1 may widen the types of household applications that can be powered by LVDC, as discussed in more detail on page 5.

What does a DC network comprise of?

The main constituents of a local electricity network can be categorised as:

- Electricity generation and storage (solar PV, wind, fuel cells, batteries)
- Distribution (wiring and electronic control)
- Loads (computers, appliances, lighting)

If two or more of the above constituents of a network are DC-compatible, it is worth exploring the viability, both technical and financial, of a DC network.

On the electricity generation side, the share of solar PV in the electricity generation mix of the EU has increased from 0.27% in 2004 and 0.52% in 2009 to 2.9% in 2013. This has been largely driven by the dramatically falling costs of solar PV technologies[10]. Furthermore, battery costs for residential applications have been steadily reducing, with the recently announced Tesla Powerwall at a price of 350 $/kWh for a 10 kWh unit, and Powerblock priced at 250 $/kWh for a 100 kWh unit.

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[3] http://smartgrid.ieee.org/questions-and-answers/902-ieee-smart-grid-experts-roundup-ac-vs-dc-power (Accessed: 16th July, 2015)

[4] Åkerlund, J., Investigation of a micro DC power grid in Glava Hillringsberg – a smart grid, UPN AB, 2012

[5] Fortenbery, B., DC Power Standards. Technical Report March, Electric Power Research Institute, 2011

[6] Ram Adapa, Guy Ailee, William Tschudi, Brian T. Patterson, Gregory F. Reed, and Brandon M. Grainger. Plugging into DC. IEEE Power & Energy Magazine, (October):19–79, 2012.

[7] Tomm Aldridge. Direct 400Vdc for Energy Efficient Data Centers Direct 400Vdc Facility Vision. Technical Report April, Intel Corporate Technology Group, 2009.

[8] Electric Power Research Institute. DC Power for Data Centers. Technical Report November, Electric Power Research Institute, 2010.

[9] Mills, M., The cloud begins with coal. Big data, big networks, big infrastructure, and big power. An overview of the electricity used by the global digital ecosystem. Digital Power Group, 2013

[10] Renewables 2014 - Global Status Report, REN21

Figure 1 and Figure 2 show cost projections for residential (rooftop) solar PV and Li-ion batteries respectively. With falling solar PV and Li-ion battery costs, they will become more prevalent in households.

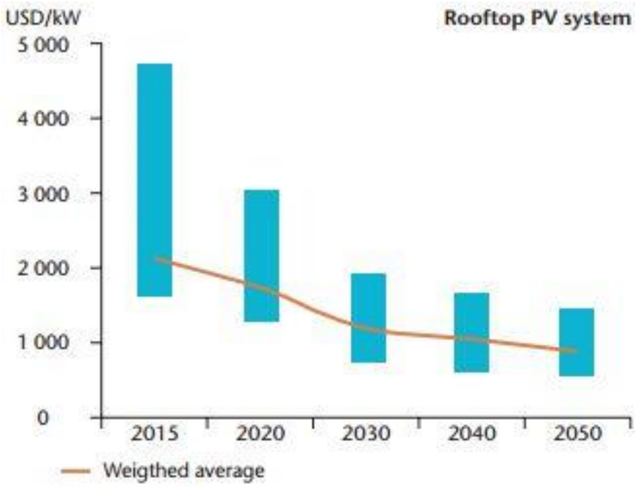

Figure 1: Cost projection of rooftop solar PV[11]

On the demand side, several end-uses are likely to be increasingly powered by DC. Figure 3 shows the electricity consumption per household and end-uses across the EU. Within these end-use categories, the following demands could be directly fed by DC:

- Potentially all modern electric appliances using power convertors such as fridges, freezers, dish washers, washing machines
- All LED lighting
- Modern air conditions with power convertors
- Space and water heating with heat pumps or direct heating

Today, in 23 of the 28 EU Member States (MS) the share of consumption of electrical appliances represents over 50% of the total electricity consumption (Figure 3). This share of electricity consumption can potentially be met using a DC network, powered by solar PV combined with a Li-ion battery storage and LVDC network.

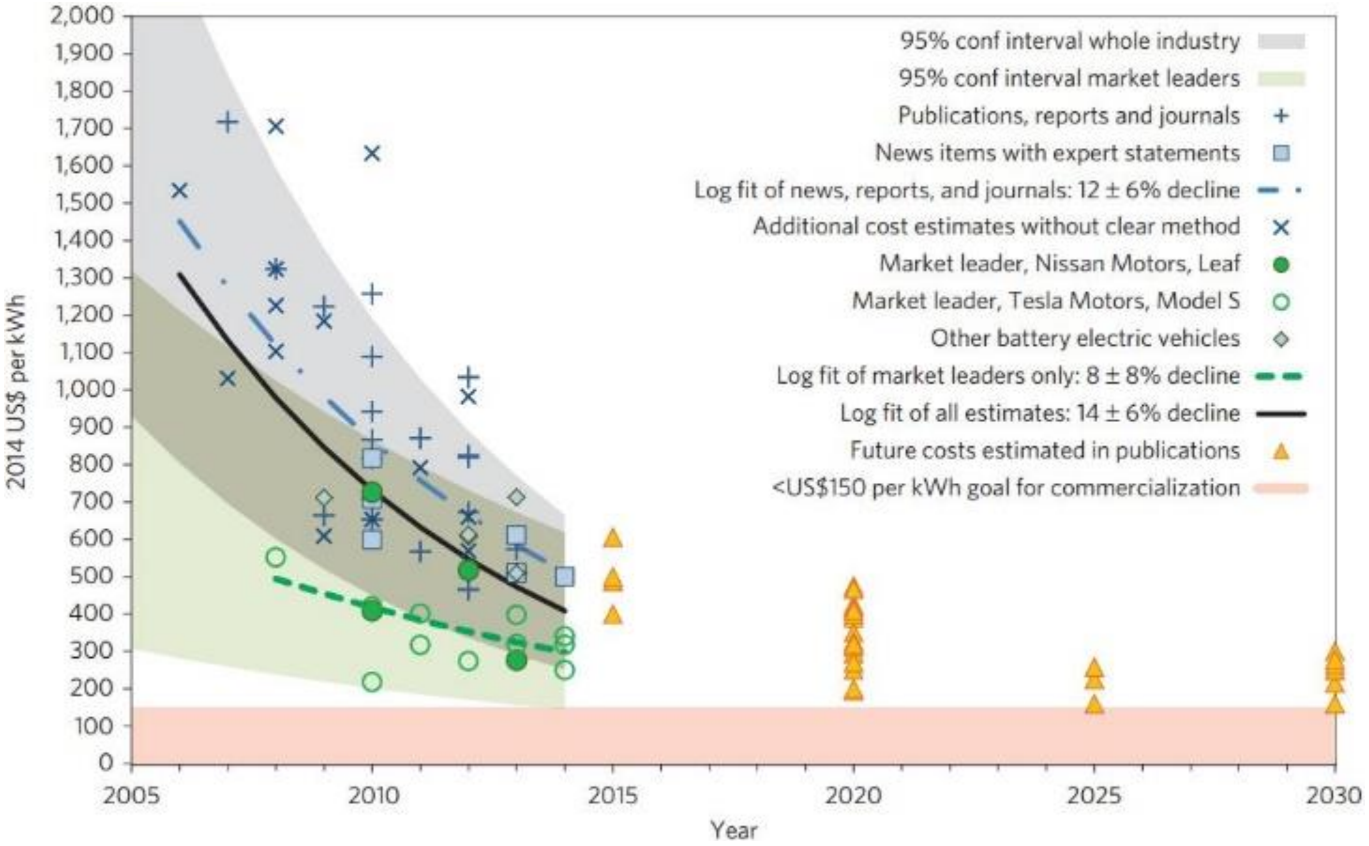

Figure 2: Cost trends of Li-ion battery technologies
(Source: "Rapidly falling costs of battery packs for electric vehicles", Björn Nykvist, Måns Nilsson, Nature Climate Change, 329–332 (2015), doi:10.1038/nclimate2564)

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[11] Technology Roadmap: Solar Photovoltaic Energy (2014 Edition), IEA, 2014

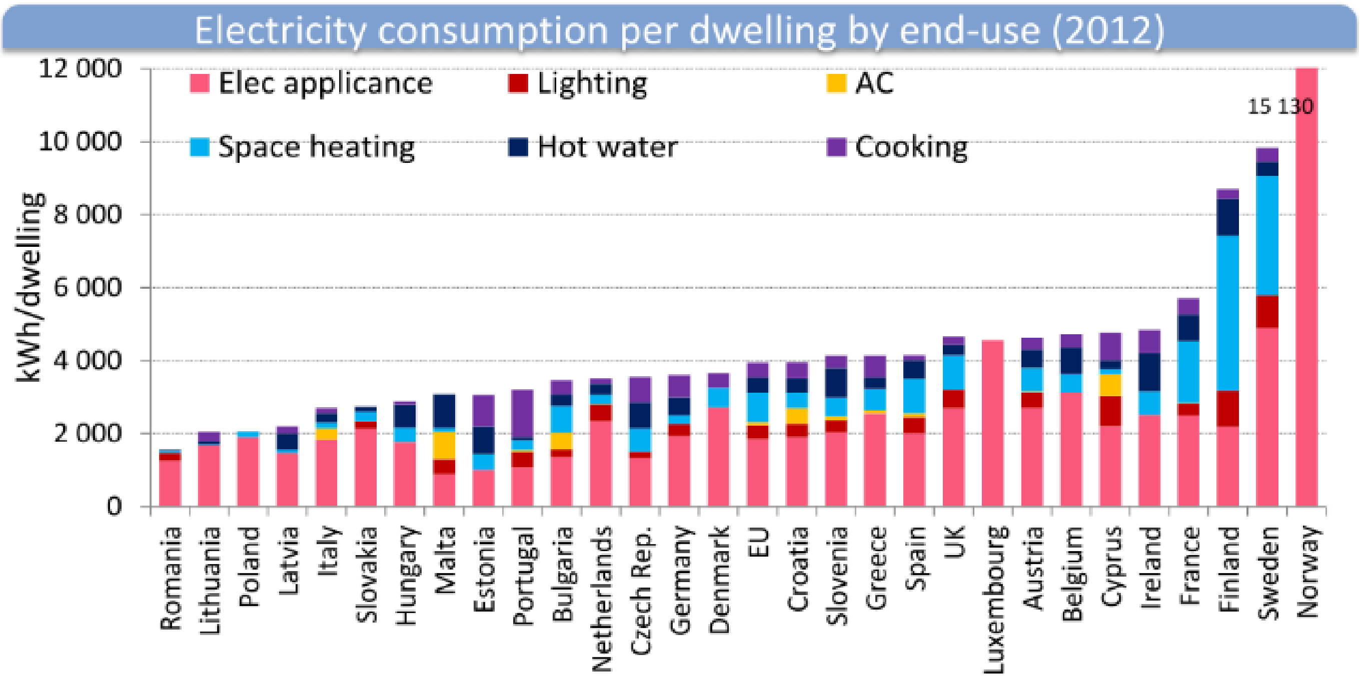

Figure 3: Electricity consumption per dwelling by end-use (2012)
(Source: "Energy Efficiency Trends for households in the EU", Enerdata, 2014 (as part of the ODYSSEE-MURE project co-funded by the Intelligent Energy Europe Programme of the European Union)

Figure 6 in Annex A shows the potential of energy savings by shifting to DC appliances. According to the figure and associated study, average energy savings of 33% can be achieved by shifting to the best DC alternative.

However, even with a LVDC network not all DC-DC conversion losses can be avoided. This is due to the several different voltage levels required for the operation of device, especially in electronic devices. For instance, a device may run on 1.8 V while its peripherals are powered by 5 V. Therefore some DC conversion losses related to appliances will continue to remain in LVDC networks.

What is the right voltage level?

A key issue to consider for DC networks is the optimal voltage level. In recent years, there has been growing consensus on the potential benefits of powering data centres with 400 V DC. Bolstered by the development of associated power products, this has led to new DC electrical standards.

The most important parameter to decide on for an optimal DC voltage standard for households and tertiary buildings is the power to be transferred. Therefore, information on the loads to be connected to the distribution system will first need to be determined and analysed. Following this, the electricity supply options will need to be studied. The main objectives of the distribution system are to link supply and the consumption in a safe, reliable and cost-efficient way. A higher voltage will result in less losses and more efficient distribution. However, it will imply that more safety issues need to be considered and new standards developed.

At present, there is no definitive consensus on an optimal voltage level. Table 1 summarises the main reasons in support of different voltage levels.

Table 1: Summary of reasoning to select a voltage level[12]

Voltage level	Reasoning
Vdc ≥ 220	Adaptability with existing building's grid
Vdc ≤ 238 or 457 (phase-to-phase)	Compatibility with single phase loads
463 < Vdc < 617	Compatibility with 3-phase loads
Maximum possible	Efficiency (use the same equipment)
Vdc ≤ 373	Insulation
Vdc ≤ 350-450	Component and devices matching (rated levels)

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[12] H, Pang, Pong, B, Lo, E W C, "A practical and efficient DC distribution system for commercial and residential applications-240 V or higher?" The international conference on electrical engineering 2008, pages 1–4, 2008.

In the case of data centres, the Emerge Alliance's standards for 24Vdc and 380Vdc are becoming the industry standard. To agree on a standard voltage level for households the required power in a room, house or building will need to be analysed, taking into consideration the necessary safety features to be defined as part of wiring rules.

Role of USB

Electronic appliances, such as smart phones and laptops, are ubiquitous at the household level and represent a growing share of electricity demand. The simultaneous rollout of the USB 3.1 standard and USB Type-C connector (also called USB-C) this year has a direct impact on the use and electricity consumption of these electronic appliances. This development is driven by a large number of companies securing a very high penetration and fast implementation of the technology. The main features of the USB-C connector are that it is reversible (both ends of the cable are identical), "flippable" (both 'up' and 'down' orientations are identical), twice the theoretical throughput of USB 3.0 (increased from 5 GBps to 10 GBps), and is compatible with the USB 3.1 standard. USB 3.1 will work with three different voltages, 5V, 12V and 20V and the highest current at 20V will be 5A, giving a delivered power of 100 W[13]. A standardisation of DC voltages is thus given by the USB 3.1 specification.

This last feature is particularly relevant to the discussion of LVDC networks. Around 10 billion electronic devices such as mobile phones, tablets, and laptops already use USB cables for charging. For example, both the Apple MacBook[14] and Google Chromebook Pixel[15] are equipped by USB-C ports. In the case of the MacBook, this is combined with USB 3.1. In addition, a host of other small USB-powered devices such as heaters, blenders, and monitors are on the market today.

Following this trend, increasingly aircrafts and hotel rooms have started to provide USB sockets as electrical fittings[16]. USB wall-sockets and chargers are easy to install and therefore look set to become the standard in new private houses and office buildings.

At the household level, Table 2 below lists the electrical appliances present in a typical household and their potential compatibility with USB 3.1 and a DC supply.

Table 2: Suitability of typical household appliances for use with a DC network and USB[17,18]

Appliance	W	DC suitability	USB suitability
Lighting	9-72	+	+
Cell phone	3	+	+
Electric razor	5	+	+
Internet router	13	+	+
BlueRay/DVD player	26	+	+
LCD monitor	32	+	+
Laptop	60-90	+	+
Computer	100	+	+
36" LCD TV	60	+	+
Home theatre system	300	+	-
Mixer	220	+	-
Blender	300	+	-
Sandwich maker	750	+	-
Toaster	1050	+	-
Coffee maker	800-1400	+	-
Vacuum cleaner	200-700	+	-
Kettle	2000	+	-
Washing machine*	500	+/-	-
Refrigerator*	400	+/-	-
Air conditioner*	1000	+/-	-
Dishwasher*	1200-1500	+/-	-
Electric oven	2150	-	-
Tumble dryer*	4000	+/-	-
Microwave oven	600-1500	-	-
Electric stove	1000-3000	-	-

* Modern appliances with a variable speed drive are better suited for DC supply

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[13] USB 3.0 (also called USB 3.1 gen 1), allows up to 1.5 A at 5 V (max. power of 7.5 W)
[14] https://www.apple.com/macbook/design/
[15] https://www.google.com/chromebook/pixel/
[16] "Edison's revenge", The Economist, October 2013
[17] Salomonsson, D. and Sannino, A., Load modelling for steady-state and transient analysis of low-voltage DC systems, IET Electric Power Applications, 1 (5), pp. 690–696, 2007
[18] Kinn, M.C., Benefits of Direct Current Electricity Supply for Domestic Application, Thesis submitted to the University of Manchester, 2011

Electric vehicle (EV) charging

Another major development in residential energy consumption is likely to be electric vehicle charging. At present the global EV stock stands at around 665000 (represents 0.08% of total passenger cars)[19]. Electric vehicle supply equipment (EVSE) is key element in the infrastructure that supports the adoption of electric vehicles – both plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV). EVSE can be divided into three broad categories, and each with different rates of charging, as shown below[20]:

- **AC Level 1:** Uses a normal wall outlet at 10–15 amps. (Every electric car has AC level 1 charging capability). Range is 3 - 8 km per hour of charging
- **AC Level 2**: Takes advantage of 220V or 240V power typically operating between 30–50 amps to deliver power of 3.3–10 kW. Range is 15 – 30 km per hour of charging
- **DC Fast Charging**: Range is 80 – 110 km in 20 minutes of charging.
- **DC "Supercharging"**: Proprietary high-speed charging option offered by Tesla. It delivers up to 600 km of driving range per hour.

Although the vast majority of charging is performed at home overnight with low or modest rate AC charging, the significantly higher rate of DC Fast Charging enables a direct connection to the DC leads to the vehicle battery for the fastest rate of charging. Two types of DC Fast Charging (DCFC) exist today – apart from Tesla's DC Supercharging option. CHAdeMO[21] is the most established DCFC interface at this time with over 3500 stations worldwide (over 550 in the U.S.) and CHAdeMO DCFC ports available on the Nissan LEAF and Mitsubishi iMIEV. The CHAdeMO DCFC coupler is not physically compatible with the standard SAE J1772 AC connector. The SAE CCS (Combined Charging Standard) or "Combo" standard was developed in a SAE committee process that was open to all automakers to participate. The CCS standard allows for a single gas-filler sized fender opening, a lower cost, and an upward compatible coupler to the existing J1772 AC coupler that is pervasively deployed. Tesla has employed a single receptacle on their Model S for both low and modest rate AC level 1,2 and DC "Supercharging". The Tesla coupler and interface architecture are designed such that a Model S driver can charge using a Tesla EVSE (either AC or Supercharger DCFC), an SAE J1772 EVSE (using an inexpensive J1772-Tesla adapter), or a CHAdeMO EVSE (using a CHAdeMO-Tesla adapter).

Efforts towards standardisation of DC Fast Charging is in contrast to current USB trends: manufacturers from different regions are developing and adopting varying standards. Many car manufacturers agree that one charging interface standard - such as CHAdeMO - is better than two or more for reducing EVSE infrastructure costs and help make EVs cost competitive. However, protectionist strategies of car manufacturing companies are leading to diverging, rather than converging, standards.

Potential household configurations

There are several possible household configurations that can be considered. One differentiating factor between these alternatives is the varying levels of DC network usage across household electrical appliances. For a transition towards DC households, the most feasible and likely configurations are presented below.

Hybrid AC-DC household

A potential solution is that a hybrid system will be installed in some households, where both AC and LVDC networks will operate side-by-side with high power appliances (such as washing machines and dishwashers) being supplied by AC (Figure 4). Power from solar PV is converted from DC to AC through an inverter. Medium and low power appliances are supplied by LVDC with voltage levels ranging from 12 to 50 Vdc.

This configuration considers a two-way AC grid connection, allowing for power from the rooftop solar PV to be fed in to the AC grid. Having such a connection favours the prospect of a hybrid AC-DC household acting as a transition solution towards a completely DC powered households. Households with existing rooftop solar PV panels and the necessary inverter equipment will therefore require less upfront investment.

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[19] "Global EV Outlook 2015", Electric Vehicles Initiative, Clean Energy Ministerial

[20] http://www.afdc.energy.gov/fuels/electricity_infrastructure.html

[21] http://www.chademo.com/wp/mission/

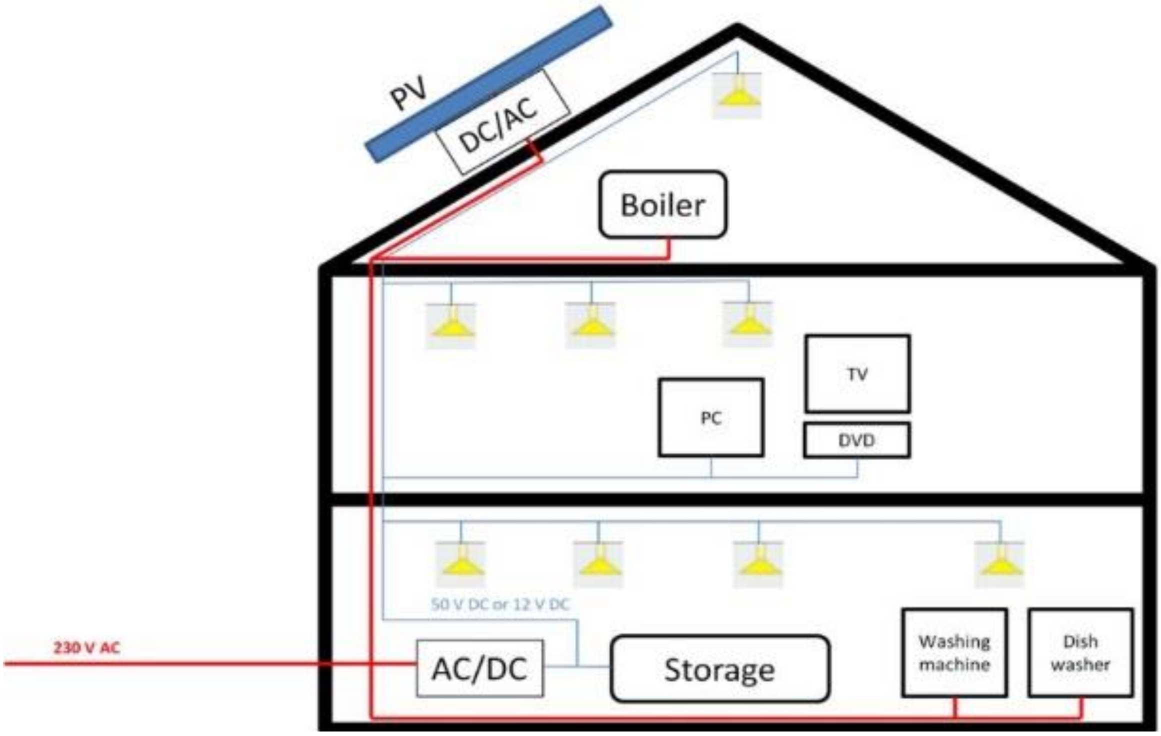

Figure 4: Hybrid AC/DC solution

DC household

Another solution is to power the entire household through a DC system. 400 Vdc can be used for high power appliances, 100 Vdc for medium power appliances and a few volts (potentially with USB 3.1) for appliances with low power ratings. This implies that there will be three LVDC networks to be installed in such a 'DC household' - all with the necessary protective measures, switching products and connections. Figure 5 below shows this household configuration.

A key prerequisite for such a household configuration to be feasible is the development of DC power electronic components with high efficiency, reliability, and low costs. This development process

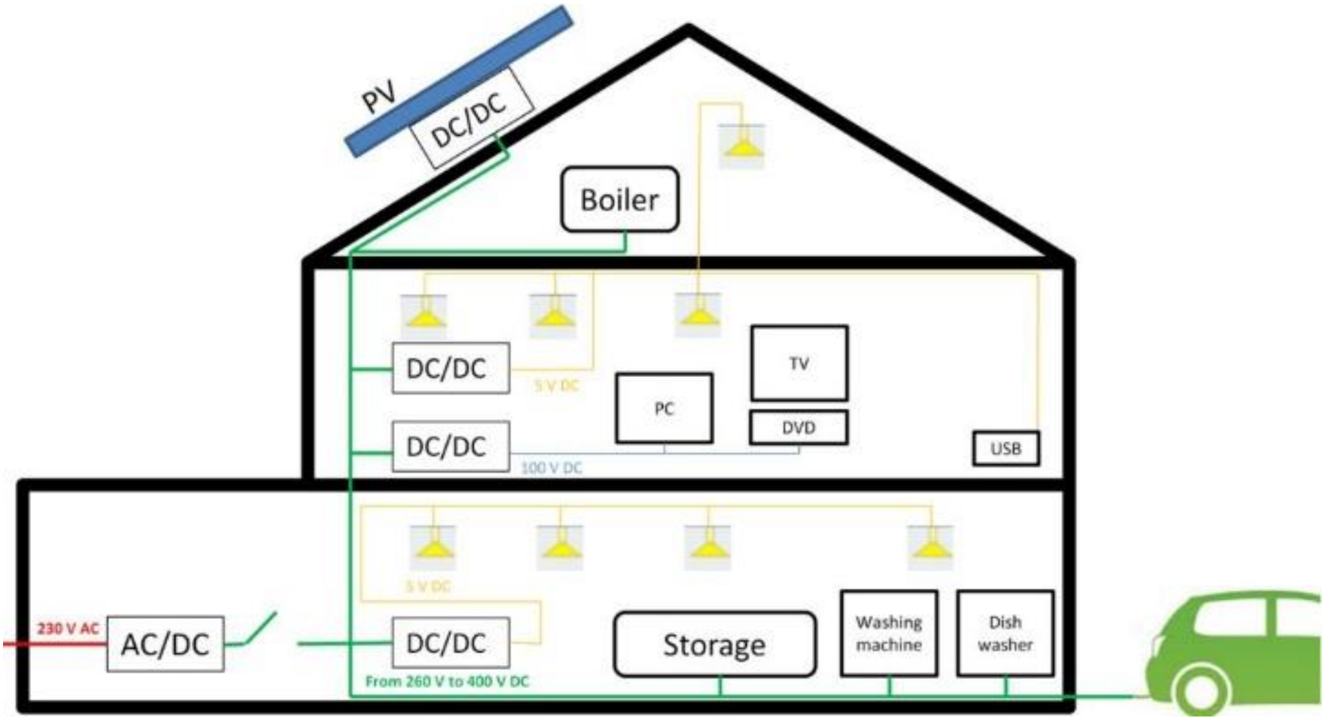

Figure 5: DC household solution

has already led to the launch of several DC network-specific products on the market. For instance, Vicor announced the first 400 Vdc to 48 V DC (nominal) bus converter to use its CHiP (Converter Housed in Package) module technology. The DC input range for the converter is between 262 and 410 Vdc. Its nominal output voltage is 47.5 Vdc, but it can be set for any output voltage from 32.5 to 51.25 V. The converter has a power rating of 1200 W with an efficiency of 98%. It can, however, handle up to a 1500 W peak, with the efficiency remaining over 90% until 10% of its rated power. In OEM[22] quantities, it priced at $120. Table 3 below compares the costs of some of the other main components that differentiate the hybrid AC-DC and DC household configurations.

Table 3: Cost comparison of selected household components

	Component	Cost (€)	Hybrid AC-DC	DC
1	USB wall charger	16-20[23,24]	+	+
2	AC-DC converter (220/230Vac to 400Vdc)	243[25]	-	+
3	AC-DC converter (220/230Vac to 12/48Vdc)	45-395[26]	+	-
4	DC-DC converter (Solar PV to 230Vdc)	33-830[27]	-	+
5	DC-DC converter (400Vdc to 48Vdc)	110-405[28,29,26]	-	+
6	DC-DC converter (48->5V)	32-126[26]	-	+
7	DC-AC inverter	500-2000[30]	+	-
Total cost (€)			581-2415	434-1624
Total annual savings (€) (high solar irradiation)			-	46-65
Total annual savings (€) (low solar irradiation)			-	24-34

suggests that, at present, there is no strong justification for a transition to household DC networks. The costs of the required DC converters currently outweighs the cost savings from reduced conversion losses. The savings are compared for the cases of high and low solar irradiation. Further details on these calculations can be found in Table 5 (Annex B).

Standardisation and legislative framework

With the use of DC currently most widespread in data centres, the standardisation work in this area has progressed the farthest.

The European Telecommunications Standards Institute (ETSI) has developed standard EN 300 132-3-1, which describes the characteristics of a DC bus between 260 and 400 V, and EN 301 605, which describes the earthing and bonding of 400 Vdc data and telecom (ICT) equipment. Further standards have been published by the USA-based Emerge Alliance, the International Telecommunication Union (ITU-T), and the International Electrotechnical Commission (IEC).[31]

For household applications, work has been ongoing for a long time within IEEE[32] and IEC. The activities within IEC has increased considerably in recent years and a Strategic Group (SG 4) has been set up to recommend technical work to define standards for LVDC networks up to 1500 V. While both IEC and IEEE are very active in this field, as of now there has been little coordination between the two bodies.

The work within IEC is currently looking at several options and one solution could be to have 380-400Vdc for high power products and 24 Vdc for electronic loads (potentially through USB) for the low power products. By October 2016, SG 4 of the IEC report will present a first suggested set of standards for LVDC networks.

It is most likely that multiple voltages will be used and apparent that on the highest level, 380-400 V

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[22] Original equipment manufacturer
[23] http://www.ebay.com/bhp/usb-wall-outlet-charger (Accessed: 20th August, 2015)
[24] http://www.amazon.com/RCA-Wall-Plate-Charger-White/dp/B0094E4A86/ref=sr_1_4?s=electronics&ie=UTF8&qid=1439294212&sr=1-4&keywords=usb+wall+outlet (Accessed: 20th August, 2015)
[25] http://www.vicorpower.com/megapac (Accessed: 1st September, 2015)
[26] http://www.digikey.com/product-search/en/power-supplies-external-internal-off-board/ac-dc-converters/590377 (Accessed: 20th August, 2015)
[27] http://www.altestore.com/store/Voltage-Converters/DC-to-DC-Voltage-Converters/c511/ (Accessed: 20th August, 2015)
[28] http://www.vicorpower.com/ (Accessed: 27th August, 2015)
[29] http://electronicdesign.com/power/400-v-dc-distribution-data-center-gets-real-0 (Accessed: 27th August, 2015)
[30] http://www.wholesalesolar.com/power-inverters
[31] http://www.ecnmag.com/articles/2015/03/next-big-thing-data-centers (Accessed: 27th August, 2015)
[32] Institute of Electrical and Electronics Engineers

will be used globally. 400 Vdc facilitates the transition to DC networks as many devices today operating on AC could, without modification, work at that voltage level. That means that the current system with 220 Vac and 50 Hz could be replaced with a common system based on 400 Vdc.

Apart from the 400 Vdc level, the standard for the lower voltage level is set by USB 3.1, and this standard is not expected to be challenged. With a capacity of up to 100 W, it could handle all low and some medium power devices. Particularly new electronic devices are likely to come with the USB standard and will thus be directly suited for DC supply via USB 3.1.

Policy recommendations

1. Encourage and support the standardisation work driven by IEC and IEEE. Clear standards are key for the development of DC networks in households.
2. DC networks in households have the potential to reduce electricity consumption and can be supported through relevant technologies such as variable speed drives (that generally reduce power consumption and are also suitable for DC supply).
3. As mentioned in an earlier INSIGHT_E report[33], clearer policy direction on self-consumption of renewables is required since legislation in different MS diverges. To foster self-consumption, the legislative framework in each MS will need to be revised. Since solar PV are well on track to reach grid parity within the next years across Europe, direct support schemes such as a premiums on self-consumption might not be necessary to foster self-consumption in most MS.
4. Increased support for batteries, other distributed storage technologies and demand side management at the household level
5. Standardisation of operating voltage levels and associated components for a household DC network. Mandate USB for power supply to electronics.

The key factors in the choice of a transition to DC networks in households will be the evolution of electricity consumption of different household devices, penetration of residential solar PV, and the cost of DC power electronics (such as converters). Increased distributed generation from solar PV, distributed storage in batteries, and decreasing costs of DC power electronics is likely to make a compelling case for household DC networks in the medium- to long-term future.

In the case of a long market transition period, the DC household may develop in parallel to the current AC system. As pointed out in the previous section, a hybrid configuration with installations of parallel networks of AC and LVDC distribution systems is a possible "transition solution", and may turn out to be the best solution if high voltage DC is found to be infeasible (for technical, economic or other reasons).

For further reading or information, please visit www.insightenergy.org

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[33] Dehler, J. et al, "Self-consumption of electricity from renewable sources", INSIGHT_E RREB

Annex A

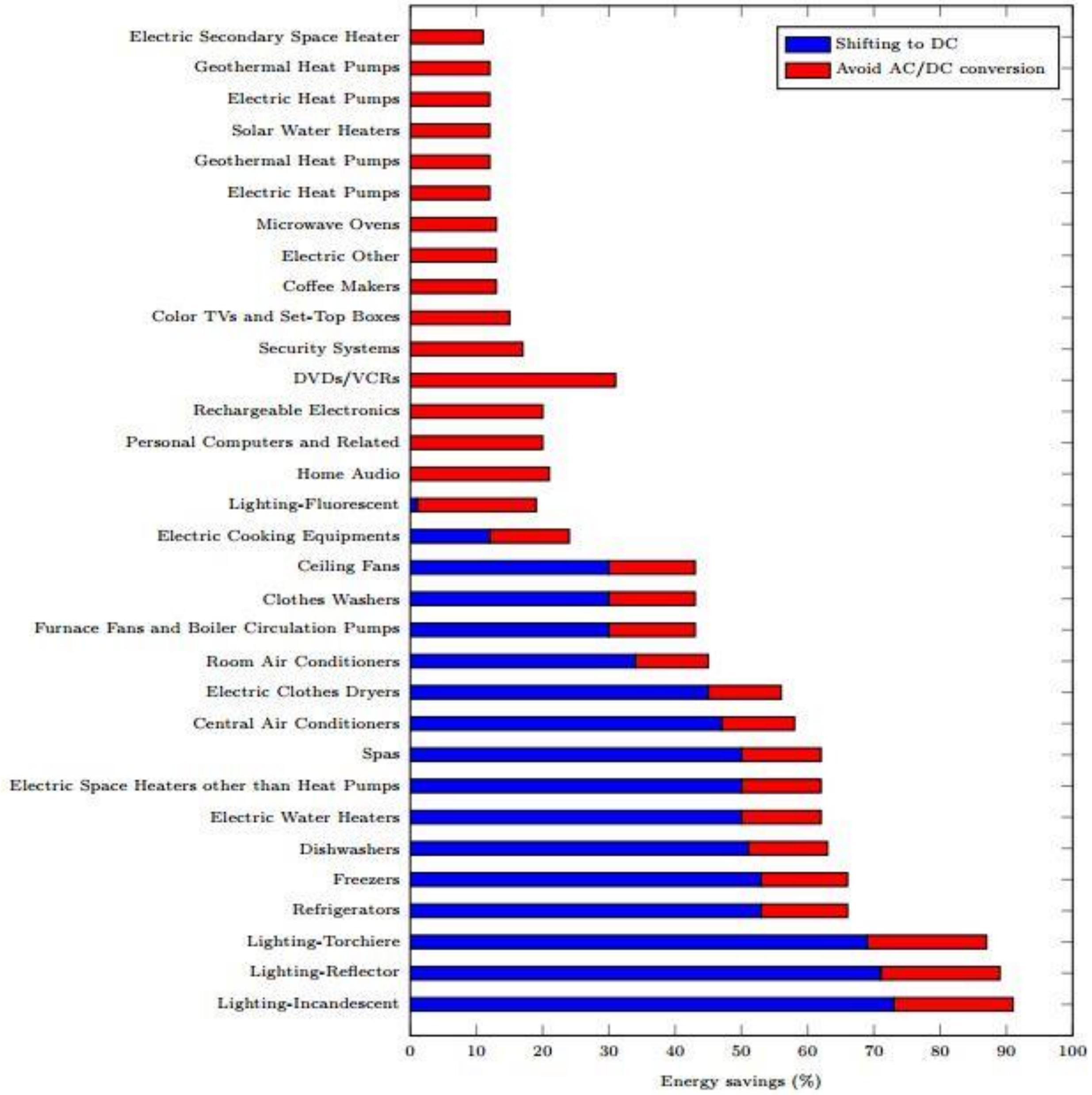

Figure 6: Potential of energy savings by shifting to DC appliances and avoiding AC-DC conversions[34]

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[34] Garbesi, K., Vossos, V., Shen, H., “Catalog of DC Appliances and Power Systems”, Technical Report, Ernest Orlando Lawrence Berkeley National Laboratory, 2011b.

Annex B

Table 4: Savings by avoiding DC-AC-DC conversion losses (EU, 2013)

Solar PV generation (TJ)	Share of residential Solar PV generation (%)	Solar PV generation, residential (GWh)	Electricity price (€/kWh)	Million €	Million €
				(5% saving)	*(7% saving)*
291120[35]	22%[36]	17792	0.1376[37]	122	171

Table 5: Annual savings for a signal household with (a) high solar irradiation and (b) low solar irradiation

	Unit	(a) Spain	(b) Sweden
Solar irradiation[38]	**kWh/m^2/year**	1700	900
Efficiency	**%**	0.15	
Solar panel area	**m^2**	35	
Performance ratio	**-**	0.75	
Annual solar PV generation	**kWh/year**	6693.75	3543.75
Electricity savings			
5% saving	**kWh**	334.68	177.18
7% saving	**kWh**	468.56	248.06
Electricity price	**(€/kWh)**	0.1376[37]	
Cost savings			
5% saving	**€**	46.05	24.38
7% saving	**€**	64.47	34.13

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[35] "Supply, transformation and consumption of renewable energies - annual data", Eurostat [nrg_107a], *Last update: 27-04-2015*

[36] "Global Market Outlook for Photovoltaics 2014-2018", European Photovoltaic Industry Association (EPIA), 2014

[37] "Electricity prices by type of user", Eurostat (ten00117)

[38] "Solar energy resource in Europe", PVGIS © European Communities (2001-2008), JRC. http://re.jrc.ec.europa.eu/pvgis/solres/solreseurope.htm#Fig6