Revisiting the AC vs. DC current wars in “light” (“shadow”?) of Solar Panels

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why did Nikola Tesla win the AC vs. DC current wars against Thomas Edison in the early 20th Century? We start with a brief explanation (our rendering). There are 3 fundamental reasons why AC dominates electricity generation and distribution today.
(1) Intuitively it should be clear that any electricity generation mechanism that ultimately rotates a turbine (a wheel in general) or moves something in a repeated pattern will inherently generate a repetitive voltage (or current) pattern. Since any repetitive waveform can be expressed as a superposition of sinusoids, it might be convenient to think of the first harmonic in this series as the AC voltage or current generated. Note that all methods of bulk electricity generation that have been used to date eventually go through some sort of turbine (for example, coal/oil/gas/nuclear-fuel $\longrightarrow$ heat $\longrightarrow$ steam $\longrightarrow$ rotates a turbine; or the water from the dam directly turns turbines in a hydroelectric station; likewise in a windmill...) and therefore generate AC to begin with. Early generation of bulk DC power was achieved via a rectification (with mechanical devices/means) of the underlying AC.
(2) Transformers can easily step-up or step-down AC voltage and/or current. This made it convenient to confine high voltages only to the bulk transmission lines; everywhere else the voltage could be easily kept only at the level needed by the application.
There was no easy way to do the same for DC.
(3) The load (end application in which the electric power got used) was pretty much neutral to whether the power came through as AC or DC.
Let us consider the realm of applications in early days of Electricity: lighting, transportation and possibly heating/cooling (note that cooling is achieved by running a compressor which amounts to driving a motor). Incandescent filaments in light bulbs work pretty much the same with AC or DC power. Synchronous motors are easier to build, operate and manage than DC motors though...; finally for heating it does not matter whether the current is AC or DC).
It was therefore natural that AC won-out and dominates bulk electricity generation and transmission today.

Solar Panels is the first technology which is radically different from all prior methods of electricity generation. The main differences are summarized below.
(d1) Solar panels inherently generate DC unlike a turbine
(d2) Solar panels are a better approximation to an ideal current source; whilst most of the prior electrical generation methods might be better abstracted/modeled as constant Voltage Sources.

Next we mention some new technologies that can make DC profitable again:
a1> Solid-state devices that can step-up or step-down DC voltages/currents now exist and are improving by the day [1]. In other words, “transformers” that were so crucial in the victory of AC over DC in the early to mid 20th century now exist for DC power as well. Their efficiency is comparable to AC transformers (and has been improving rapidly).

a2> DC transmission incurs a lower loss (the skin effect is absent in DC conductors). For very high amount of power transfer HVDC (High Voltage DC) turns out to be better (less loss) than AC [1],[2, Section 5](that reference claims that for long water crossing, the capacitive losses in AC transmission are prohibitively large, making HVDC as the only viable method of bulk electricity transport in such scenarios).
a3> DC transmission causes much less interference with other electrical/electronic systems.
a4> For ultimate efficiency in extreme bulk transfers it might be feasible to invoke superconductors to achieve HVDC transmission across superconducting lines [3]. The temperature at which superconducting phenomenon manifests has been steadily raised in newer generations of superconducting materials, since the big breakthrough in 1986. As a result, instead of requiring liquid Helium temperatures (4.22 Kelvin, barely above absolute zero), superconductivity is now achievable at liquid Nitrogen temperatures (77 Kelvins) and even higher (currently the record seems to be HTC at 138 Kelvins [4]). To cool only the transmission lines to such low temperatures seems unrealistic and wasteful. However it is conceivable that an extremely high pressure or a cryogenic gas pipeline could carry a superconducting electric transmission line at its core. The cryogenic temperatures might be achieved by letting the extremely high pressured gas expand, perhaps by allowing some small amount of gas to escape in a controlled manner to an "outer shell" which carries gas at a substantially lower pressure, along the entire length of the pipeline (in all likelihood such a pipeline would need to be subterranean). Such an architecture could achieve the duel purpose of transporting Gas (Natural gas or Hydrogen... etc) as well as electricity in Bulk and could become the building block of future energy distribution super-highways.

For all these reasons, we think that at the lowest level, for example in a subdivision where every house has rooftop solar panels, the aggregation of electricity should be done in DC form. This completely avoids the need for AC phase synchronization which can be a very tricky and expensive.

Today a DC to AC converter is integrated with the solar-panels. This is unnecessary and unfortunate. The panel output should be left as DC, thereby avoiding the loss inherent in the DC to AC conversion (even 1 or 2 percent gain could be significant). We think that the panel output should be left as DC and the power available should be used first to operate/run everything that does not need to be AC. For example, lights (note that almost all modern lamps are LED based and can run on DC power). Likewise, all flat screens, TV displays... can also be operated directly off-of DC. The bulk heating devices (almost all houses have a hot-water heater) can run on DC. Potentially in the near future, charging the batteries in fully electric vehicles can also be done by DC power. After all the household needs are met, any leftover/spare electricity can be aggregated in the DC form. Then once a sufficient amount of aggregation has occurred, one single highly optimized DC to AC converter could be thrown in, to couple the entire subdivision's surplus-power back into the main grid. The economy of scale achieved by this method needs to be investigated. It should easier to keep track of which house contributed how much energy when the aggregation is done in the DC form rather than in AC form.

Such an aggregation will solve another big problem with the way the solar panels currently work: If the power-grid has failed for some reason, then the solar panels are immediately turned off. This is done to ensure the safety of repair crews that work on the grid. Last summer (2012) a very powerful summer-storm toward the end of June knocked off a whole bunch of tress and power lines in a single night in the mid-atlantic and north-eastern parts of the USA. Within a day after the storm had passed, the weather reverted to being very hot and sunny again and remained that way for at least the next 10 days or so. Yet the households that had solar panels installed could not use those panels until their electricity was restored, which took 15+ days in many cities. The panels were off for the safety of utility crews trying to restore power back. When people needed the electricity the most and the panels had the capacity to provide it, the panels remained disconnected. This is the result of a bad design and therefore must be fixed. In the so called smart grid, there ought to be enough smartness to put in a relay/switch which disconnects the grid from the home in case of a power outage. At least the solar panels can then continue to supply power to the house. The relay should automatically reset when the grid power is restored.

Finally, if separate wires are required (albeit within a subdivision) for DC power distribution, it is likely to be prohibitively expensive. We therefore think that researchers should investigate "generalized transformer architectures" that can take AC superimposed over (sufficiently large) DC and independently step up or down the DC and the AC components and re-combine them at the output if required. Building such devices is certainly feasible today. If it could be done cheaply on a large scale, that would go a long way toward increasing the overall efficiency of the electric grid.

Accordingly, research should focus on what are the implications of a hybrid AC/DC distribution on the same wiring within a building? What would the interface to the power grid be?
will future appliances be robust enough to work off-of either AC or DC? if not, then what about the enormous base of installed appliances, most of which need AC supply? What are the implications for separating AC/DC for individual appliances?

References

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