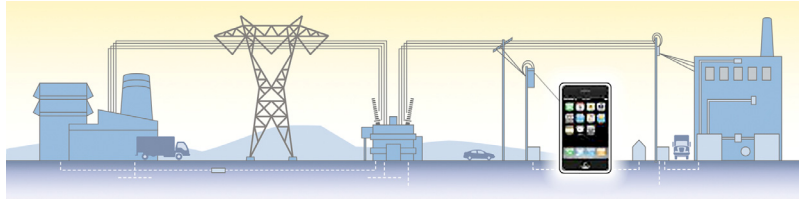


Re-Inventing the Grid With Your iPhone



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Given the major shortfall between the speed with which renewable energy is being deployed and the goals set for its adoption, fundamentally new ideas are welcome, especially where they do not require new technical breakthroughs. DC Microgrids are just such an idea, and - with a bit of courage - a critical look at the grid today tells us how to use them for every stakeholder's benefit. This is a classic "big-picture" idea that needs some new terms for the concepts involved and the first casualty is the Smart Grid.

We do not need a Smart Grid, if by Smart Grid you mean a grid that is only better doing what it currently does. The national power grid system in the US and around the world was not designed to do the things we are asking of it now, and by shoring it up here and there to become a two-way street for power, we risk further embedding a major design flaw vis-à-vis the contemporary needs of the grid's customers today.

The truth is power grids would not exist if they had no load to serve, "the load" being what those in the business refer to as the collection of devices and appliances that use the power that gets generated. The source of electricity and the load have to more or less equal for the grid to function, and so let's refer to the problem that needs to be tackled as improving the "Power Equation" instead of creating the "Smart Grid" to better reflect the reality of our situation - that what needs improving cannot be fixed by focusing on only one-half of the problem.

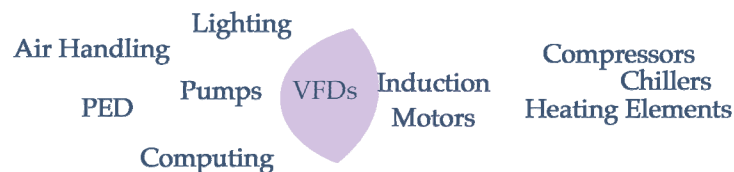
Let us consider the guiding principles of the Smart Grid discussion today. These principles, outlined below, handily apply to the Power Equation discussion as well, only better, because approaching grid challenges as an integrated system of generation, transmission, and loads allows a more holistic view and a larger set of possible solutions. In any event, the things we want in Smart Grid are the same things needed in the Power Equation:

- Reliability; Security; Storage; Distributed Generation
- Efficiency; Sustainability; Renewable Inputs
- IT / Communications Leverage
- Load Awareness; Demand Side Management

Let's un-roll a clean sheet of paper for this discussion and think for a moment how the grid would look if we designed it for today's load. Here's where the iPhone comes in. It is a good proxy for the load-half of the Power Equation for two reasons: first, because it is an iconic device that has unlocked people's thinking regarding many problems, and secondly because it is an electronic device that consumes direct current, also known as "DC", and electronic devices are the growing part of the load already over 50% in many buildings.

This is a trend in place since the advent of semi-conductors in consumer products fifty years ago, which continues to expand. If we look at what's going on in a typical building, the trend is clear:

A Building's Load Set



Computing and Internet connectivity is showing up in many appliances, incandescent lights are giving way to electronic ones, either fluorescent or LED, and portable electronic devices continue to proliferate. These all make gut-sense for many people as evidence of the growing DC load, but one major element of this trend is not well appreciated, and it has been the undisputed champion in the energy efficiency stakes for the past two decades: the Variable Frequency Drive (VFD), sometimes referred to as an Adjustable Speed Drive.

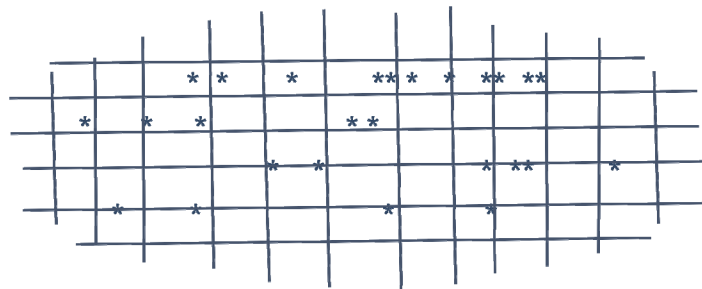
These electronic gadgets have been deployed in the millions to improve the efficiency of the nearly ubiquitous AC induction motor. By installing VFDs in front of their AC motors, building owners and operators are able to control the speed of the motor which delivers an outsized benefit: for every *one-eighth* the motor slows in speed, *one-half* of the energy is saved. Therefore, when a pump, fan or blower motor can opportunistically be throttled back, a great deal of electricity is saved for the customer. The grid benefits too, by not suffering the great spikes in demand that are

caused when regular AC motors are turned off then on because they cannot modulate their speed.

You might be forgiven, when looking at a VFD, for thinking it's an alternating current (or AC) device itself because it has AC going into it from the grid, and AC leaving it to the motor, but as is often the case, looks are deceiving. In order to accomplish its job, of turning AC power of one frequency into AC power of a different frequency, the electricity must pass through a DC state, meaning that the AC motor connected to a VFD has become a DC consuming device, just like your iPhone, laptop, LCD or plasma TV and overhead lights.

Let's sprinkle these loads on a map of a building and imagine how we should power them, borrowing the Smart Grid's guiding principles for our better-optimized Power Equation:

Establishing a DC Network



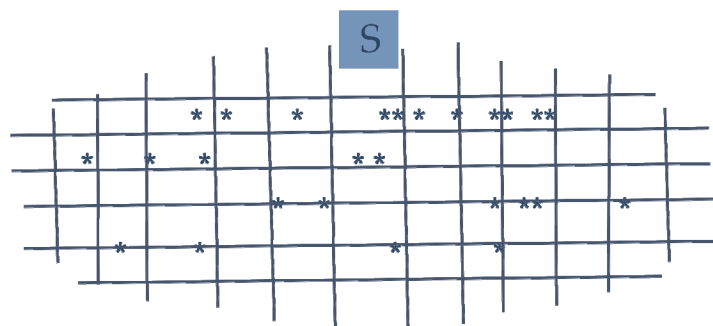
If we are looking for reliability and redundancy, we'll want to create a DC environment to deliver power to these loads just like the telephone company did when it first considered how to best power their DC switches. In fact, Nippon Telephone & Telegraph (NTT) of Japan did a great deal of research in the 1990's when it was planning on how to support the large amounts of new data running over its networks. What it discovered is that when it comes to reliability, AC doesn't come close to the reliability realized in DC power systems. Over nine years, with more than 2x the DC systems observed versus the AC systems, the DC systems delivered better uptimes by eight-to-one. Given the trend of increasing data (which, thanks to VoIP, is what many phone calls are now instead of analogue signals) NTT has deployed hundreds of new DC systems to support their Data Centers. A group convened by the US utilities trade organization, EPRI, has implemented such a demonstration in California and is working with interested parties to do more.

But better redundancy is only the beginning benefit a DC network brings because a DC Network does not need the ubiquitous AC to DC converting power supply (like the brick that plugs into your laptop) for every electronic device. Assumed to be a necessity, these power supplies impose losses on the power going to the device on

the order of 15 to 40%, all of which can be recouped in our DC network by avoiding the need to convert AC to DC inside the building envelope.

Another clear benefit that falls out of the decision to go DC in building a Power Equation is the superior compatibility of the DC power network with electricity storage. During every major grid blackout, or brown-out as periods of insufficient power production are called, experts note that if only means of grid-scale power storage were developed, the stability of the grid would be vastly improved. This is another concept to set aside because of the wrong image it conjures of some giant C-Cell Battery in the desert that would hold the grid up in case of emergency. This is technically possible, but so expensive as to be impractical. The DC network, however, improves the economics of batteries (which are themselves DC devices) by marrying them closely to the DC devices they back-up in a highly distributed fashion. This configuration not only gets more from the battery by avoiding the conversion of its output, it also equals the sum of its parts precisely, such that 1000 small battery banks that each have 10 hours of capacity to run a laptop that needs 100 watts to operate equals 1 megawatt hour just as surely as if it came from a giant battery owned by the utility. But this analogy is too generous: power from the distant battery would suffer other losses the local battery would not. These include inversion losses (going from the DC in the battery to the AC of the grid); Transmission and Distribution losses (estimated to be 7 to 11% by the US Department of Energy); and finally rectification losses when it gets to your electronic load. I'm going to add that up to about 20% in favor of the DC domain, and consequently add Storage to our developing DC Network:

Adding Storage to a DC Network



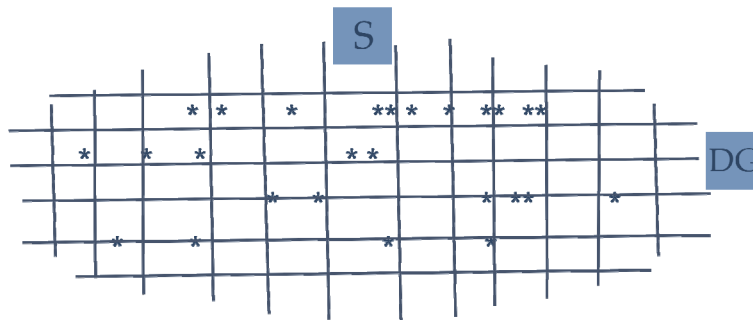
Adding DC Storage to a DC Network is a comparatively simple piece of engineering compared to the complications of integrating DC storage in the AC domain where additional hardware and software are required. The figure above might be how Bell Telephone engineers might have simply drawn the electrical system in one of their

switching stations 100 years ago, where the asterisks would be clattering DC relays completing telephone calls for our grandparents.

This very stable circuit shown above is becoming something transformative as a key piece of innovation in the Power Equation. We have in this set of DC building loads the opportunity to integrate – at higher efficiency – other renewable energy generators that are intrinsically DC sources like solar PV, small wind turbines, or fuel cells. Unlike an AC system these various DC elements can all work in concert without regard to matching phases. In a DC system, only the voltage needs to be considered, whereas AC systems require each element to have identical wave shapes – or be synchronized - in order to operate. This coordination is achieved through a complex device called an inverter, which is the perennial weak link in Distributed Generating systems.

This developing DC Microgrid then can accommodate DC inputs because they are not just more compatible; they all enjoy a common currency:

Adding Distributed DC Power Generators to The Network

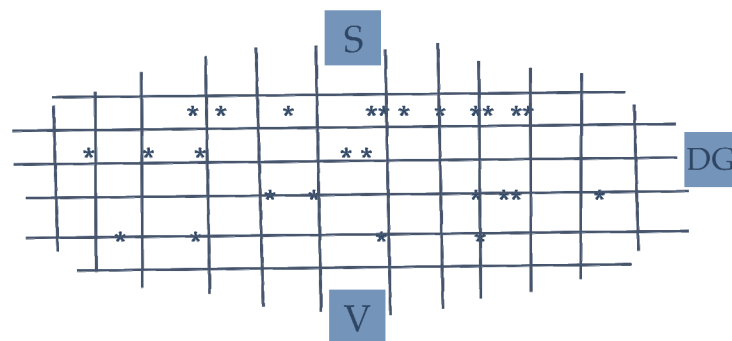


Therefore, given a suitably robust generator and ample storage, we now have quite an efficient local grid network that uses solar PV and integrates electrical storage at higher efficiencies than are possible in a conventional AC system.

This idea of a building as a DC Microgrid can also simplify and raise the efficiency of how Hybrid Electric Vehicles and Electric Vehicles plug into the Power Equation. Rather than automatically requiring the grid to negotiate opportunistic givers or takers of electric power, which could have large adverse impacts on the grid's stability, a DC Microgrid can act like a high-efficiency buffer, sharing generation and storage to better stabilize the system, providing it greater reliability. Moreover, because DC power has no phase to match, the connection to the vehicle is simplified, providing a more efficient path to the DC battery. As a system, the DC Microgrid also creates more possibilities for the vehicle's stored or generated power by enabling

either high efficiency on site use, or the more marginal economics of sending the power to the grid. This option is valuable to the customer and will help create more efficient markets for all Distributed Generation available in the system.

Hybrid Electric Vehicles and Electric Vehicles Fit Better



By locally managing sources and loads, a DC Microgrid can optimize – which in this instance is equal to the minimization of – its net surplus of power (output to the grid) or deficit (input from the grid). This greater local management of both supply and demand buffers the grid and relieves some of its burden. Conventional means of Demand Side Management (DSM) do not accomplish these ends as efficiently. This is possible because we are better exploiting the natural characteristics of DC, the lifeblood of all electronic devices and the de facto fuel of the digital economy.

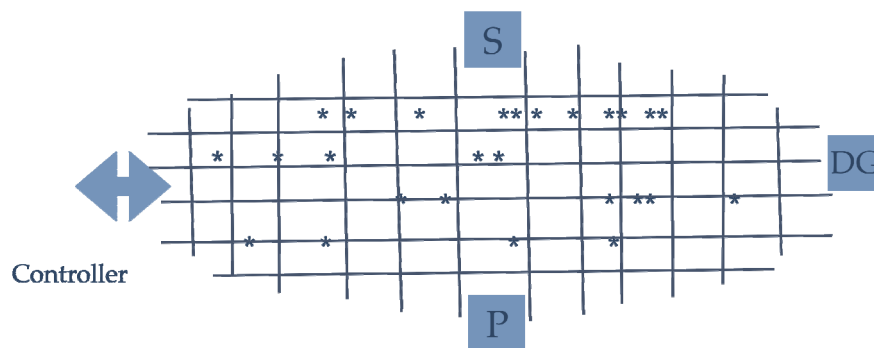
This now leaves us to better exploit the intrinsic characteristics of AC.

Looking back a century at the struggle for dominance in the business of electricity, a great battle was fought over which paradigm would hold sway, AC or DC. A great deal of business history was written about these attacks and counter-attacks, as well as a few torrid battlefield accounts, which all boil down to, for our purposes, four important points. First, wholesale power production in large plants was cheaper than many distributed small ones. Second, AC could travel long distances with low losses, unlike DC. Third, incandescent lamps were the majority of the load and they operated on AC or DC. And fourth, semi-conductors had not yet been invented.

These facts led to Westinghouse’s triumph over Edison in many ways; but they are also the reason why we need to resurrect some of Edison’s arguments to better serve the load today. As the Smart Grid guiding principles remind us, our Power Equation has to protect the environment more, and has a growing need for Distributed Generating DC inputs like solar PV and DC Storage. What is also abundantly but more subtly apparent is that electronic devices are the fastest growing segment of the load, showing decades of growing momentum.

The key strength of the AC paradigm, which DC has not assailed, is its un-matched efficiency as a long-haul operator. While some short high voltage DC transmission is used as a buffer between large utility service territories in order to isolate potential phase mismatches, it is still relatively rare. We should, therefore, use the AC currency of the grid to the maximum benefit, as we have done with DC. If we can minimize the 2-way traffic on the grid and deliver greater reliability and efficiency to the customer's load, it should be done. If this change in system architecture also improves the economics of storage and renewable energy inputs, it must be done.

Optimizing the DC Microgrid Connection to the Grid



In this configuration, buildings become truly Smart Buildings that are not just reactive but meaningfully proactive in the Power Equation. This move properly places a great deal of the work being done to achieve the Smart Grid principles closer to the Load in the DC domain where the power needs to be processed less, yielding higher efficiency and greater compatibility with stored and renewable energy. The Power Equation, then, can better match the load to its sources.

Furthermore, the old saw about the installed base being an impediment to upgrading the architecture of the grid can be – and is being – discarded today. Fifty companies, including about half of the lighting market in North America, are backing the idea of a low-voltage DC power standard for manufacturers and systems integrators to use in their commercial products. That will only gain momentum as LEDs come to market, themselves mostly 24 VDC devices, already compatible with the 1.0 version of the standard.

Over the past 10 years, the company I work for has provided DC power systems and components to 40 customers in the US and 6 other countries. We recently developed a product to power a new kind of suspended ceiling that distributes low-voltage DC power through the metal grid support structure in which ceiling tiles sit. Our partners in this new system deliver enough ceilings to the market every year that, if all were specified to distribute DC in this new way, with solar inputs, the US

could double its installed base of grid-connected solar PV in one year to over a Gigawatt.

Similarly, roof-top solar could be used in its native DC form to offset air handling loads at 99%+ efficiency to the tune of approximately 10 Gigawatts in the US. This is power that, as in the lighting example, brings both the user and the wider grid consumer base benefits the AC paradigm does not, avoiding transmission and distribution losses as well as conversion losses at the building site.

These kinds of innovations are required if we are to meet the RPS standards in the US, or by extension the Carbon mitigation demanded by the Copenhagen Treaty. Neither set of goals will be met without DC Microgrids as part of the solution set.

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