The Ravina Project

Solar PV Capacity Factor

Insights and Comments

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An Introduction to The Ravina Project

The Ravina Project, conceived in late spring 2006 and up and running in November of that year is a household-focused engineering science project. We are collecting high fidelity data and writing formal papers on such topics as: household cooling and heating efficiencies, solar PV efficiencies versus ambient heat and sun angles, solar PV Capacity Factor, the invention and use of a new solar PV efficiency standard, household resiliency, household thermodynamics, and how 'livable' a lower carbon emission lifestyle can be, among other things.

Our high fidelity databases are large and growing, totaling over 100,000 pieces of data. They allow us to validate or falsify various speculative hypotheses. They also allow us to anchor our published papers in data rich analysis. Some papers rely upon the analysis of several thousands of observations.

Our programmable dynamic solar array structure is unique. It is specifically designed to enable the collecting surface to tilt and compensate for the sun's altitude in the sky on an hourly basis. This ability is critical here at 43.7 degrees latitude where for about 90 days a year, the sun does not get above 30 degrees in altitude above the horizon at noon, sun time. As a bonus the dynamic array produces observations which allow us to calculate a solar array's aperture. For those areas outside the Tropics, the calculations we have made help us define the best algorithms for low cost, simple, hand operated 2-axis sun tracking systems which lose little in potential harvested energy due to poor sun angles upon the collecting surface.

In addition to the science and data gathering, The Ravina Project is conceived and built as a prototype upgrade to an existing and very common housing type in the Greater Toronto Area. We are testing the integration of various sub-systems over an extended number of years to determine their compatibility both with each other and with the people, plants and pets making up the household. Our modified 1920s era house allows us to empirically test out our resiliency, especially Grid resiliency, as real world disruptive events occur. We understand that technology is changing and the particular technologies we are using to provide resilience will be obsolete in future years. However, we see the resilience functionality we have created being incorporated into future technologies which will be more powerful, compact and probably cheaper in real dollars to adopt. It is our view that future events will create market demand to the extent that Grid resilience is either designed into new houses or provided as an upgrade package to current householders at much lower cost than a new bathroom. Refurbished and reconfigured used electric automobile batteries may provide a key piece among the technologies included in the future Grid resilience packages available to householders.

We envision a future in which the availability of electrical Grid power and carbon based fuels will be, of necessity, much lower than today. Due to growing climate disruption/global warming, residential Grid power supply may become intermittent on a regular basis as it is today in many parts of the Second and Third Worlds. When resiliency to Grid interruptions are built into housing infrastructure, such interruptions will not be as catastrophic as they would be in present day First World neighbourhoods. On a city wide level household Grid resilience allows utilities to build smaller scaled, lower carbon, centralized power supplies because they have the option of disconnecting whole neighbourhoods during peak power demand.

We understand that reducing a household's carbon footprint is vital to reducing overall atmospheric carbon release. We are looking closely at our attitudes and lifestyle for insights into such areas as: household carbon accounting, using software rather than hardware defined devices, carbon based functional analysis of both the technology we employ and the consumer products we purchase. These changes are our attempt to modify our attitudes and desires so that we may decouple ourselves from the current and prevalent consumption based modernity. However, we also know that high technology, applied correctly, will allow for this decoupling on a massive scale.

As the changed lifestyle part of the experiment unfolds today, it becomes apparent we are living a future lifestyle in an old house modified for tomorrow.

All our data and papers are published on our WEB site at: www.theravinaproject.org

Regards,

Susan and Gordon Fraser
Directors

The Ravina Project

Solar PV Capacity Factor

Abstract

There are many who envision industrial sized solar PV generation as being a major player in the Canada's clean power generation suite. In this paper we introduce the concept of Capacity Factor (CF) for non-technical readers. We examine on a seasonal basis solar PV Capacity Factor using over 2100 continuous days of observations across six years. We model the revenue stream of a 20 MW solar PV power plant here at 43 latitude. We analyze the actual seasonal power harvesting capabilities of solar PV using several different criteria including length of day and efficiencies. And finally we analyze industrial sized solar PV energy harvesting both on its own and systems-integrated into a much larger generation mix whose goal is to replace existing fossil fuelled and nuclear powered generation. The conclusions are, from our analysis, that firstly, solar PV is a 'boutique' or 'niche' market power harvester very good for rooftop solar installations and the like, and secondly, that industrial sized solar PV power harvesting is not viable as a replacement for baseload power supply.

Introduction

Many people believe that solar photovoltaic (PV) panels will provide one of the backbones of our energy production. Many others believe that we can eliminate all our carbon emissions and nuclear based power supply using solar PV plus other renewables to power our complex civilization. We want to present our generation data for each season as an exercise in building a realistic model for planners at this latitude of 43 degrees. We use the word 'complex civilization' as a short form for the idea that we have many more choices in doing almost anything today than we did 100 years ago. In food, materials employed for everything we use and wear, to communication options, our choices are many. We see a direct correlation between our civilization's complexity and energy use. We also 'tip our hat' to Joseph Tainter.

Our goals in this paper are:

- to provide the reader with a realistic understanding of the energy harvesting potential here at about 43 degrees latitude,
- to align expectations for solar generation with the actual data describing solar generation at this latitude,
- to explore the unique properties of solar PV power generation, highlighting some insights we gained from our data and finally,
- to examine the implications of those unique properties for all stakeholders everywhere who use, or plan to implement, industrial sized solar PV generation.

Capacity Factor (CF) and Nameplate Capacity (NC)

We introduce Capacity Factor and Nameplate Capacity together at the start because these two metrics are critical to understanding power generation. Every kind of generator, renewable, nuclear or fossil carbon based has a value assigned to them for both these metrics.

What is a Nameplate Capacity? The Nameplate Capacity is defined as the number of watts the generator can provide at full rated power. Generators are typically called by their Nameplate Capacity. Our generator was a 1,500 watt solar PV array (since upgraded in September 2013 to 2,800 watts, 10 panels of 280 watts each).

What is Capacity Factor? The Capacity Factor for a generator is simply the percentage of the generator's Nameplate Capacity available over a period of time. A 1000W generator provides 500W on average over one hour. The Capacity Factor of the generator is 50% for that hour.

Capacity Factor is very helpful to power utilities when they are planning for changes in their generation mix. You are a power utility and your primary job is to provide adequate electrical power for your customer's load. Your customer load is growing which means you are going to have to increase your generation capacity to cover the projected increased usage plus, of course, a cushion, a margin to cover outages with existing generators. You also know that several generators are going off line for good over the next years, so new capacity must be brought on line to compensate. Capacity Factor allows utilities to make more confident assessments about the amount of energy an extra generator will make available in the future. This analysis is a bit simple minded because a utility could purchase the required power from another utility and not build/lease new capacity. Be that as it may, let's assume it expands its generation mix.

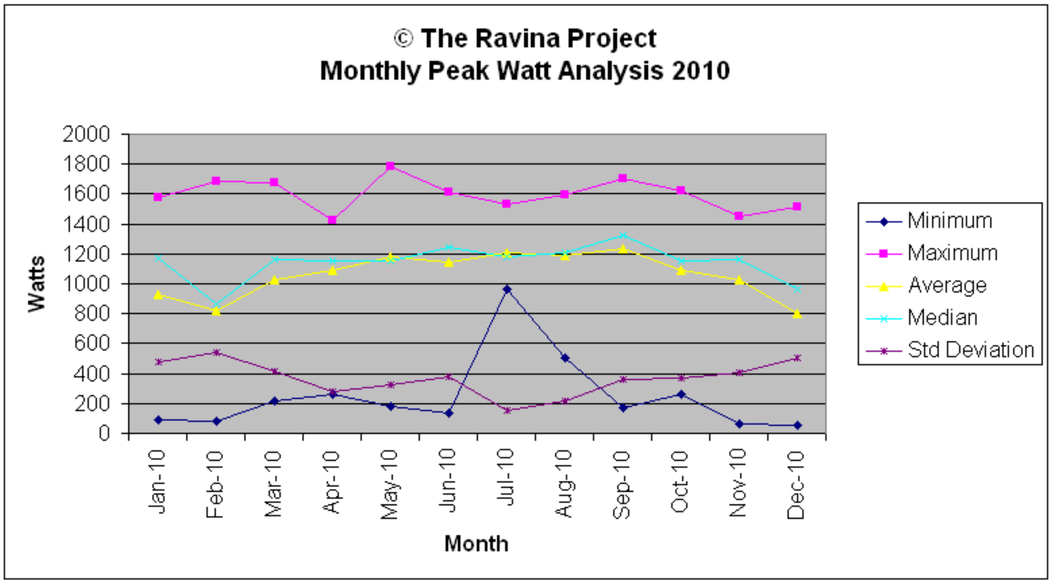
The first thing to note is that Capacity Factor is not some value created from nothing. Let's say the first wind turbine in the world is erected and placed on line. What is the CF for this turbine? Well, there is none! Why? There is no CF for this turbine because it has no generation history other than the test data from NREL (National Renewable Energy Laboratory) or some like organization. Today we have data from tens of thousands of wind turbines of every design, in every kind of wind environment providing us with a huge database of generation history. No matter where a generator is built we either know or can calculate roughly what its CF will be. We assume that it is erected in an area that has good steady winds and we know the range of CF it will fall into. Wind turbines have a CF of between 20 and 40 percent no matter where they are built. There are few exceptions to this range but they are outliers.

Capacity Factor for various Generators

A generator's Capacity Factor can be used in a misleading way by rhetoricians who want to argue for and against various modes of commercial electrical power generation. Did you notice that CF has no time duration associated with it? If the time duration shrinks and a particular period of time is carefully chosen, Capacity Factor can be calculated using real data (not predicted data from models) to be really any value between zero and 100% … or even more as we will show. For every generator, more or less, there is a time duration where it generates power at 100% output. If you find that duration you can legitimately say that 'data' indicates this power plant has a Capacity Factor of 100%. We here at The Ravina Project have calculated our CF on a daily basis for over seven years so far. We break out six years of data by season and by length of day as you will see below.

You might counter that calculating CF on a daily basis is itself a scam and a gross manipulation of the data. We disagree and here's why. Solar PV is unlike any other renewable resource in so many ways (as we will demonstrate below) that it needs to be treated separately from other green sources. One of the outstanding differences is that solar PV is off line at sun set and stays that way until sun rise. No other form of green energy harvesting has this characteristic. This unique 24 hour ON / OFF cycle gives us a natural and enforced pause each day to calculate a daily CF. Our database of over 2100 contiguous daily observations allows us to make some significant statistical assessments regarding solar PV at this latitude.

Consider the following graphic from our WEB site:



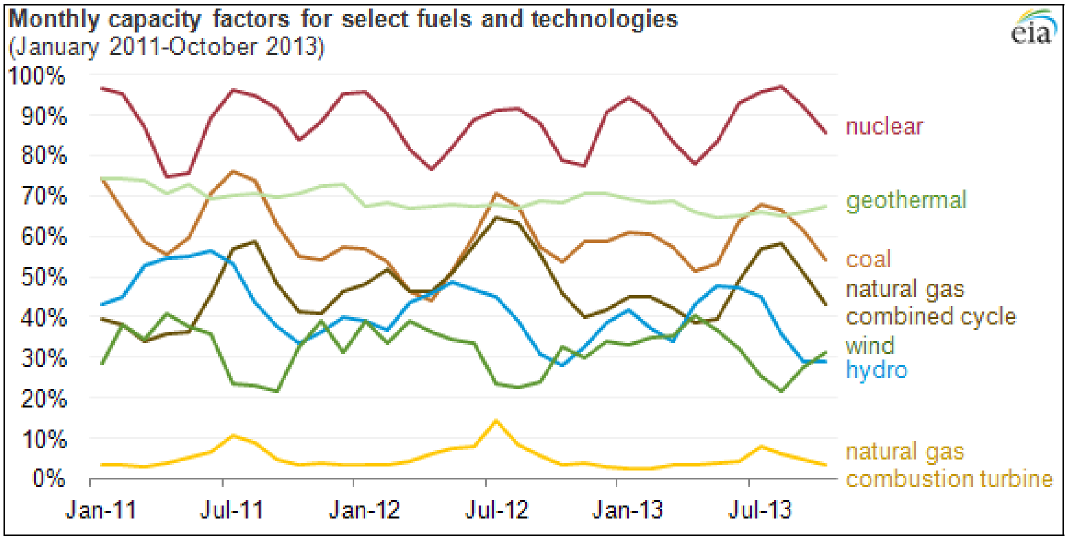
Our solar array had a Nameplate Capacity of 1,500 watts in the year 2010. We record the maximum power level for each day from our solar charge controller. Every month we crunch the daily maximum power recorded into standard statistical values like: maximum, minimum, average, median and standard deviation. The chart above is a statistical synopsis of each month's daily peak power recordings. So for January, in the depths of the poorest solar PV generating season the highest daily peak power came in at a little under 1,600 watts. The lowest January daily peak power value came at about 100 watts. But back to our argument that Capacity Factor can be manipulated to be any value you wish (almost), notice that every month of that year except for two have peak power values over 1,500 watts. That means of course, if those peak power time durations were used for CF calculations our array would have a CF greater than 100%. And to make matters worse, firstly, we are credible; we have actual real world data to back up our claim and, secondly, to repeat myself, there is nothing in the definition of CF to make such obvious chicanery invalid. Most recently we have talked with a wind project investor who swore his new project would have a CF of over 60%. Nothing I said deterred his belief in the numbers.

Below are the Capacity Factors from the U.S. EIA and others assigned for different power supplies:

- Natural gas plant: 42.5%
- Coal fired: 40% to 60%
- Oil : 7.8%
- Hydroelectric: 44%, the range is from 10 to 99 percent depending on design and water availability
- Nuclear from 70 to 95 percent
- Wind from 20 to 40 percent
- Solar PV in Arizona 19%
- Concentrated Solar Power (CSP) in California: 33%
- CSP in Spain with storage: 75%
- Geothermal, from Bloomberg New Energy Finance looking at 71 generators: 73%
- Rance Tidal Power Station 240MW: 26%
- SeaGen Tidal Power 1.2MW: 66%

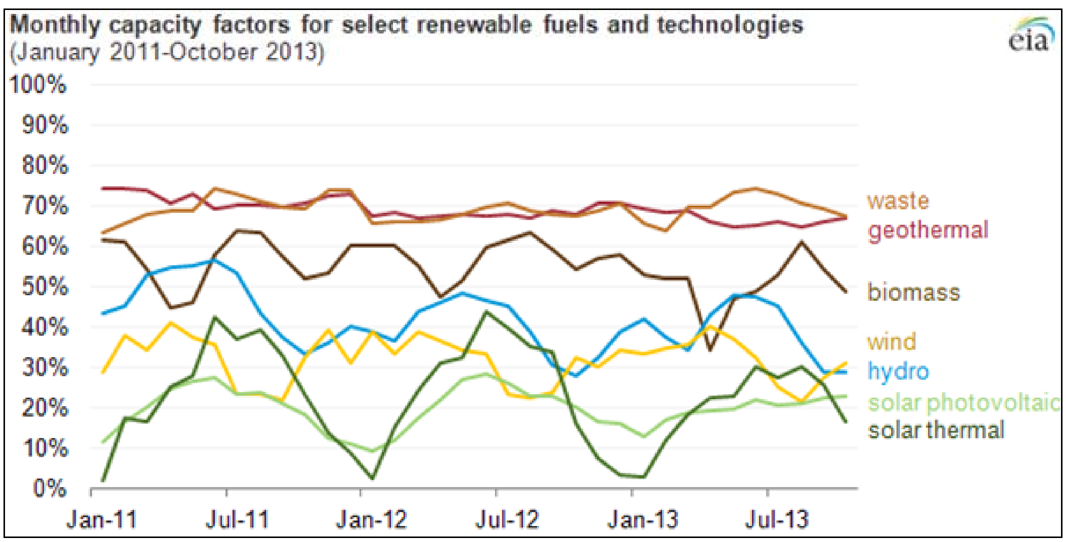
But as we have seen, putting one value on each generator has pitfalls. A more accurate way of assigning CF to various generators is to chart the output over a period to time as we do with our data on a daily, seasonal, yearly and multi-year basis.

The EIA supplies these kinds of charts: http://www.eia.gov/todayinenergy/detail.cfm?id=14611



There is a lot on this chart and I'll leave it to the reader to have a really close look at it and think about the implications for the current ongoing arguments among factions regarding which power generation technologies to use for base load going forward into this century.

Consider the companion chart also published by the EIA.



Contrast these charts with the static values mentioned above. Even a cursory examination gives one a whole new and much deeper understanding of the generator's CF characteristics than that implied by their static numbers.

The important thing to note is that the larger the Capacity Factor for a generator the more reliable it is and of course the more valuable it is to the utility/investors. Big Capacity Factors over time ensure available power to customers who are using power at all times of the day and night.

A Short Note on Calculations

Many calculations follow in this paper. Here is a list of a few principles we follow:

- To calculate 1 kilowatt of solar harvesting potential we use solar PV panels at 20% efficiency which means one kilowatt of solar (NC) contains five square meters of panels.
- To calculate a generator's effective power output we multiply average Capacity Factor by Nameplate Capacity. The answer is expressed in watts.
- To calculate a generator's energy output over a time period we multiply its effective power output in watts by the length of time in hours. The result is expressed in watt-hours or the like.
- To put various generators on equal footing we reduce each to its effective power output before we make the comparison.

This is a non-technical paper but there is arithmetic involved in many of our calculations. We want to demonstrate the reasoning behind the various calculations we make in order for the reader to better follow the arguments.

Here are some typical problems to be solved.

Suppose we have an average 18.5% CF solar array which generates 1 GWh of energy in a year. How many square meters does the array cover on the earth's surface if it is constructed of 20% efficient panels?

There are 8,760 hours in a year so the effective power output of the array is 1,000,000 kWh divided by 8,760 hours equals 114.16 kW. We know that the array's effective power output is calculated by multiplying the average CF by the Nameplate Capacity. Therefore the Nameplate Capacity is calculated to be 114.16 kW divided by .185 CF equals 617.08 kW. We know that there are 5 square meters of 20% solar PV panels in one kW of Nameplate Capacity. Therefore there are 5 square meters/kW times 617.08 kW equals **3,085.4 square meters** of solar panels which if arranged in a square would be 55.5 meters long on a side.

A 250 MW Nameplate Capacity hydro dam runs at an average CF of 80% over the year. How many 5 MW Nameplate Capacity wind turbines running at CF of 35% would be required to replace the dam?

The dam's total energy output for the year is 8760 hours times .8 CF times 250 MW Nameplate Capacity equals 1,752,000 MWh or 1,752 GWh. One 5 MW wind harvester working at 35% CF would harvest 5 MW times .35 CF times 8760 hours equals 15.330 GWh in a year. The number of 5 MW wind turbines required would be 1,752 GWh from the dam divided by 15.330 GWh for each turbine equals **144.3 five MW wind turbines**.

The alternate solution is to reduce the generators to their effective power output and then divide while ignoring the number of hours which are identical in each case. The hydro dam's effective power output is 250 MW times .8 equals 200 MW. The 5 MW wind turbine has an effective power output of 5 MW times .35 equals 1.75 MW. The number of wind turbines needed to replace the dam is 200 MW divided by 1.75 MW equals **144.3 wind turbines**.

A 1 GW coal fired power plant running at a CF of 90% is to be replaced with solar PV and wind in equal proportions of 500 MW each. How many 5 MW turbines at CF of 35% will be required and what area will be taken up with the solar harvesters working at a CF of 20%?

The effective power output from the coal plant is 1000 MW times .9 is 900 MW. To replace 450 MW with wind we need 450 MW divided by (5 times .35) equals **257 turbines**. 450 MW effective power output from solar equals Nameplate Capacity times CF of 20%. Solar Nameplate Capacity is equal to 450 MW divided by 20% CF equals 2,250 MW of solar PV. 2,250 MW of solar will cover 2,250,000 kW times 5 square meters per kW equals 11,250,000 square meters or **11.25 square kilometers.**

The more traditional method of calculation would be as follows: a 0.5 GW power plant running at 90% CF would generate 450 MW times 8,760 hours in a year or 3,942 GWh per year. A 5 MW wind turbine running at 35% CF would generate .35 times 5 MW times 8760 hours in a year equals 15,330 MWh. The number of wind turbines required to replace 450 MW of coal generation would be 3,942,000 MWh divided by 15,330 MWh equals **257 turbines**. We know that 5 square meters of 20% efficient solar PV makes up 1 kW of Nameplate Capacity. The effective power output of 1 kW of solar PV is equal to 1 times 20% equals 200 watts. Therefore 1 kW of effective power output from 1 kW of solar requires 25 square meters of solar PV panels. In a year the 1 kW of solar will generate 8,760 kWh energy using an area of 25 square meters. Therefore half the coal plant's output can be replaced by 3,942,000,000 kWh of coal generation divided by 8,760 kWh equals 450,000 1 kW effective power solar generators of 25 square meters each. The total area for the solar plant will be 450,000 times 25 square meters equals 11,250,000 square meters or **11.25 square kilometers** of solar collector.

Four Seasons of Solar PV Power at 43 Degrees latitude

We have been watching the sun and its seasonal angles for over seven years along with recording hourly (more or less) observations of the sun's current power and sky conditions. We have also written papers on many aspects of energy harvesting using solar PV including: inventing a new energy efficiency standard that we use and calculate on a daily basis, and modeling the power being harvested at any time of the day in relation to the sun's angle upon the solar array's surface. See www.theravinaproject.org/project_papers.htm for more.

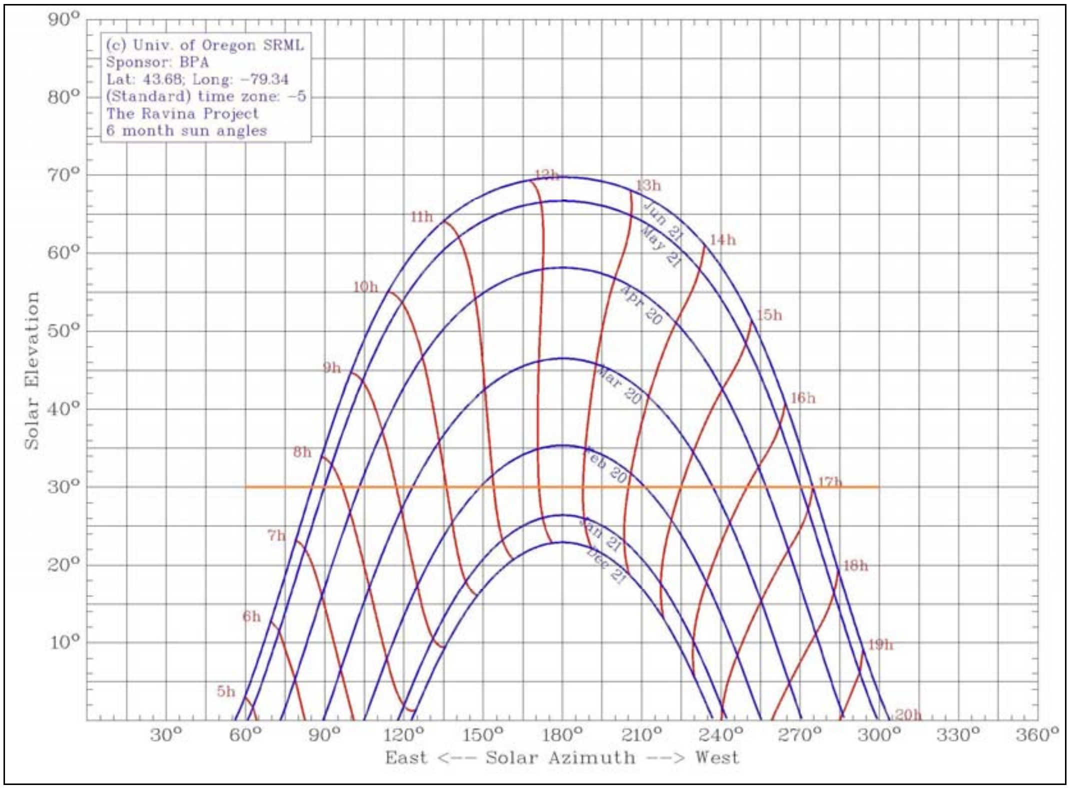
We are at 43 degrees 40 minutes of latitude. So some of our comments regarding the sun must be understood in this context. That being said, many of our insights are applicable to anywhere on the surface of the planet between the Polar Circles and the Tropics. In fact to demonstrate that our observations and CF calculations are applicable to a range of places on the surface of the Earth, we have included sun charts at 38 degrees and 48 degrees latitude. More on this discussion below.

Our solar array is moveable such that it can compensate for the sun's altitude in the sky. This allows us to make observations regarding the effects of different sun angles upon the array's collecting surface and its power output. We have several papers that demonstrate these effects. However, the bottom line for this paper without getting too technical is that the more acute the sun's rays upon the collecting surface, the less power harvested. The predictive models we have built based upon this insight co-relate with real world power output to over 0.90 ($r>0.90$).

Maximum power occurs when the sun's rays fall at an angle of 90 degrees upon the array surface. Think of it as the relationship between the array's angle with the sun and the total area of shadow cast by the array. The array is programmed to maximize the size of its shadow as the sun progresses across the sky. Our tilted array structure allows us to 'correct' for the sun's altitude above the horizon so that the sun is falling at about 90 degrees on one axis. We do not correct for the sun's off angle on the azimuth but as the sun traverses the sky, an optimal orientation occurs on this axis once as the day progresses even in the depths of winter. 100% power output occurs by necessity and design every day.

So how does it work? The array when tilted has a direction of tilt towards the horizon. Note a flat array has no direction. Our array when tilted points to a direction of 150 degrees on a great azimuth circle of 360 degrees where 180 degrees is directly South. Every day the sun passes a bearing of 150 degrees which maximizes the width of the array's shadow. We have no control over this situation but we can however, adjust the array's elevation such that the height of the array's shadow is also maximized. We look at the sun chart for the week and program the array controller to change the angle at various times during the day keeping the shadow within 1% of maximum. In real terms this means we keep the array's compensation within plus or minus 5 degrees of the sun's actual altitude in the sky. Even in the depth of wintertime when the sun is only 17 degrees above the horizon at a bearing of 150 degrees the array tilts to 70 degrees ensuring the sun's rays strike the array at 90 degrees on one axis and 87 degrees on the other.

If we look closely at the sun's journey across the sky on a six-month basis we can make some interesting observations. Consider the following graphic which we have modified with an orange half power line:



The sun chart above was generated by the University of Oregon for our latitude and time zone.

This six-month sun location chart (December 21st to June 21st) calculates what a person observes from a fixed location upon the Earth's surface. As you can see the chart mentions our latitude and longitude as the fixed location. The solar elevation scale on the left side of the chart is a measure in degrees of the sun's altitude above the horizon. The sun's azimuth scale on the bottom of the chart is a measure of the sun's location on a great circle at the horizon with a bearing of 180 degrees being due South. The blue line traces the sun's location in altitude and azimuth each minute of the day when the sun is above the horizon. The time of day is specified in Standard Time (for our Time Zone) and the dates are written on each of the curves. Note that noon does not mean that the sun is directly South of us. This is not an error. Because of the great Canadian, Sir Sanford Fleming we have Time Zones on a worldwide basis. Our Time Zone ticks over to 12 noon as a whole corresponding to the sun being (theoretically) directly South when viewed from the far Eastern end of the Time Zone. However, here in Toronto, the sun has to travel for some time in a westerly direction to get to us before it is directly South of us.

Anyway, technicalities aside, observe that the sun climbs higher in the sky for half the year at 12 o'clock noon (more or less) sun time. The other half year is a mirror image but opposite of the first. We did not include the sun chart for the other half of the year but you can imagine it. Nevertheless, observe that the sun spends a few months lower in the sky and a few months higher in the sky. Note that the sun travels quickly from the lower daily noon sun altitudes to the higher daily sun altitudes in the same number of months as it does lingering at the high or low daily altitudes. This shape of the sun's journey through the sky is dependent upon our latitude and our axis-tilted Earth. That is, all places on the Earth's surface at latitude 43 degrees both North and South will have the same yearly sun pathway through the sky. Christchurch NZ has the same sun angles as we have here in Toronto but they are offset by 6 months and 180 degrees (the sun travels through their Northern sky).

Here at The Ravina Project we call the months the sun lingers at its maximum noontime altitudes in the sky, for about 90 days, summertime. Similarly, we call the months where the sun lingers low in the sky for about 90 days, wintertime. When the sun races from the low angles to the high angles, another 90 days, we call this time spring and finally, when the sun races from high to the low angles, we call that fall. These dates are related only loosely to the seasons as we know them. Our 'seasons' are based entirely upon the sun's daily power output as a function of its angles upon a flat plate horizontal with the Earth's surface at this latitude.

On a technical note, we have measured that the sun's power upon a flat plate is proportional to the Cosine of the sun's offset from Normal or in other words, the sun being directly overhead. This sun orientation would never occur outside the Tropics. So if the sun anywhere on the planet has an altitude of 30 degrees above the horizon then its relative power upon a flat plate as compared to the sun being at Normal, directly overhead, would be Cosine (90-30) = .5 or 50% (half power). We have added an orange half power line to the above chart. Whenever the sun is above this line it is delivering more than half power to a flat plate. It looks like it takes until about February 5th noon, sun time, for the sun to move to an altitude of 30 degrees in the sky and that, strangely enough, is the start of our springtime!

From the sun chart above on December 21st at noon sun time, the sun's altitude is about 23 degrees and has a relative power upon a flat plate of Cosine (90-23) = 0.39 or 39% of the power it would have at Normal. Similarly on June 21st at noon sun time, the sun is about 70 degrees in altitude and has a relative power of Cosine (90-70) = 0.94 or 94% of the power the sun would have at Normal at our location upon a flat plate. Note that if the array elevates such that the sun falls on it at 90 degrees even though the sun it not at Normal on a flat plate, the array will operate at 100% relative power, Cosine (90-90) = 1.0 or 100% on one axis.

The actual dates for our 'seasons' are based entirely on the sun's power at 43 latitude:

- winter, from November 6th to February 5th
- spring, from February 6th to May 5th
- summer, from May 6th to August 5th
- fall, from August 6th to November 5th

From our data each of these periods has a distinct sun power and energy harvesting characteristic even though the spring and fall sun angles are essentially identical … more discussion on this apparent anomaly below.

Four Variables

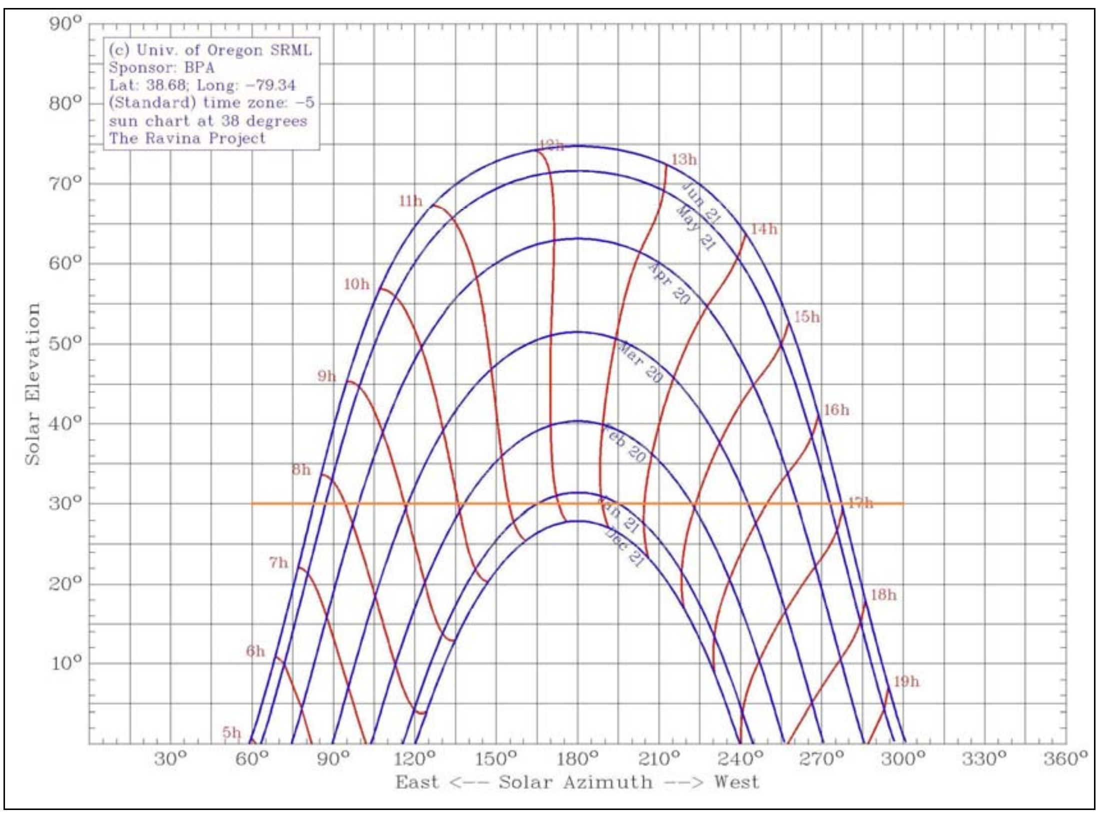
There are really only four variables that a user of solar PV panels can control:

- the physical size / panel efficiency of the solar array,
- the circuitry of panels installed, that is, the shape of the strings of panels that are wired together,
- the angle/azimuth of the collecting surface and
- the location within the local area complicated by time-of-day shadows of trees, buildings and the like.

Everything else is beyond the user's control. From our daily observations we have found the sun's location in the sky and sky conditions (clouds, haze, smog, jet vapour trails, the amount of atmosphere the sun's rays have to travel through and the like) are the two greatest determinants of the sun's power at any moment in time. The lower wintertime sun angles are solar energy killers even for us, with a one axis compensating array, for no other reason than the amount of atmosphere the sun's rays have to travel through to get to us. This long journey attenuates the very light frequencies that are critical to harvesting power from the sun using solar PV collectors.

Harvestable power at other latitudes

One might assume that all our observations and calculations of Capacity Factor are limited to our latitude only. This argument is true but only partially so. To demonstrate this point, observe the following charts. We have added the half power line like the graphic above.

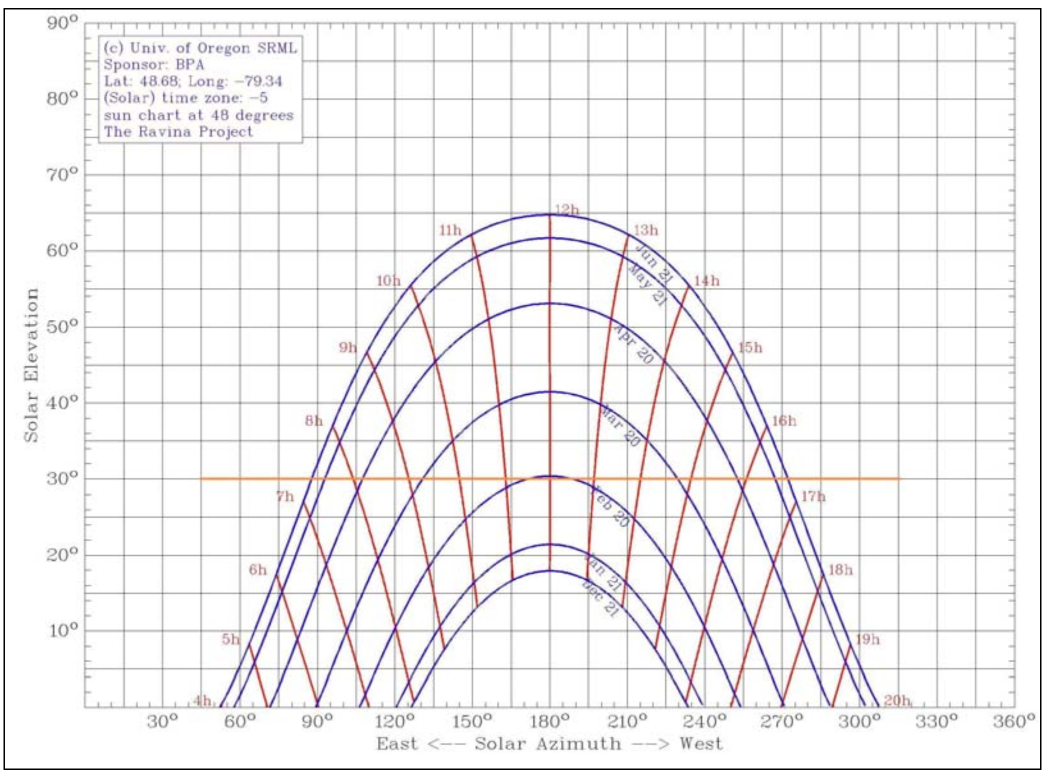


The chart above is based upon a location near Franklin, Pendleton County in the Eastern part of West Virginia, U.S.A. Any location at this latitude will have the same sun chart. On the East coast of the USA this sun chart would be seen on the Southern border of Delaware on the Delmarva

Peninsula. Or on the West coast it would be seen at Sea Ranch CA on the coastal highway in North West Sonoma county. This 38 latitude forms a line right across the USA with many states intersected or North of the line. All the huge population centers on the East coast are North of this line. Note the chart's times of day are relative to each time zone. It's the shape of the sun's journey through the sky that determines the sun's power and unless your are programming a sun tracker like us, time is of no consequence with respect to the sun's power.

As we observe the chart we see that the sun at noon June 21st is 5 degrees higher giving a slightly greater sun power upon a flat plate of cosine (90-75) = 0.97 or 97% of the sun's power at Normal. This is up from the 94% at 43 degrees latitude. If we compare the longest day sun rise locations on the azimuth we find that both charts show the sun rising at about 60 degrees and setting at about 300 degrees. So the longest days are about the same length. The shortest day of the year again has about the same location for sun rise and sun set at 120 and 240 degrees. The chart is slightly wider in the summer time indicating more minutes of better daily sun angles upon a flat plate, hence the area of the chart totally above the ½ power point is greater than for us here at 43 Lat. Spring starts around January 14th. As you can see the charts are very similar even though we have moved 5 degrees South of Toronto.
In Europe the 38 degree line starts in Southern Spain proceeds South of Italy, through Athens, North of Afghanistan, emerging well South of Beijing, China in the Bohai Sea. It continues to Sendai, Japan in the North of Honshu. All these places have the same (more or less) sun chart as above compensated for by the local time zone.

Consider the following sun chart for 48 degrees latitude modified to show the half power point.



The chart above is based upon what a person would see if they were in Rouyn-Noranda, Quebec about 5 degrees North of us here in Toronto. On the East coast of North America, 48 latitude intersects Southern Newfoundland. 48 Degrees latitude defines the border between Canada and the USA from the Great lakes to the West Coast. The vast majority of Canada lies North of this border and of course will have poorer sun angles than shown on this chart. As far as North America is concerned, there is a huge population between 38 and 48 degrees. In Europe and

Asia the population is large as well. 48 Lat cuts through Paris, France and on to Vienna Austria, North of the Black and Caspian Seas, and on over Mongolia to Khabarovsk, across Sakhalinskaya Island and the Gulf of Patience on to North America just South of Vancouver.

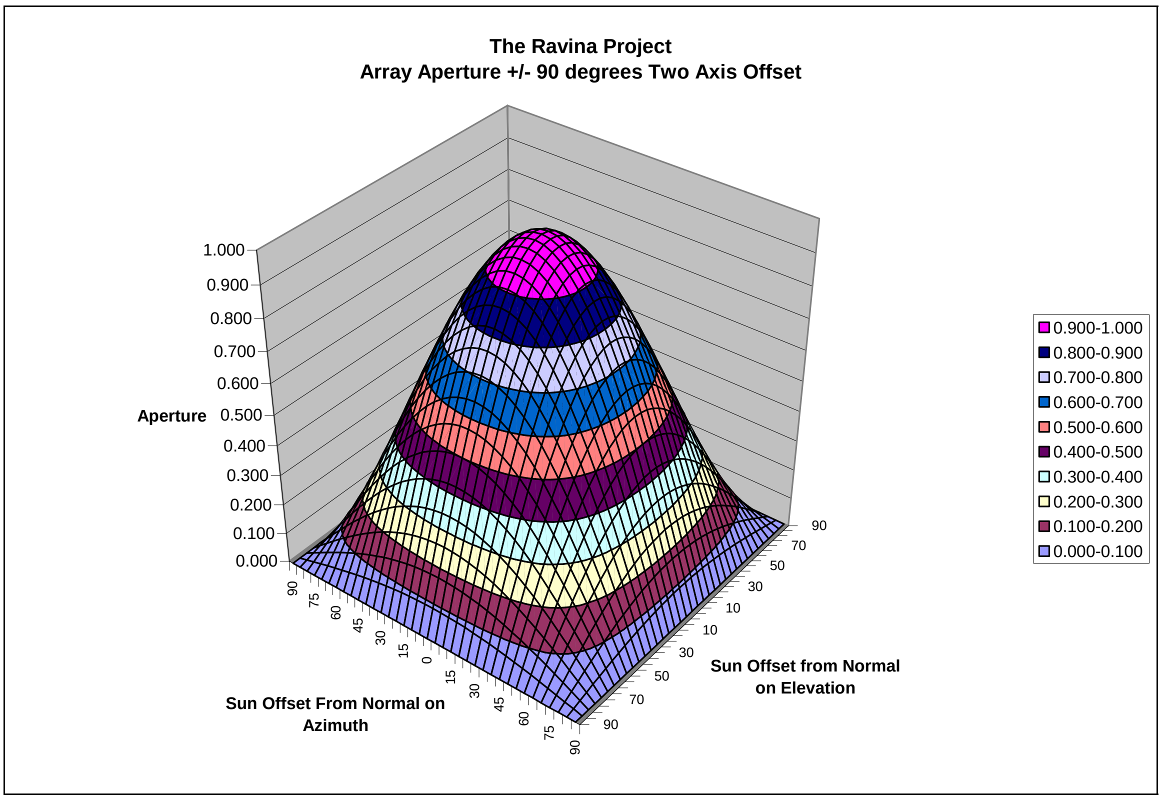
Note that the sun rise and sun set locations on the azimuth are about the same. The summertime sun altitude on June 21st noon sun time is only 65 degrees which translates into a relative power of Cosine (90-65) = 0.91 or 91% of the sun's power if it were Normal to a flat plate.

So we have moved 10 degrees and the sun power moves just six percent at noon sun time on the longest and most powerful day of the year. What this tells us is that the analysis we do here upon our data at The Ravina Project is applicable to this huge swath of geographical locations and humanity all living between 38 and 48 latitude in both hemispheres.

On the other hand we would not like our data applied to a location outside this band. The differences especially in the number of days with good sun angles quickly amount to significant changes in Capacity Factor and daily generation numbers. The bad news for Canada and solar PV is of course, that the vast majority of Canada's surface area lies well North of 48 degrees latitude. If wintertime CF is lousy here at 43 latitude in the extreme South, just think of the implications for the rest of Canada.

Power Roll-off from Normal for Solar PV Arrays

Consider the graphic below:



This graphic is taken from our 2008 Paper, "*The Ravina Project – Solar Array Aperture Analysis*" in which we calculate the aperture roll-off as the sun moves away from Normal (90 degree angle) on both axes. The aperture is directly proportional to the power harvesting ability of the array so really this graph above defines a power roll-off as the sun moves away from a 90 degree angle on both the horizontal and vertical axes of an array. An aperture of 0.900 corresponds to 90% power harvesting ability due to sun angles. Half power is the orange ring. A fixed-angle array has a huge issue with power roll-off both on the azimuth and elevation as each day progresses.

The 90% power band from experimentation documented in the same paper mentioned above, has an 18 degree width on both the azimuth and altitude. Note that there are no lobes or other interruptions apparent in the smooth power fall-off as the sun's angle becomes more acute on both axes.

Note that this model is applicable to any solar PV array on the surface of the Earth. The aperture or the size of the collecting surface is directly proportional to the power harvested due to sun angles at any point in time and is directly proportional to the shadow the array casts upon the ground. In short, the bigger the shadow, the more power the array can potentially harvest at any point in time during the day.

A 24 Megawatt Solar PV Harvester

We are going to use our data to model a much larger harvester than our 1.5 kW array. We will be referring to this 'hypothetical array' several times below so we thought it might be good to show you what one looks like.

At $5.00 a watt installed this power plant would cost about $100M. It may be $3 or even $6 a watt but for the rest of the paper we'll use $100M as the cost. We do not include: legal, interest, labour, capital equipment other than related directly to harvesting power, maintenance, land taxes, payroll taxes, hook-up costs, licenses, other taxes/fees and expenses.

Note with global warming, semi-arid landscapes will have huge dust problems … Haboobs and the like. Imagine you and a few workers with your specialized water/spray trucks washing off a coating of dust on this number of panels? Or maybe each block of panels has its own automated washers that are attached to the structure. High altitude, semi-arid lands have great sun but lots of both dust and heat. Even solar PV can use water and in some cases use a surprising amount.

The array above is located at a much lower latitude and higher altitude than we here at 43 degrees and a few hundred meters above sea level. We just needed to show you, dear reader, the actual physical size of a 24 MW solar PV harvester. Note that a natural gas generation plant of 240 MW would fit on a piece of land much less than 1/10th the size. That's the result of comparing the concentrated power density of fossil fuels (chemical bonds) with the orders of magnitude less concentrated, diffuse energy of harvested photons.

Bottom line, industrial sized diffuse energy harvesters (solar PV, solar CSP, wind, tidal power) require monster collectors. Any massive rollout of these harvesting technologies, to fight global warming, will require a monumental, long term industrial and installation effort on a world wide basis just because the harvesters are so huge and use phenomenal amounts of raw materials.

Wintertime Capacity Factor

Our Capacity Factor (CF) calculation for winter is based upon our 1,500 watts or 1.5 kW of polycrystalline 12.5% efficient photovoltaic panels. We calculated our Capacity Factor on a daily basis over 6 winters totaling 552 days. We see that the average daily CF over these 6 winters is 6.10%. The Median, which is a more important number for understanding the distribution of the data, is 4.44%, ranging from 3.61% to 5.28%. The range simply means that the value for the Median in this dataset has a 95% chance of being located within this range, end values inclusive. Adding more days to this data set will not change this value much because 552 datum in a sample is considered to be adequate for reasonably sound statistical analysis.

Remember that our array is attached to a movable structure which can compensate for the sun's altitude in the wintertime sky. The azimuth of the tilted array is 150 degrees. It favours the morning sun because the afternoon sun is obscured by large trees from late September to early April from about 13:30 to 14:30 sun time onward. The length of wintertime days here are so short that this afternoon shade problem is marginal at best. The array elevates to 70 degrees every day during our wintertime, compensating for the sun's daily noontime altitude of about 25 degrees. Our wintertime generation numbers are therefore augmented by this ability plus to make it even better we can tilt the array and dump off accumulated show unlike fixed angle arrays.

Consider the chart below of our daily CF calculations for 552 days across six winters:

n	552				
Mean	6.10%		Median	4.44%	
95% CI	5.67%	to 6.53%	95.5% CI	3.61%	to 5.28%
SE	0.221%				
			Range	18.9%	
Variance	0.27%		IQR	8.61%	
SD	5.20%				
95% CI	4.91%	to 5.53%	Percentile		
			0th	0.00%	(minimum)
CV	85.2%		25th	1.67%	(1st quartile)
			50th	4.44%	(median)
Skewness	0.66		75th	10.28%	(3rd quartile)
Kurtosis	-0.84		100th	18.89%	(maximum)
Shapiro-Wilk W	0.90				
p	<0.0001				

Using the Median calculated from our data we can scale up the daily effective energy harvested by our hypothetical, 43 degree latitude, 24 MW model by multiplying the installed base of 24 MW by 3.61% times 24 hours equals 20.8 MWh and if using 5.28% CF, it becomes 30.4 MWh. Over 6 winter seasons our 24 MW array will generate daily between 20.8 and 30.4 MWh half the time.

How big a power plant working at 100% Capacity Factor over a day will produce 20.8 MWh? We take the energy produced in 24 hours and divide it by 24 to get 20.8/24 = 866.7 kW and 30.4/24 = 1,266.7 kW. Our huge 24,000 kW power plant shrinks to between 866.7 kilowatts and 1,266.7 kilowatts? Unfortunately this is the case and is the result of our latitude. Wintertime is not a good season for solar PV here in the GTHA both for sun angles and sun time above the horizon.

At $200/MWh wholesale price the 24 MW array would have earned between $4,080 and $6,040 a day for half the wintertime days. Total revenue estimated would be the daily Mean CF of 6.10% times 552 days times 24 hours in the day times 24 MW times $200/MWh equals about $3.9M over 6 years of wintertime days. I suppose one could argue that these would be state of the art panels whereas ours were a 2005 variety so the CF would be better than ours. They would have a point there. However, our panels compensate for lousy sun angles by moving to create much better angles. So our CF would be better than a fixed array in the wintertime, late fall and early spring. Let's call it a 'wash' and move on with our argument.

These numbers are instructive. We can understand the very limited ability of solar PV energy harvesting at 43 latitude in the wintertime. As we pointed out above, this latitude is very, very low for Canada as a whole … we are in the extreme south of the country. So for other parts of Canada, wintertime daily values are less because of poorer sun angles.

Springtime Capacity Factor

Consider the following chart of daily CF calculations for 536 days across six springs:

n	536				
Mean	13.34%		Median	13.47%	
95% CI	12.67%	to 14.02%	95.8% CI	12.22%	to 15.28%
SE	0.344%				
			Range	27.5%	
Variance	0.63%		IQR	15.44%	
SD	7.96%				
95% CI	7.51%	to 8.46%	Percentile		
			0th	0.00%	(minimum)
CV	59.6%		25th	5.56%	(1st quartile)
			50th	13.47%	(median)
Skewness	-0.03		75th	21.00%	(3rd quartile)
Kurtosis	-1.40		100th	27.50%	(maximum)
Shapiro-Wilk W	0.93				
p	<0.0001				

If we go through the same process as above using our data and the daily Median Capacity Factor we find that our 24 MW solar array model will provide 12.2% times 576 MWh = 70.3 MWh on the low side and 15.3% times 576 MWh = 88.1 MWh to the Grid on the high side for half the springtime days. The value 576 equals 24 hours times 24 MW Nameplate Capacity.

Note the 25th percentile has a Capacity Factor of 5.56%. What does this mean? It means that if all the daily springtime CF values were sorted smallest to largest, the CF value one quarter the way from the bottom is 5.56%. That means three quarters of all days across 6 springs will have a value equal to or greater than this value. In real terms this means that ¾ of the days in the springtime will have a daily output, from our 24 MW array of about 5.56% times 576 MWh = 32.0 MWh and generating a revenue at a wholesale price of about $200/MWh of at least $6,400.

The spring revenue estimation over 536 days with a Mean CF of 13.34% would be 536 days times 24 hours times 24 MW times 13.34% CF times $200/MWh equals $8.2M.

Summertime Capacity Factor

Consider the following chart of our daily CF calculations for 552 summer days over 6 years:

n	552				
Mean	17.89%		Median	19.17%	
95% CI	17.39%	to 18.40%	95.5% CI	18.61%	to 20.00%
SE	0.259%				
			Range	27.8%	
Variance	0.37%		IQR	8.89%	
SD	6.09%				
95% CI	5.75%	to 6.47%	Percentile		
			0th	0.83%	(minimum)
CV	34.0%		25th	13.89%	(1st quartile)
			50th	19.17%	(median)
Skewness	-0.71		75th	22.78%	(3rd quartile)
Kurtosis	-0.32		100th	28.61%	(maximum)
Shapiro-Wilk W	0.94				
p	<0.0001				

If we go through the same process as above and use the daily Median Capacity factor 95% CI range we find that our 24 MW solar array will add 107.2 MWh on the low side and 115.2 MWh on the high side to the Grid for half the summertime days. Daily revenue will be between $21,440 and $23,040 for half the season.

Note the 25th percentile has a capacity factor of 13.9%. This CF value at the 1st Quartile is huge. In real terms this means that three quarters of the summer days our 24 MW array will have a daily output of 13.9% CF times 576 MWh or 80.1 MWh. Using our wholesale price above of $200/MWh our array will generate 80.1 times $200 = $16,020 gross revenue for 3 out of every 4 summertime days.

The revenue estimation by the 24 MW array for all summertime days is: 552 days times 24 hours times 24 MW times 17.89% (daily average CF) times $200/MWh equals $11.4M.

Clearly the summertime is the best season to make money from a large solar array at 43 latitude.

Note that our use of $200/MWh is arbitrary.

Fall Capacity Factor

Consider the chart below of CF calculations for 552 fall days over 6 years:

n	552					
Mean	12.20%		Median	13.06%		
95% CI	11.68%	to 12.72%	95.5% CI	11.94%	to 14.17%	
SE	0.266%					
			Range	24.2%		
Variance	0.39%		IQR	11.11%		
SD	6.24%					
95% CI	5.90%	to 6.64%	Percentile			
			0th	0.28%	(minimum)	
CV	51.2%		25th	6.67%	(1st quartile)	
			50th	13.06%	(median)	
Skewness	-0.23		75th	17.78%	(3rd quartile)	
Kurtosis	-1.22		100th	24.44%	(maximum)	
Shapiro-Wilk W	0.94					
p	<0.0001					

If we go through the same process as above and use the daily Median Capacity factor we find that our 24 MW solar array will add 68.8 MWh on the low side or 81.6 MWh on the high side of the range to the Grid for half the days based upon the 13.06% Median value and its 95% CI range. For half the days the revenue is between $13,760 and $16.320 at the same wholesale price quoted above.

Across all fall days over 6 years estimated revenue will be: 552 days times 24 hours times 24 MW times Mean CF of 12.20% times $200/MWh equals $7.8M.

We can compare the fall Median value and its 95% CI range to that of the springtime. The sun angles are identical on a daily basis for all intents and purposes but we see a difference in the Median values with the spring coming out on top. So what's going on here? We have noticed that the weather is the difference. Sky conditions in the fall are typically not as good as spring for solar generation here in Toronto. Other places on or about 43 latitude may experience somewhat different local conditions also making the two seasons different statistically.

Total Yearly Revenue from 24 MW Solar PV Array

For each season we have crunched the statistics in order to get an handle on what the Capacity Factor is for the GTHA (Greater Toronto Hamilton Area) on one hand, and on the other, what revenue we should expect as an investor in industrial scale solar PV power generation.

Our estimated total revenue across all six years is: $3.9M + $8.2M + $11.4M + $7.8M equals $31.3M on an initial investment of $100M plus all the other costs/expenses listed above. Since the revenue model spans six years then the yearly gross income is $5.2M from which ongoing expenses/costs must be paid. Whether this is a good investment given the alternatives in today's market I leave for the experts.

Note as well since our choice of $200/MWh wholesale purchase price is entirely artificial, the estimated revenue could be 50% or even 25% of the calculated total. Yikes!

Some Interesting Characteristics of Solar PV

Correlation (Pearson) between Capacity Factor and Daytime Length

How much does the length of day affect the daily calculated CF of a solar PV installation here in Toronto? What we have done below is to compare the daily CF of our solar PV array with the number of minutes in the day.

When CF is correlated with the number of minutes the sun is above the horizon over a database of 2192 continuous days, there is a correlation of sorts … that of 0.60 (r=0.60) as seen below.

n	2192		
r statistic	0.60		
95% CI	0.57	to 0.63	(normal approximation)
t statistic	35.16		
DF	2190		
2-tailed p	<0.0001	(t approximation)	

This correlation between the daily CF and the number of minutes in the day stands to reason. The less time the sun spends above the horizon the less energy harvested. Why is 'r' not a higher value rather than just 0.60? The reason is that solar PV power output is also held hostage by the sky conditions. Sky conditions will tend to randomize the amount of energy harvested each day making the day length/CF correlation more random and hence 'r' is smaller in magnitude than what one might imagine.

Note that solar power is the only form of power generation that has a predictable downtime outside of maintenance, which is a common property of all generators. In fact, 100 years into the future, one can predict the downtime of a solar array here in Toronto! Why can we do that? It's because we live on an accurate timepiece called the planet Earth. That kind of predictability is amazing, pointing to the fact that solar power is totally unique among all energy harvesting technologies.

Correlation (Pearson) between Capacity Factor and Efficiency

To demonstrate the effect of randomized/chaotic sky conditions, let's correlate the Capacity Factor with daily efficiency. We use our own in-house efficiency calculation. We calculate it as the number of watt-hours of energy harvested divided by the size of the array in kW and further divided by the number of minutes the sun is above the horizon. We do this to put the harvesting power of the array on an even footing no matter how long the day is. Without this balancing parameter (minutes in the day) in the calculation, summertime days would always be calculated to be more efficient. We have demonstrated in another paper that this daily efficiency calculation is very sensitive to sky conditions. It is even sensitive enough to demonstrate the effects of summertime ambient heat upon the power output of our PV array. As well, since we have upgraded our panels from 1,500 W of polycrystalline at 12.5% efficiency to 2,800 W of mono panels at 17.1% efficiency, it will be interesting to see whether there is any difference in efficiency between the two technologies as we get a few more years of data into the database.

Bottom line, the efficiency calculation has the randomizing effect of heat and sky conditions already built into its daily value.

Consider the following chart of 2192 continuous days:

n	2192		
r statistic	0.95		
95% CI	0.95	to 0.96	(normal approximation)
t statistic	148.17		
DF	2190		
2-tailed p	<0.0001	(t approximation)	

And indeed we do see that they are tightly correlated. So daily efficiency which takes into consideration sky conditions (and heat), and the Capacity Factor calculated for that day are highly correlated. The efficiency standard eliminates the dark times of the 24 hour day and focuses entirely upon the power generation during daylight hours. If we were to make this same calculation for any other form of power generation like geothermal, wind, wave power or the like, discovering such a correlation as this, between the daily CF and efficiency defined this way, would be absolutely mind-boggling.

This correlation above is further evidence that solar PV is totally unique among all other power harvesters. This leads us to speculate whether there exists a more useful calculation, other than the traditional Capacity Factor calculation, that can be used to better integrate solar PV harvesting potential into traditional Grid capacity planning.

Daily Solar Power Output

Let’s take a look at the above calculation for power output on a daily basis for our 1.5 kW solar array over 2,192 continuous days. We are going to look closely at our daily power output and see how powerful our 1.5 kW collector really is on a daily basis. To understand this calculation imagine we have a 1.5 kW gas powered generator running for 24 hours in a day at peak power output. For the day we would generate 24 hours times 1.5 kW or 36 kWh. The generator’s CF would be 100%.

On a particular day we harvest 8.0 kWh from our 1.5 kW solar array. Our CF for the day would be 8/36 times 100% equals 22.2%. Suppose another gas generator ran at 100% CF for the 24 hour period. How big would this new gas generator have to be (its Nameplate Capacity) to produce 8 kWh over the same period? It would have to produce power of 8 kW divided by 24 hours or .333 kW or 333 watts. Our 1.5 kW array acted like it was a 333 watt Nameplate Capacity generator running at 100% CF for 24 hours. In other words this calculation provides us with a daily effective power output.

To create the data for the chart below we took our energy harvested for each day and divided it by 24 hours to calculate the Nameplate Capacity of an equivalent generator for that day. The numbers below are expressed in kilowatts.

Consider the following chart:

n	2192				
Mean	0.1857		Median	0.1917	
95% CI	0.1808	to 0.1905	95.3% CI	0.1833	to 0.2000
SE	0.00247				
			Range	0.429	
Variance	0.0133		IQR	0.2083	
SD	0.1154				

			Percentile		
95% CI	0.1121	to 0.1190	0th	0.0000	(minimum)
CV	62.2%		25th	0.0750	(1st quartile)
			50th	0.1917	(median)
Skewness	0.02		75th	0.2833	(3rd quartile)
Kurtosis	-1.26		100th	0.4292	(maximum)
Shapiro-Wilk W	0.95				
p	<0.0001				

Again as above we are going to use the Median values because they better represent the distribution of values over the database.

So how powerful is our 1.5 kW array?

Over the database the Median value of our 1,500 watt array's 24-hour continuous daily power output is only 191.7 watts. The Median value ranges from 183.3 to 200.0 watts

Is this all? Indeed it seems to be. With a muscular database of 2,192 datum doubling the number or even an order of magnitude larger database will not change the range of the Median daily Nameplate Capacity values all that much. There are no gaps in this data meaning that there is no compensation for missed days required.

So we paid all those thousands of dollars for a 1,500 watt Nameplate Capacity array and got only an effective power output of 191.7 watts? Yikes! This is a fact of life here at 43 degrees latitude and for solar PV harvesters in general.

Effective Power Output of Solar PV

Ok let's do an analysis upon our seasonal Median daily Nameplate Capacity from our 1.5 kW array. We can understand this as a daily calculation of effective power output for our solar array.

Consider the chart below:

Compare 95% Confidence Intervals for Median Daily Power Output By Season for a 1.5 kW Solar PV Array over 6 Years

Season	**Daily Median Power Output Range**			**1st Quartile**
	Value	**Low**	**High**	
winter	0.0667	0.0542	0.0792	0.0250
spring	0.2021	0.1833	0.2292	0.0833
summer	0.2875	0.2792	0.3000	0.2083
fall	0.1958	0.1792	0.2125	0.1000

From the chart above we see that the daily effective power output from our 1,500 watt solar array over 6 years broken out by season. The numbers are in kilowatts. The winter is brutal with our 1,500 watts reduced to a Median value of between 54.2 and 79.2 watts. The first quartile value is interesting because it provides a number which is lower in magnitude than three quarters of the data. The first Quartile of the summer data is quite good, if we can use that word, where three quarters of the days our array has an effective power output of 208.3 watts or more.

Consider the chart below:

Compare 95% Confidence Intervals for Median Daily Power Output By Season for a 24 MW Solar PV Array over 6 Years				
Season	**Daily Median Power Output Range**			**1st Quartile**
	Value	**Low**	**High**	
winter	888.89	722.22	1055.56	333.33
spring	2694.44	2444.44	3055.56	1111.11
summer	3833.33	3722.22	4000.00	2777.78
fall	2611.11	2388.89	2833.33	1333.33

In the chart above we have taken our calculations for Capacity Factor and plugged them into a model for a 24 MW or 24,000 kW array. The same calculation holds. What is the effective power output for the 24 MW array? The numbers are in kilowatts.

Capacity Factor rules at this latitude. It's hard to argue against that observation when all the data is considered. The nice thing about using real data over such a large number of continuous days is the fact that it captures in its randomness the chaotic nature of the real world. These data provide a robust and high fidelity baseline for models to use.

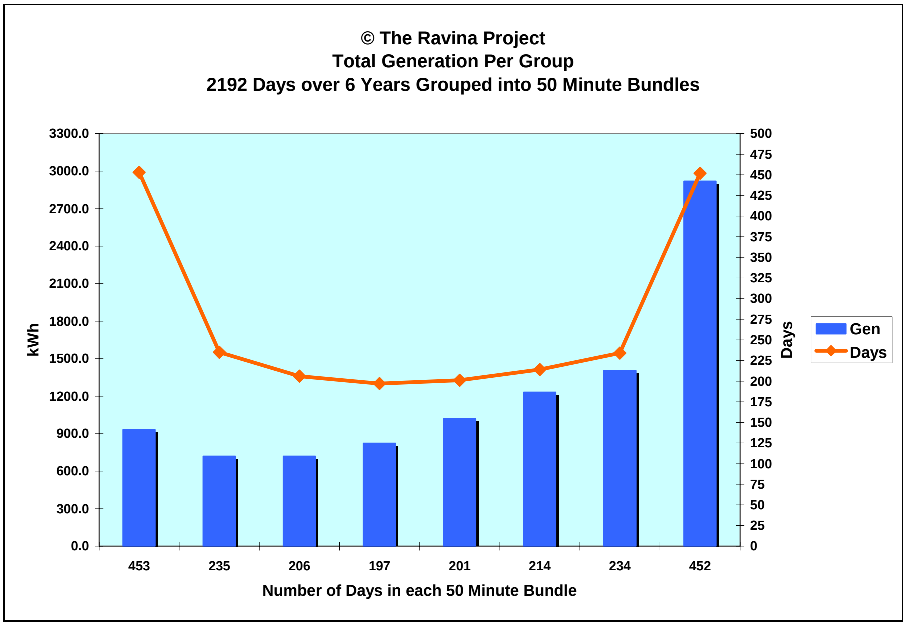
One might comment that our 1,500 watts of 12.5% Polycrystalline panels were not high tech enough to provide the baseline for speculation on the performance of newer, more efficient panels. There might be some credence to that argument but, and this is important, the daily output might be marginally better but statistically significantly better? We really can't comment on that argument at the moment. We have recently upgraded our panels with 2,800 watts of 17.1% efficient mono panels. We are noticing a slight improvement in power output and efficiency. They are acting more like 3,000 watts and we are seeing efficiencies between 0.5 and 1.0 higher than what we have ever seen on some days. It will be interesting to revisit this paper 5 years from now with comparable databases for each panel set.

Generation Total by Day Length

At any point on the surface of the Earth the number of minutes in the day determines the sun's pathway through the sky, the daily arc of the sun if you will, for that particular day. This curiosity is just an outcome of the mechanics of one being at a location on a globe and the sun being so far away that its rays arrive in parallel lines with each other among other things. One's latitude and the Earth's axis tilt are the only parameters affecting this phenomenon.

The shortest day length we have here at 43.68 degrees is about 535 minutes and the longest is about 932 minutes. The difference is 397 minutes. We can very easily group the days into eight bundles of 50 minutes each, which means that all the days in each grouping have similar sun pathways through the sky. Each grouping should have its own unique set of qualities based upon its unique set of sun angles experienced each day. And of course, every day in a particular bundle will have virtually the same harvested energy potential as every other day.

Consider the following graphic.



Let's unpack this graphic.

The bottom of the graph totals the number of days in each bundle. The blue bars total the number of kWh generated by all the days in that bundle read from the scale on the left of the chart. The orange line is a graphic representation of the number of days in each bundle read from the scale on the right of the chart.

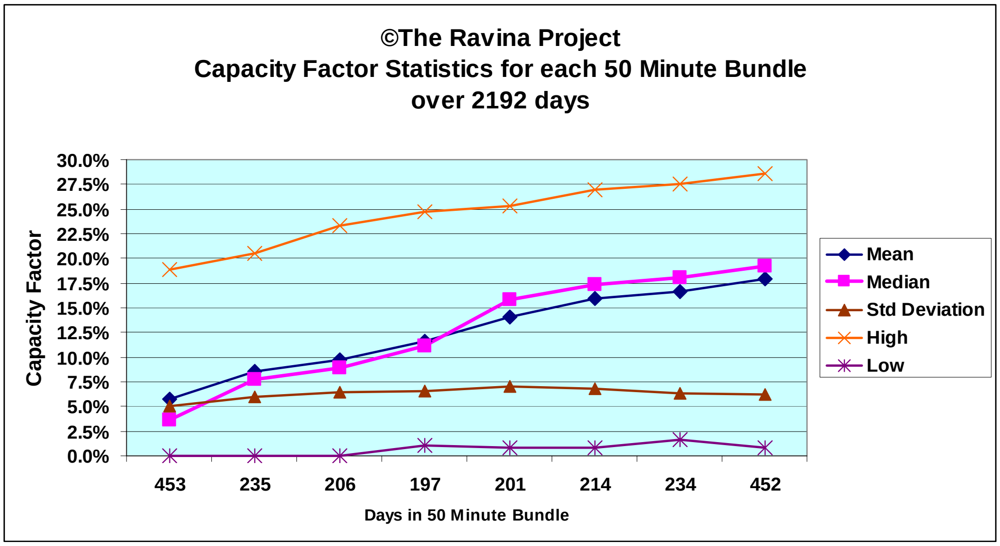
Several things become apparent as we look at this chart. The number of days seems symmetrical but the generation totals are very much skewed to the right. Welcome to 43 degrees latitude folks! This is the reality at this latitude. If you look at the 6 month sun chart above you can see the result in the generation totals. As the sun gets higher gradually from its lowest noon altitude of about 23 degrees the total energy harvested gets gradually larger.

The last three bundles with a day length greater than 785 minutes generate much more energy than the rest of the year, 5555.6 vs. 4212.5 kWh. Note as well, the wintertime generation numbers are 932 kWh over 453 days whilst the fifth bundle of only 214 days tops 1230 kWh. So sun angles and day length are really important for generation here at 43 latitude even for a sun altitude compensating harvester. Note between the Topics day length and sun angles are not factors in solar PV generation. PV panels are laid flat all year around … flat plates if you will.

Capacity Factor Statistics by 50 Minute Bundles

Given the groupings of days with similar sun angles, we can compare the median Capacity Factor for each group. As the days get longer the sun's pathway through the sky gets both wider and higher. We see in the chart below the gradual increase in the Capacity Factor from the depths of winter to the best generation months, the summertime. The chart is instructive in the sense that we have a good map of the range of Capacity Factor we have to deal with here at 43 latitude. The graphic above shows us the number of days in each of these groups so this again allows us to make some definitive claims about our solar power harvesting potential.

Wintertime solar PV generation is poor here Toronto. One can argue that it is not viable as a harvester for about 1/3 of the year (more or less).



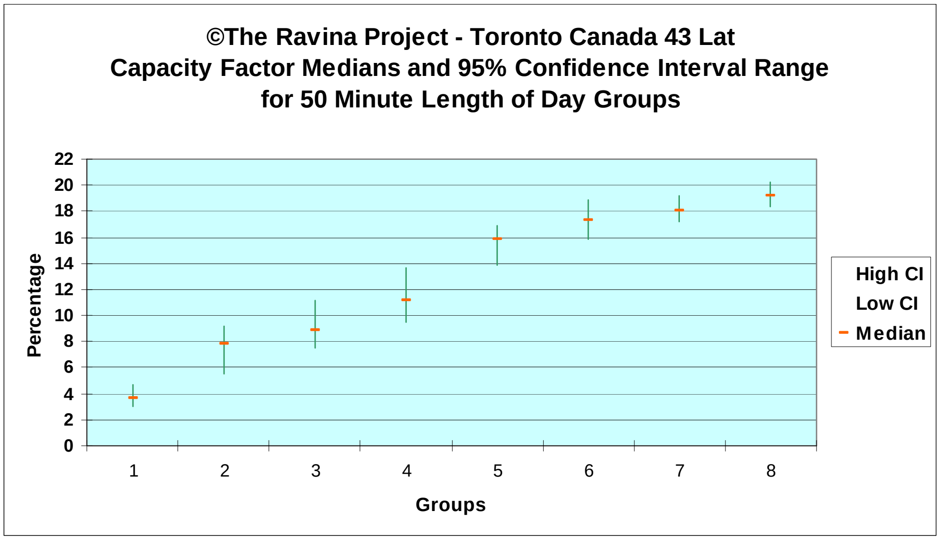
The chart above breaks out each bundle into a crude statistical analysis. We think it's sophisticated enough to see some interesting trends. The high value per bundle increases from 18% to about 28% which one would expect. Ditto for the lowest values staying at or under 1.7%. The relationship between the Mean and Median indicate that there are some of really high CF values in the first four bundles pulling the Mean higher than the Median. In the bundle with 201 days the Median is greater than the Mean meaning that there are more really low values in that bundle than before pulling the Mean lower then the Median. And as the days get longer in length the trend in a few much more lower daily CF values continues. Note as well, between bundle 197 and 201, the late afternoon shading disappears as the days get longer. The array lays flat and collects this additional afternoon energy. The surprising thing for me is the relative consistency of the Standard Deviation across all these values. It ranges from 5.1% to 7.0%. The values mean that the data are grouped around the Mean basically in the same manner in each bundle. It seems to suggest that each bundle has its own internal consistency common to all other bundles. That stands to reason since we have grouped days with similar sun arcs through the sky and hence similar sun power at each moment of time during the day. Note as well that the 'spike', if you will, of the Standard Deviation, the only value in the sevens occurs in the bundle which also has the crossover between Median and Mean. But I'm probably reading too much into it. We never would have wagered that the Standard Deviation of each bundle would have such a small variation over the 2100 or so days.

The more exact Median breakout is shown below:

Capacity Factor Medians by 50 Minute Group

Group	High CI	Low CI	Median
1	4.72	3.06	3.61
2	9.17	5.56	7.78
3	11.11	7.50	8.89
4	13.61	9.44	11.11
5	16.94	13.89	15.83
6	18.89	15.83	17.36
7	19.17	17.22	18.06
8	20.23	18.33	19.17

The graphic below puts the chart above in picture form. The bars are the 95% confidence Interval over which there is one chance in 20 that the Median value does NOT lie somewhere on the bar. We see a steady improvement as the sun angles allow for a better daily energy harvest.



Solar Panel Striping

Now not to confuse the matter the new panels are wired differently than our older ones. They are striped vertically whereas the other panels were striped horizontally. We know our shading patterns here from over 7 years of observations. The horizontal striping was not optimal for our environment. We made the call when the original set was put up but it turned out not to be optimal for our local environment. Goes to show a call made without data is a guess. These new panels are wired in vertical pairs when seen from the front and the array is set at 70 degrees.

Here is a pic of the old Poly panels and their configuration:

The dark lines identify the panels that are wired together in series which means all the current generated by the whole string passes through all panels. If a panel is totally shaded across its width then its resistance to current increases dramatically thereby reducing the current flow in the whole string. As a result the power output of the whole string drops substantially. As you san see the shadows of the morning sun fall upon three of the 12 panels in the array and totally across one panel. Since the panels are wired horizontally in strings of four panels each, you can see that that small amount of shade attenuates the power output of one whole string which is 33% of the total collecting power. The Nameplate Capacity drops to 1000 watts. The same happens at the end of generating day from late September to early April when several strings are shaded at the same time. So both ends of the day produce shadows that attenuate power production on whole strings.

The new Mono panels are striped vertically and the same shadows would take much less (20%) of the total collecting power off-line. The Nameplate Capacity drops from 2,800W to 2,240W which is only 1/5th of the total generation power. This difference in attenuation is 1/3rd minus 1/5th equals 13.3% which is significant. With the old striping all the strings would be off line or at least near idling current. With the new striping, only one string at a time would be in the shade and off line.

Bottom line, just the striping alone will account statistically for some of the slight difference in efficiency, power output and hence Capacity Factor between the arrays. We look forward to the day when we can write a paper incorporating the data from our newer panels and pursue several hypotheses.

Conclusion / Discussion

Now that we have a fair understanding of solar PV characteristics and potential here in Toronto based upon actual data, we can use this insight to discuss solar PV power generation in general.

When one gathers data, day after day, over 7.5 years, so far, one gets a ‘feeling’ for the capabilities of solar PV as a power source. Obviously, one’s feelings can help focus one’s hypothesis creation but feelings by themselves are void of any relationship to reality without a data component that can be mined for evidence for and against generated hypotheses based upon those feelings. We 'tip our hat' to David Hume - "Reason is and aught to be the slave of the passions".

Here in what follows are some of the ideas we have come up with.

Intermittency

Intermittency, in the context of wind or solar PV power generation is defined by us as low power or no power durations suffered by the generator during times when power should be generated. Think clouds covering a solar PV field or the wind dropping off or changing direction in a wind farm. In both these situations, power drops dramatically during the course of the generation day. We can also think in the longer term when days go by with little wind or sun.

Short Term Intermittency

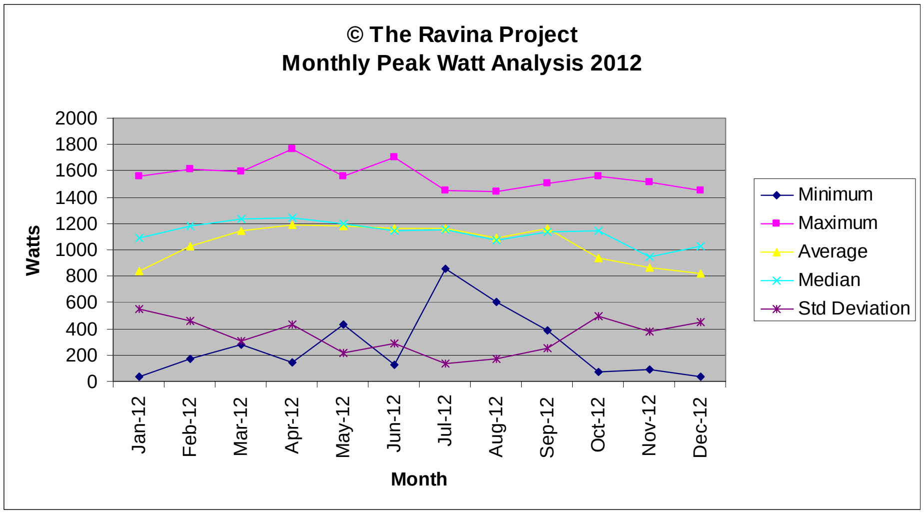
We have experienced short term intermittency here many, many times each year. The largest ones usually occur when the 1,500 W panels are generating a steady continuous full power which, depending on the time of year and the air's ambient temperature, could be from 1050 W to 1250 W. The cooler the ambient air temperature, the greater this steady, full sun output will be. We have a whole paper devoted to this topic on our WEB site.

Anyway, into this common scenario a cloud drifts over the panels and drops the sun's power output to 300 to 400 W. We are still receiving the sun's radiation but the frequencies that the panels use to push electrons have tanked. A typical scenario which we have seen hundreds of times, ends after awhile with the sun coming out from behind the cloud, illuminating the panels with full power sunlight and the power generated skyrockets. What has happened in the panels is very interesting. Their internal temperature has cooled to the ambient temperature of the air surrounding them. Our panels are situated about 8 feet off the roof's surface so are very well ventilated. If you might think the power returns to the original 1050 to 1250 watts you would be mistaken. We have seen the power output jump to 1700 watts and stay there for a time before gradually decreasing to the original, say 1250 watts.

What's going on here? The efficiency of the panels in the energy conversion process from photons to electrons at the quantum level has a lot to do with the internal temperature of the panels. Lots of sun on a hot day will heat the panels to such an extent that they become less efficient at moving the electrons out of the conversion areas. This reduction in efficiency is marked by increased internal resistance prompting a falloff of both current and voltage. But as we have seen on occasions too numerous to count, when the sun hits the cooled panels full force the panel's output power increases dramatically, staying that way for awhile before decreasing as they heat up over a period of time.

On a cool day with ambient air temperature of about 10C, with brilliant sun and a few clouds between 10 AM and 2 PM (the best time of the day for solar PV generation) we have seen this bouncy effect happen over and over again. The output power goes from 1250W to 350 W and few minutes later, from 350W to 1700W with a slow decline of about 5 minutes to 1250W and 15 minutes later the whole process starts again under another cloud.

Consider the following chart from our WEB site.



We record the peak power output from our Outback MX-60™ solar charge controller each day. This above chart shows the crude statistics for each month in 2012. As you can see there are four instances where the highest daily peak watts for the month was greater than or equal to 1600 W plus every month had a daily peak of over 1400 W with the vast majority of the months with peak watts greater than or equal to 1500 W.

Imagine now an array of 1.5 MW bouncing around like this? What sort of Grid infrastructure is set up to handle this kind of short term variable output generation? From moment to moment during these kinds of days the available power scaled up from our array would go from 350 kW to 1,750 kW in a matter of seconds only to decline gradually to 1,250 kW over the next 5 to 10 minutes only to repeat the whole process at random times during the day.

We do not have the technical knowledge to fully appreciate the effects this kind of dynamic periodicity and dynamic range (about 6.0 dB) would have upon our current Grid design. From everything we know, limited as it may be, load and generation management/matching are huge problems for utilities. Unmodified grids are very inelastic and store little energy.

We see this real time dynamism as a possible showstopper for industrial sized solar PV arrays unless huge resources are used in rebuilding the Grid into an Intelligent Grid. We do not see this rebuild happening between now and 2050 if Grid infrastructure continues to suffer damage because of climate change caused by AGW. We have seen price tags in the trillions of dollars for a Grid rebuild net of any AGW caused repairs. World affairs, corporate dominated policy making, austerity budgets and anti-tax fervor plus an overlay of AGW inspired world political unrest and War will most probably, in our view, combine to stifle any re-build/redesign of the Grid in the first half of this century.

Does that mean that solar PV is not viable in general? Absolutely not! We have demonstrated here at The Ravina Project that solar PV is eminently suited to boutique and niche markets like roof top solar. There will be more on this topic below.

Long Term Intermittency

Long term solar PV intermittency means that the power down event lasts much longer than a few hours or minutes. It occurs every night for solar PV and sometimes for days during the daytime. At this latitude it is really easy to pick out days/weeks of poor generation in the wintertime. Basically 1/3 of the year has poor generation (more or less). We'll get to that below but for now observe the following chart:

Date	Gen	Weather	Max W	CP
6/1/2012	0.3	oc wind rain dull	126	0.83%
6/2/2012	2.5	cld sun late pm	1679	6.94%
6/3/2012	3.7	dull oc sun L8R	1701	10.28%
6/4/2012	1.8	dull oc	542	5.00%

The above data is taken from our daily records at the peak of our generating season. Here we have four days in a row where the generation is lousy. So for all intents and purposes the solar PV generator had been off line for four days or about 96 hours, that is, from the end of generating day on May 31st until the start of the generating day on June 5th. The accumulated Capacity Factor is 5.8% and not unlike a four day run in the depths of wintertime. The utility would be prepared for poor wintertime generation but would be expecting much better generation in the summer especially at peak season. This is an anomaly for the planners but I can pick out all kinds of them during the summer months in over six years of daily data.

The question then is, what is covering off this lack of generation if this were a 20 MW solar PV power plant? Other forms of generation would have to cover. Combine this with almost 1/3 of the year where the solar PV power generation is the 'pits' one quickly discovers that big industrial sized solar PV is not viable here or probably anywhere. Why? Well it's because another form of generation must cover for the solar PV intermittency. In many areas of the world including North America the lack of solar PV generation must be covered off by coal or natural gas. Many of these plants are called, Load Following Power Plants. They respond to load demand by quickly changing their power output. A load demand may be caused by a large solar PV plant going essentially off-line because of bad weather (long term) or clouds obscuring the sun (short term).

There are many who agree with the statement that to build a wind or solar PV generation is also to build a gas plant each working in parallel, each servicing the load as the day progresses.

In a world where we must drastically reduce our fossil fuel CO2 emissions for the rest of the century, the idea of building a solar PV plant or converting our backbone workhorse power supply into solar PV is totally in the realm of fantasy. For every watt of solar PV and Wind we will need another watt of standby, load following power supply. As it stands right now that power supply in many places is fossil fuelled now and will be into the foreseeable future.

In 2010 according to the "*REN21 Global Status Report*" the size of the world's power supply was 17.5 TW, 80% or 14 TW was fossil fuelled. Of the 17.5 TW, solar PV accounted for 0.06% and wind accounted for 0.51%. Rapid expansion of solar PV means the fossil fuelled generators stay around to provide load following power for a long time.

Solar PV as Backbone Power Supply

Much of this paper has been devoted to getting a handle on solar PV Capacity Factor here in Toronto, the fourth largest city in North America. In what follows we are going to further discuss CF in the context of intermittency. So what can we learn from our data in the context of CF to make a case for plastering everything with solar panels and getting rid of fossil fuelled generators (and nukes as well as we hear from some quarters)?

Let's assume we make solar PV the backbone power supply.

For discussion purposes let's add 100 MW of new solar PV to the Grid here in Southern Ontario. We already have the numbers from earlier in this essay crunched from a revenue point of view.

But now let's look at the actual energy generated by the addition to Ontario's power supply of a 100 MW solar PV power plant.

From our data the Mean 95% Confidence Interval range of CP on a per seasonal basis is:

winter: 5.67% to 6.53% over 552 days,
spring: 12.67% to 14.02% over 536 days,
summer: 17.39% to 18.40% over 552 days,
fall: 11.68% to 12.72% over 552.

The expected yearly energy generation from a 100 MW solar PV installation on a seasonal basis is calculated as follows: Mean Capacity Factor range times 0.1 GW times number of days in sample divided by 6 times 24 hours equals GWh of energy produced per season.

winter: 12.5 GWh – 14.4 GWh from an effective power generation capacity between: 5.67 MW and 6.53 MW.
spring: 27.2 GWh – 30.1 GWh from an effective power generation capacity between 12.67 MW and 14.02 MW.
summer: 38.4 GWh – 40.6 GWh from an effective power generation capacity between 17.39 MW and 18.4 MW and finally,
fall: 25.8 GWh – 28.0 GWh from an effective generation capacity between 11.68 MW and 12.72 MW.

A yearly total for our 100 MW solar PV plant is between: 103.9 GWh and 113.1 GWh. Contrast this with a 100 MW nuclear plant or hydro plant running at 90% Capacity Factor which over the same period would generate 788.4 GWh. So we seem to have a 7 to 8:1 ratio between solar PV and either hydro or nuclear right off the top.

As I write this here in Toronto on a summer day with the temperatures in the mid 20's C (70's F) the generators across the Province are putting out a total of 19,308 MW. At this rate today alone they will generate 19,308 MW times 24 hours equals 463.4 GWh (463,392 MWh) of energy and at this rate for the year it would be 365 times more: 169.1 TWh (169,138,080 MWh)

The current breakout of today's Provincial generation is as follows:

Nuclear: 11,230 MW
Natural Gas: 2,790 MW
Hydro (Dams):4,306 MW
Wind: 818 MW
Solar PV and others: 164 MW.

This is a nice day with no real need for air conditioning, so the total output is much below the 29 GW or so required on a Max usage day. Note nuclear makes up 58% of the Province's power generation at the moment and has been putting a constant 11,400 MW (+/-) into the Grid for the last 48 hours. The reactors have been running at about 90% CF for that time. Two of the 18 reactors that form our nuclear infrastructure are off line with no output recorded.

The installed generation by Nameplate Capacity is:

Nuclear: 12,947 MW
Natural Gas: 9,920 MW
Hydro (Dams): 8,014 MW
Wind: 1,824 MW
Solar PV and others: less than 200 MW.

De-carbonizing by Elimination of Natural Gas Power Generation

So now we know the numbers here in Ontario. Let's replace the fossil fuelled generation with solar PV. Well that's simple, we know that a 100 MW solar PV installation gives us between 103 and 118 GWh of yearly generation. We also know that the output from Natural Gas plants varies in time because they are load followers here in Ontario. From their histogram charts they vary between 1,200 MW and 4,200 MW more or less of the 9,920 MW (according to the IESO – Independent Electricity System Operator) of total gas generation available in the Province.

Let's assume that we can replace 30% of the gas generation Nameplate Capacity with solar PV and we can use efficiencies, greater use of our own hydro power and imported hydro power from Quebec to eliminate the other 70%. So let's replace the gas generators with 2,976 MW of solar PV generation. How many 100 MW power plants will be needed to replace 2,976 MW of gas generation? Well it's 2,976 MW of effective output times 24 times 365 equals 26,069,760 MWh of yearly energy output divided by 118,300 MWh a year from one 100 MW solar PV plant equals 220 100 MW solar PV power plants.

Let's assume that panels are 20% efficient. A panel efficiency of 20% means that the panels generate 200 watts per square meter of panel area when insolated with a 1 kW light source containing standardized frequencies through a standardized atmosphere. To collect 1 kW of solar power requires five square meters of solar PV. To collect 100,000 kW (100 MW) requires 500,000 square meters of panels. So 220 100MW plants will encompass 220 times 500,000 square meters equals 110,000,000 square meters or 110 square kilometers for the panels themselves.

So we know how much we will need to build to replace the natural gas generators the Province uses. If we get a bargain of let's say $1.00 a watt installed, the price comes to $1.00 times 220 times 100 MW times 1,000,000 (conversion MW to watts) equals $2.20**10 or $22.0 Billion!

There is a further issue. What will generate power at night, in the winter and on poor days when little or no generation is available from our solar PV power plants and power is needed? We have ignored CF! Note that our assumptions include huge efficiencies, much more output from our hydro and lots of imported hydro power from Quebec. We just can't turn up the flow from Quebec because they have their own needs to be filled. So what happens on poor generation days? We will have to keep many of our natural gas plants on standby (load following generation) to cover for the power shortfall from the solar PV arrays. So we spend all this money but must keep some of our natural gas generation on line. And to add insult to injury, we have to make massive/costly upgrades to the Grid for it to handle far more dynamic power sources. Brutal!

Intermittency and Capacity Factor both rule when using solar PV and of course, wind to a lesser degree. We can spend a Queen's fortune and still not achieve our goal of ridding ourselves of fossil fuelled power generation by using renewable energy sources like wind and solar.

Nuclear Power Elimination

There are many who think that Nuclear Power is dangerous, nasty and a bomb just waiting to explode. Some believe that Nuclear plants leak radiation making those who live around them sick from cancer. Still others worry that the waste products which must be housed for tens of thousands of years is a huge risk for humankind (they are probably correct with this worry IMO). The bottom line in these arguments is that there is a feeling that Nuclear Power stations should be shut down and decommissioned as soon as possible. Any upgrades to extend their lifetimes should be terminated immediately. As each reactor reaches the end of its lifetime it should be decommissioned paving the way for a gradual termination of Nuclear Power generation in the Province. The goal is to be free from nuclear powered electricity generation.

The problem of course is again intermittency and Capacity Factor. From where is the base supply power coming from? The Nuclear base supply which today and for the last 48 hours, has been pegged at 11,400 MW will be replaced … with? This is a special kind of power, it's there in huge qualities at all times day and night. It is this constant source of power that builds and enhances our highly complex and energy intensive civilization.

Intermittency still rules but in this case the replacement for this kind of power output must come from a similar amount of base load power supply. From our point of view only geothermal and hydro provide this kind of base load supply.

The argument locally here is to replace the nukes with imported hydro power from Quebec Province. I don't have the technical expertise to evaluate the repercussions of importing a constant 11,400 MW of power from Quebec Hydro 1,500 KM away. I do know that the power in that quantity is not available … not even close to that quantity. We don't know where the power is to come from. This argument is enhanced by the idea that all increased requirements for power will be covered off by efficiencies … doing more with less. Good luck!

Just imagine an ice storm cutting 11 GW of power to Ontario with little load following power supply left after the conversion and no nukes. Such a scenario would entail immediate and total disaster for all large populated areas here in southern Ontario.

Bottom Line

We can't but wonder that the implications of our arguments above places solar PV power into the 'boutique' or 'niche' category. That is, solar PV is incredibly useful for special power supply needs. In fact it is probably the only power supply technology that can satisfy these needs.

Solar PV

For instance, we have been running solar PV since January 2007. We can say without a doubt that it is one of the most reliable forms of generation. There are no working parts; the Mean Time Between Failure is huge. The panels just sit there and do their thing. Most days now with our panels upgraded from 1,500 watts to 2,800 watts (although they act more like 3000 watts) we send many kWh back to the Grid. Our household is optimized for a smaller power supply so when the power supply is doubled much power is left over after topping off the batteries and running the household. As of today we have pushed well over 1 MWh back to the Grid so far this year (2014).

Solar PV allows us to offset the increased electricity used for household cooling. This is the first summer with our new panels so we are getting some experience with them. This summer has been cool; we have not used air conditioning. In fact we have not even installed the small window unit that cools the house. Given the numbers we have been generating and the amount we have been sending back to the Grid, we have more than enough power generation to run the household, charge the batteries and run air conditioning (at 500 W and 40% duty cycle) 24 hours a day with very minimal or no Grid support depending on the sun. Actually with our 14 kWh (usable) of batteries and the summertime generation numbers we have seen, we in fact could have been off-Grid with air conditioning this summer.

Solar PV allows us to run a much more resilient household. Since we have been up and running we have not suffered one minute of unscheduled power outage on our battery powered protected AC circuits since January 2007. During that time Toronto has suffered through many outages including the recent great ice storm which left tens of thousands of people off the Grid for a week or more.

Solar PV is great for remote backup power applications. Summer cottages, if access to the sun is suitable, are prime candidates for solar PV generation. Add solar PV, a battery and inverter/charge controller and an unpowered cottage is electrified allowing for all the accoutrements of a high tech civilization to be used. The same addition to an already electrified cottage allows the refrigerator to operate when the owners are away and the local Grid is down for awhile after a storm … no more finding a fridge full of rotten food.

Solar PV is great for general energy harvesting diffused throughout the urban landscape. We understand many people like us are living semi-independently at this time using (wind and) solar PV as their main power supplies. Commercial buildings, schools and other buildings with good sun access and flat roofs with little in the way of time-of-day shading through the whole year are great places to generate watts to offset usage especially in the summers with increased use of electricity for air conditioning.

We contrast these niche applications with the workhorse kind of power supply required for our high energy, complex civilization now and for others moving from the Second World to the First in the next 25 years. Workhorse power supplies are not intermittent; they are capable of unfailing production of prodigious amounts of power every hour of every day. They may be taken down for maintenance, upgrades or just because their power is not needed at the time. The important part is that when they are on line they work steadily to provide an unwavering power supply. In many areas this need is satisfied by fossil fuelled plants. Here at the moment in Toronto I can see from a WEB site that monitors hourly what technology generates our Grid power that 71% comes from nuclear (11,386 MW), 6% from Gas (973 MW), 19% from hydro (3,012 MW), 4% from wind (615 MW) and 1% from other sources like solar PV (148 MW). Ontario is one of the lowest carbon emitting regions in the world.

Intermittency and Capacity Factor rule and as such we have a choice going forward into this century of embracing technologies that provide high Capacity Factor base load power or not. The big divide is whether we exclude fossil fuelled generation or not. If we decide to eliminate as much fossil fueled generation as we can, then the options come down to: Hydro, Geothermal, Biomass and Nuclear. Wind, tidal power, batteries (of all kinds), solar, solar thermal, all have both capacity factor issues and intermittency problems in Canada. They are not base load generators.

Complexity Equals Risk

And finally, designers may be able to *a priori* cobble together a laundry list of technologies that would work in theory and deliver virtual base load power to the masses. I have read papers that assume a redesigned Grid as a Smart Grid with huge energy buffering capacity using batteries of various kinds, 10's of thousands of huge wind generators, remote control of appliances, pumped hydro (another kind of battery), geothermal, banks of lithium ion cells in electric cars, "yet to be developed" technologies and the like. They use mathematical models to account for the intermittency of wind, solar PV and tidal sources. The proposed design becomes a patchwork of overlapping power sources that, when working together, eliminate the need for all present day baseload nuclear and load following fossil fuelled power supplies. These plans are absolute monuments to high technology planning using both present day and future 'to be developed' technologies. The operational complexity of the resulting highbred integrated system would be offset by the use of computerized Expert and AI systems. They also require the population to radically change their energy use and world view regarding technology and how they use it to realize the large efficiency component to the plan.

This complexity is, in simple terms, a simulation, a doppelganger if you like of today's much simpler baseload power supply. So what happens to the assessment of risk in this highly automated, highly complex, cobbled together group of overlapping systems-integrated technologies? What would be the Mean Time Between Failure (MTBF) of the critical parts? Could it even be calculated for such a complex, highly integrated system? Would the public be more, or less, in danger of catastrophic, cascading Grid failure with this complex system versus a simpler one composed of the current marginally upgraded Grid using non-carbon, base load generators (hydro, geothermal and nuclear) augmented by intermittent green power generators (wind, solar PV and their ilk)?

That is, other than an increased risk of Grid failure, increased fragility if your will, what is gained by the increased complexity? We ‘tip our hat’ to Nassim Nicholas Taleb.

The increase in fragility of a system that uses a tightly integrated ensemble of technologies bound together by low latency communication links, operated mostly by Artificial Intelligence and Expert Systems, would seem to be a fitting risk given we are sidestepping the greater risk of nuclear power plants in use now, and the risk of building a new wave of 4^{th} generation nukes and LFTRs in the future.

But is this risk analysis valid? The current nukes are based upon an obsolete design which is not inherently safe … that is, if all the power or cooling goes off line they will NOT shut themselves down without human intervention. Everyone understands that particular risk but everyone also understands that compared to the risk entailed in the use of coal power plants which emit toxic substances and produce huge coal ash waste lands, nukes have been clean and have amassed an impressive safety record. So to build this hugely complex system to sidestep a nuclear risk to human safety that is not shown in the data, does not stand up to analysis.

So maybe the argument is really about the accumulated poisonous solid fuel rods accumulating in waste ponds. This is thought by many to be an unmanageable problem given these waste products will be super dangerous for 100,000 or so years. This concern is very real and should not be downplayed. However, we remember the 20 year long Megatons to Megawatts project, successfully completed in December 2013, that burned 15,000 tones of low enriched Uranium from Russian nuclear warheads in American nuclear power reactors. As much as 10% of the electricity made by nukes in the USA came from this program over the 20 years.

We also know that the next generation Gen4 nuclear reactors under construction now or being researched now as in the case of Liquid Fluoride Thorium Reactors all are designed to burn down all the high level waste products from the first generation reactors as fuel. The burn down is very efficient leaving little waste with a small amount of that hot for few hundreds of years. So the new generation nukes solve the waste problem by using it as fuel, solve the safety problem by being inherently safe (self shutdown with no coolant nor power nor operators), solve our civilization’s de-carbonization problem by providing endless high Capacity Factor clean power, provide a huge source of high grade waste heat that can be used for endothermic organic chemistry like fuels production and desalinization of water just to name two.

So, to get back to our argument, we are assuming risk by building a super complex fragile system to counter the low risk, as shown by historical data, of first generation Nuclear baseload power? As well we want to ignore the next generation reactors that will come on line over the next 10-15 years …. just because? The analysis falters at this point.

The argument boiled down to the basics, is simply that we must replace a less risky Grid ensemble of generation with more risky, systems integrated generation … just because nuclear? We don’t understand the logic there. It sounds more like a fear based ideology.

Cosmic Risk

But there’s more! There are risks other than those inherent in operating such a complex system. Call them external risks if you will, external to the systems. I see them as dividing themselves into two categories, cosmic and terrestrial.

The cosmic risk has to do with the sun’s behaviour. Just recently the sun ejected massive amounts of substance from its surface. If that ejection had hit the Earth it would have disrupted our satellites and land line wire based communication systems plus done huge damage to our electrical power distribution system. Such a disruption would paralyze a tightly integrated power generation system like the one proposed. It’s difficult to speculate the consequences of large cities being without electrical power for weeks while someone fixes the problem without satellite communications and the like … I don't know the consequences; my mind boggles at the thought. The idea that all the power generation, storage and distribution technologies, hooked together into an integrated whole by communication links and distributed computer power in a cloud would be more resilient that our current dumb Grid with baseload generators is not obvious to me. And that 1,500 km multi-gigawatt link proposed to bring in Quebec's hydro power to us here in Ontario would be fried many times over by such a cosmic event … think Ontario mostly in the dark for months.

Terrestrial Risk

We also face the risk of cyber warfare / cyber terrorism or just bright, bored people with too much time on their hands. We have seen state sponsored cyber warfare in the case of Russia and Lithuania. We await a terrorist group doing the same thing. It may manifest itself like the state authorized Stuxnet computer Worm that attacked Iran's centrifuges or some other attack that reduces or destroys critical civilian infrastructure operation. In any case, a Smart Grid integrating on many levels a whole grab bag of separate generators is a fragile target. One may argue the whole enterprise of Smart Grid and associated technologies might communicate via its own private Intranet. It would still require huge Internet (cloud) integration to control appliances, electric car batteries and external privately owned generation just to name a few. From my experience as a Cisco Certified Design Professional (CCDP), I asses this new tightly integrated, cyber controlled system as a: Hacker Heaven!

We have on one hand the risk associated with the rollout of a new highly integrated Smart Grid / power generation / communication / computational mix which is for the most part 'vapourware' and on the other hand, our dumb Grid upgraded slightly to support green generation and the slotting in of the next generation of baseload power supplies. Which of these options is most likely to succeed and help us to dramatically decarbonize our energy use in the next 10-20 years? Which has, after it is implemented, less operational risk as we have detailed above? And to add to the pressure, we can't fail in this effort to stop CO2 pollution in a human generation. We lack the time and money for a do-over. Which therefore, has the least risk of project failure or delay?

From my personal R&D background, I can truthfully say that as we (our 'skunk works' group) got better at our craft, we always looked to the simpler of competing solutions to a problem as being the better choice. Many times the simpler solution did not have all the 'bells and whistles' and extras that a more complex solution might have (and marketing wanted!). But the simpler design did cover all the core functionality quite well. We were together long enough to see the results of fancy systems mistakenly being developed, placed into production, installed in the field and being a total 'bitch' to service and support. We also experienced the joy of much simpler systems, not as 'shiny' as the complex ones, being rock solid and requiring much lower maintenance costs when they did break (because of course, everything breaks!). A 'tip of the hat' to Occam.

So our advice to today's infrastructure designers is to keep it all as simple as possible and design the system to execute the core functionality of reliable, resilient, clean power generation / distribution exceedingly well.

Note: I have been made aware of a Technical paper by: **Heskes, Myrzik, and Kling (978-1-4244-6551-4 IEEE Heskes et al.)** entitled, "*Harmonic Distortion and Oscillatory Voltages and the Role of Negative Impedance".* They outline Grid distribution problems with harmonic oscillations caused by solar PV inverters because they add high parallel capacitances and negative output impedances to the Grid. Another problem they identify with wind power is the generation of sub-harmonic oscillations due to the negative differential impedance of constant power loads and the generation of sub-harmonic resonances which have negative impedance in some cases. These problems produce nasty Grid voltage instability.

As we understand it, a Grid under the proper conditions can become a resonant circuit with resistance, inductance and capacitance values. In the past extra capacitance was added by utilities to enhance stability and damp out unwanted resonant sub-harmonics. After all we distribute power on an 'audio' wave of 60 Hertz with voltage and current in a lockstep phase relationship. Normal traditional generators that we have been using for decades have well known sub-harmonics that have been engineered out of the Grid's Alternating Current power distribution system. Now, we are adding new kinds of generation … adding new resonances that have not been compensated for in the Grid's infrastructure. The current build-out plans will add overwhelming amounts of extra capacitance from solar and inductance from wind generator windings plus of course the sub-harmonics from their vibrating blades. Some of these new resonant sub-harmonic frequencies become destructive by quickly accumulating energy or acquiring negative impedance, the term the paper uses. A whole new set of sub-harmonic management challenges are being created for the Grid engineers to solve. Hence we include this paper above, written by engineers, as a 'red flag' for those more technical readers.

If nothing else this discussion demonstrates that from the Grid's point-of-view the addition of huge green power generation is a risky proposition for the Grid in and of itself. Note as well that hydro, nuclear, geothermal all use generation equipment whose characteristics are well understood and Grid friendly.

"If we knew what we were doing, it would not be called research."
- A. Einstein

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