The Ravina Project

Household Grid Resiliency

Surviving the 19th Century

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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

Household Grid Resiliency

Surviving the 19th Century

Introduction

How quickly can one move from the 21st century back to the 19th?

Lose your Grid power and suddenly your household surrenders more than 100 years of technological progress. Everything electrical, that is everything that needs electricity to work, is now useless; everything battery powered will soon be useless. When you think about it, household devices and appliances that require a constant source of electrical power makes for a long list.

And on a grander scale but illustrating the same idea, when Hurricane Gilbert hit Jamaica the fuel for the power saws, generators, emergency vehicles and the like remained in the ground storage tanks. The generators that could have provided the energy to pump fuel were few and far between because most were needed for other important things like powering refrigeration and medical centers. Fuel quickly became scarce as the ironic situation matured with all the fuel needed just meters below ground level and no power to pump it out.

Gilbert taught us in the emergency response community that the Grid is a systems integrator on the grandest of scales. It knits various dispersed technologies together so they may work together as a whole and, from a functional point of view, become something greater than the sum of their individual parts.

Using our hands-on experience with emergency response plus our years of professional work in Research and Development we modified our 1925 era house to be a Grid resilient prototype for this latitude. Note, our prototype house is a functional prototype, designed and built using 2006 era, well tested technology. This design approach, well known in the R&D community, allowed us to concentrate on the systems integration of the various technologies employed rather than debugging “bleeding edge” individual technologies. An actual marketable product based upon the functionality we are testing out will be available we hope in the near future as a house upgrade. We envision future high tech entrepreneurs designing and building these kinds of upgrades possibly using repurposed batteries from electric vehicles.

In this paper we want to give the reader an insight into the lessons we have learned from living in our prototype house and especially insight into whether a much less expensive ‘Grid resilient lite’ design is possible.

Definitions

We know that the Grid is an energy distribution system. But ‘household’ and ‘resiliency’ are open to interpretation. So let’s start this paper with some definitions.

Resiliency

What does 'resiliency' mean? There are several definitions. The term can be applied to almost anything, but the common thread through them all is the idea that resiliency embodies the ability for something to withstand abuse, stress and otherwise destructive forces. Resiliency in the way we want to use the term in this paper is simply the idea that resiliency is a quality that allows an entity to carry on through a disruption of some kind that would otherwise destroy that same but non-resilient entity.

So whatever entity is imagined, if it's 'whacked' a few times and survives, it has a level of resiliency to whatever 'whacked' it.

Household

What does the term 'household' mean? We will borrow from Jane Jacob's definition and define household as a structure including the infrastructure within the structure, and the people (plants, and pets) that make up the inhabitants. Simply put, the household is defined as the structure and those that inhabit the structure. If they are torn apart the household ceases to exist. People living apart from their home are not a household but a different, reformed one, and similarly an empty structure is not a household.

Household Resiliency

When we put these definitions together we get a definition of a resilient household. A resilient household is a household that can be maintained through stressing forces that would otherwise destroy it. In short in a resilient household some kind of 'normalcy' is maintained throughout the stressing event(s).

Hierarchy of Stressors

However, a problem soon arises when one looks at the long list of possible stressors. It really is impossible for a householder to anticipate stressing events on one hand and then go to the expense of modifying the house to fend off the stressors. Due to the chaotic and unpredictable nature of the world, we have to chose the stressors we will fortify against with great care because the adaptation expenses would quickly overwhelm the budget. So let's narrow down to the nastiest and most likely stressors when we make our plan.

It makes no sense to fortify the house against flooding if it is on a hill with the land sloping away from it but it makes perfect sense to modify a house on an old flood plain. So just like everything else, each house requires an analysis of its environment and the unique risks associated with its environment.

From our point of view and because we have a limited amount of resources to put into this project, we have disregard all kinds of catastrophic stressors like major fire, overland flooding, hurricane, tornado direct hit, insurrection, earthquake, and the like. Most of these catastrophic stressors involve the total or partial destruction of the house. In such cases, the householder must move from the house thereby destroying the household.

So what's left? There are a few others, energy consumption being one of the most critical.

From our point of view, given our latitude, we must be very conscious of the energy we use. Here at 43 degrees we power our household using electricity and heat it with fossil fuel.

Here are our statistics for both energy sources. The first is natural gas (NG).

Totals for NG

Billed Days		3,192
Cubic Meters used		22,244.00
Total Billed	$	13,384.56
Cost per M3	$	0.60
M3/day Average		6.97
Billed per day	**$**	**4.19**

These numbers are derived from utility invoices over many years. We have entered months of utility bills going back to 2004 into one of our databases. Since we started our daily meter readings in January 1st, 2007 there is an overlap of many years of data with the daily data being of much higher fidelity.

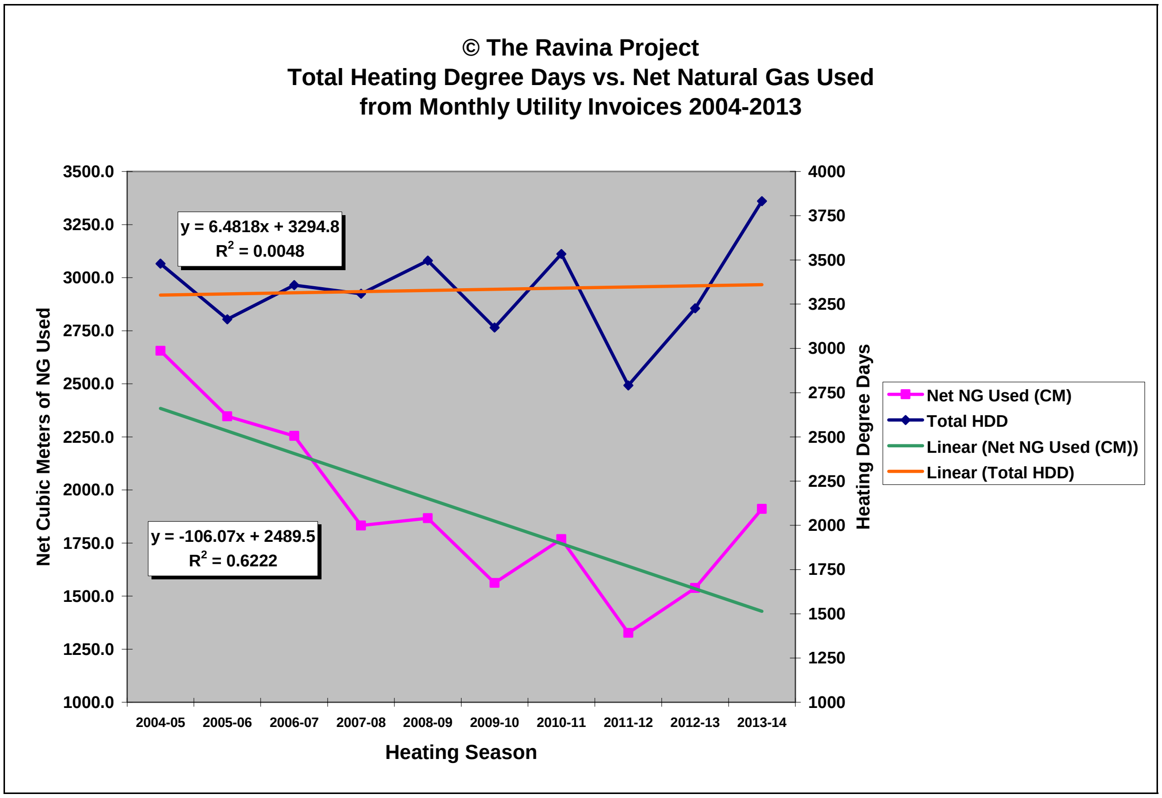
Totals for Electricity

Days		2,498
KWH billed		31,318
Total Billed	$	4,679.37
cost per kWh	$	0.15
KWH/day		12.54
Billed per day	**$**	**1.87**

Note that the current use of natural gas is much less than the average calculated above because of our increased efficiency of about 35% over the last 10 years. This efficiency is based upon the number of cubic meters of natural gas consumed for every heating degree day (HDD) during the heating season.

We'll have more to say below on the surprising effects of increased household efficiency upon our topic of household Grid resiliency.

Consider the following graphic that illustrates our efficiency increase.



Natural gas usage for heating is calculated as the cubic meters we use each heating season minus the cubic meters we use for hot water, cooking and clothes drying. The number of total heating degree days per heating season is directly proportional to the amount of coldness in a heating season. It is anchored to 18 degrees centigrade. If a day's 24-hour average temperature is 17 C then one Heating Degree Day (HDD) is generated. If the average temperature is 10 C then the day generates 8 HDDs. We observe, above that the number of HDDs (the wintertime temperature) stays about the same but the amount of natural gas used decreases. The efficiency is simply the number of cubic meters of natural gas we use each heating season divided by the number of Heating Degree Days in that season. As the number of cubic meters of natural gas used decreases but the temperature expressed in HDDs stays the same, the resulting fraction decreases in value. So in the chart above, a 'falling' efficiency value is better.

One might think we have strayed off topic but household heating and cooling efficiency are vital factors when modifying for Grid resiliency.

So, back to the topic at hand, when examining the hierarchy of stressors we face here, the lack of energy is a huge issue and should be high on the list. From the last page we used 22,244 cubic meters of natural gas over 8.7 years. This translates into 22,244 multiplied by 10.35, which is the conversion factor between natural gas and energy in kWh we are using, equals about 230 MWh. Add in the electrical usage over 6.8 years of about 31 MWh and the total is about 260 MWh of energy usage in about 8 years. Since we use so much energy, the lack of it might be a household killer.

Continuing with our argument, let's look for the stressor that reduces the maximum amount of household functionality.

- **Water** – we consume thousands of liters of water a year. Being cut off means we drink out of our rainbarrels through a filter system or we purchase water and bring it home. Community action may provide water trucks in the neighbourhood.
- **Natural Gas** – We convert the energy in natural gas to heat in all cases. We heat our house, our water (domestic hot water), our food and our clothes for drying purposes. Depending on the time of year, a natural gas outage would range from inconvenience in the summertime to a major household stressor during winter. One could heat the house enough using Grid energy so that the household is maintained. But of course that depends in part upon house insulation efficiency.
- **Electricity** – When we lose the Grid we lose the services of every electrical appliance in the household. The furnace cannot start without electricity and of course there is no hot water. The household is basically 'dead'. We are thrown into the 19th C in a blink of the eye. If you heat your house with natural gas and it's the wintertime, there is plenty of natural gas under pressure in the distribution piping. But no one can use it because of the Grid power outage. If there are other appliances like sump pumps, they will be overwhelmed and flooding may occur. Depending on the time of year, no Grid power can mean a cold dead house which may cause burst pipes. This stressor seems to have the power of household destruction.
- **Sewage** – We consume sewage not in the meaning of bringing sewage into our house but we consume the space in the sewage system that our sewage takes up. If there is no space for ours for whatever reason, then our sewage backs upon into our house's basement. Water and bacteria are a very nasty mix. Lack of sewage means we dig latrines in the backyard or we deal with it by renting a portable toilet. If you are in an older house then ensure your rain water downspouts are disconnected from the sewage system. This has potential to be a household killer in situations where bacteria filled basements are impossible to live near. A one way flow valve in the sewer line solves this problem.
- **Plain Old Telephone Service (POTS)** – This is the telephone system that people have used for more than 100 years. POTS is delivered by thin copper wires from a central office connected to the house's phone wiring and eventually the phone jacks. Cell phones have largely reduced the importance of this service.
- **Digital Communications Channels** – These digital only channels may come in via many physical media. Some come in via the POTS line (on a different frequency band than those devoted to the analog voice signal), co-axial cable or even wirelessly. If this service goes down we live the lifestyle of 1990 or before. Modern cell phones which are in effect mini workstations have reduced the importance of this outage.

We have gone through this analysis here at The Ravina Project and determined that there is one risk that towers over all others. It is the risk of Grid failure.

Household Resilience to Grid Failure

Here at The Ravina Project we had completed the above analysis in the spring of 2006. However, looking over our engineering notebooks from that time period, the design was not straightforward. We rejected many of our initial ideas. We built the project on paper before we committed funds to it.

Grid Resilience Design Analysis

To give you an idea of our thinking, here are a list of the various design ideas we generated to provide us with Grid Resilience. Some of these designs may work well for other people in different situations.

Gasoline Powered Electrical Generator

In our first analysis the use of a gas generator was considered. It had lots of good points in that most vehicles have gas in their tanks so lots would be available. But in the event that the Grid was off line for an extended period of time gas stations could not pump fuel. Our analysis in this scenario was that the fuel would be plentiful initially but for any extended time the fuel sources would quickly become unreliable. Three other negative votes against this means of electrical backup were: one, a household power interruption would occur, that is the house would be dark for a period of time, two, someone would have to be at home to get the generator fired up, make the switch changes in the house and three the house only uses a fraction of the generator's output. Fuel, a valuable commodity will be wasted when running the house from the generator. Generators are most efficient when working at or near maximum capacity. There are and were automatic generators that do all the work but they were beyond our budget. In all cases the household would experience a blackout for a time.

We were also concerned about CO2 release, even in 2006. We wanted a clean solution rather than one built upon fossil fuels and mechanical devices that require maintenance.

Battery and Inverter

We thought that a cleaner and more automatic solution would be to limit the technology to an inverter connected to the Grid, a battery, and through a separate electrical panel, to all the protected circuits in the house. In this configuration, the battery would be constantly charged so it never discharges when the Grid is working. When the Grid fails the protected circuits do not notice because they, at all times, are powered from the battery. This design solves the interruption problem but another pops up. This design is based upon a battery that has a lifetime. After that the house goes dark. Note that this design world work quite well in areas of the world where the Grid is offline for part of the day on a more or less regular basis. The battery could be sized to allow for uninterrupted power to protected circuits which draw a known quantity of energy for the period the Grid is off line. The inverter is sized to energize the protected circuits plus has enough capacity to charge the battery within the time the Grid is on line. When the Grid goes off line again the battery has been topped up. So this design has merit but not for us here in Toronto.

Battery, Inverter and Gas Generator

This scenario allows the household to be both powered without interruption and have a large amount of energy on hand, both in battery chemistry and fuel supply. This is an inviting design. Lack of fuel, and fuel storage plus the maintenance and storage of the generator are all factors for consideration. We know that fuel gets scarce quickly in a Grid outage. Finally the generator is powered by fossil fuels. We felt that a resilient house should not rely for its primary backup power supply upon a fossil fuelled generator. Below we show that a fossil fuelled generator has a place but not as a primary battery charger.

Battery, Inverter and Wind Turbine

We placed our Wind Power Request for Proposal on our WEB site. It is still there in fact. However, in 2006 we didn't have a WEB site but we did our homework. It seems that here the Wind Rose data, the graphic that tells you the amount of wind an location gets at various heights and azimuths, does not justify a wind energy harvester. And further, we have serious turbulence issues so the tower supporting the wind turbine would have to be massive, too massive for the neighbourhood, the size of our property and budget.

Battery, Inverter, Solar Panels

This design hit a sweet-spot with us. The Xantrex 4800 inverter provides 4000 watts continuous output and 10,000 Watts short term for large inductive loads. The battery consists of eight, three cell, 6-volt off-Grid lead-acid batteries wired together in series on a 48-volt bus. Their total usable capacity about 14.0 kWh. The solar energy harvester consisted at the time of 12 square meters of 12.5% efficient polycrystalline panels with a nameplate capacity of 1,500 Watts.

Our Grid Resilience Design, Installation and Testing

The Protected Circuits

One of the questions was: what should be on the protected circuits? We do not have any 220-volt appliances in our house so that makes the design much simpler. We looked at all the appliances we needed to keep working plus those devices that were part of the house's infrastructure. We settled for the refrigerator, stove, one circuit of lighting in each room on each floor including the basement, bathroom, office, master bedroom and one more for the boiler (furnace and hot water heater). From our initial testing we discovered that many rooms had two circuits servicing the lighting and wall plugs. We placed only one per room on the new distribution panel.

All other circuits remained on the old distribution panel including circuits that provide outside lighting both in our backyard and front porch and a separate circuit dedicated to an outside duplex socket in a waterproof box at the side of our porch. This circuit is common here in Canada. It is used to power a car's engine block heater in the winter time.

The only area of improvement that is on our current 'to do' list is to bring out a protected circuit at the side of the house located in a waterproof box. If there is an extended Grid outage, we probably want some power in our yard. For now we would have to run extension cords from inside the house … which during 'bug season' or cold weather is not the best way to solve the problem.

Testing

We test our Grid resiliency by severing our connection with the Grid. We ensure that all the circuits that are backed up are still backed up. We test the fridge and stove. We turn on the boiler to heat the house. We turn on the hot water tap and ensure we get hot water. These tests are done every few months. If there is a Grid outage we use that as a test. There have been quite a few over the last years so the frequency of our manual tests has fallen off.

Upgrades

Our Xantrex inverter was installed with a feature we did not use initially. It has a generator input port built into it. A generator was always part of the design but not as a primary provider of energy to the battery. After 6 years we purchased a tri-fuel generator and hired an electrician to run a 120-Volt power cable through our basement wall to a waterproof external box which contains a male 30 amp, 120 Volt twist lock connector. This male connector made our house into a big appliance that could be 'plugged into' a generator. There is more on the idea of the house as an appliance below.

We upgraded our 1,500 Watts of solar panels to 2,800 Watts of 17.1% efficiency monocrystalline panels in September 2013, increased our collection area from 12 to 16 square meters and changed the striping from three strings of four panels striped horizontally to five strings of two panels striped vertically. We installed new wiring from the roof to the external fuse box and added two more circuit fuses, one for each new string. All else remained the same.

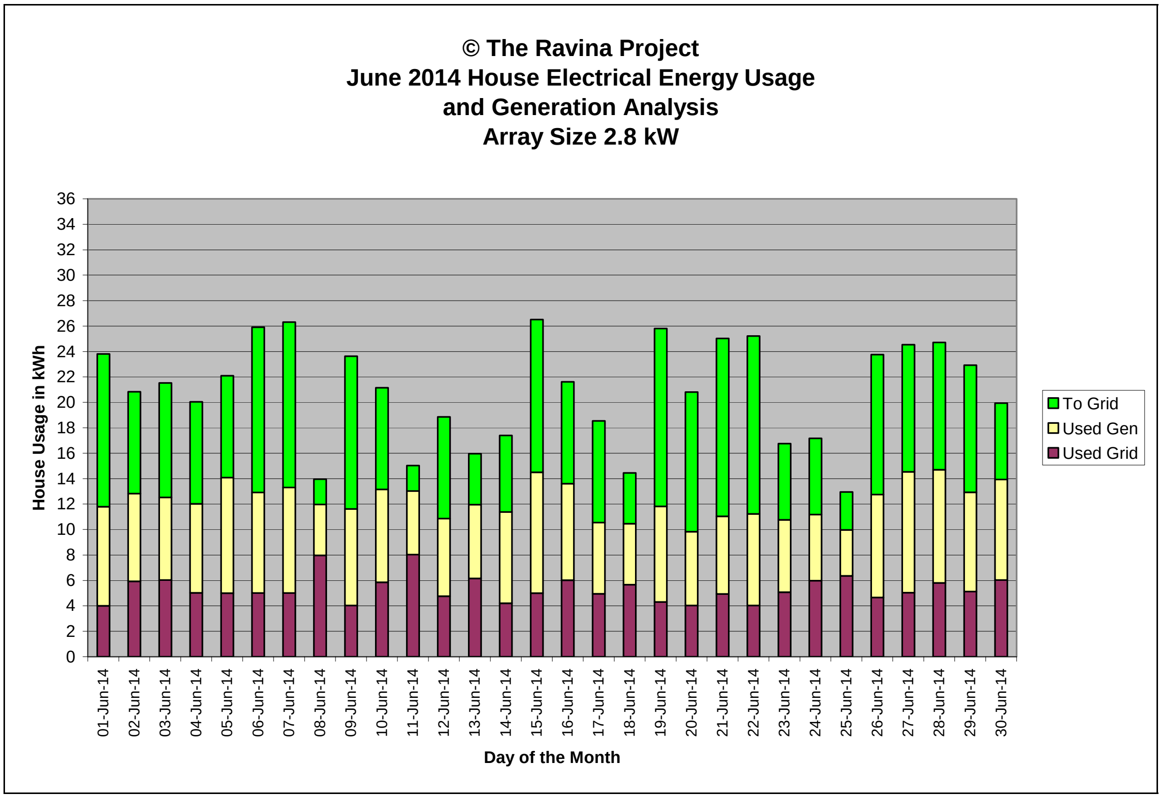
Performance

We have had 15 months so far to test the collection capabilities of the new array. We noticed that it is slightly more efficient in collecting energy. Both our own in house efficiency standard and the daily Capacity Factor calculations are slightly improved. We have also noticed that the daily generation amounts during the prime months for generation (April to September) are about twice the previous amounts. Of course we need a few more years to fully understand their performance. The house has been optimized for just 1,500 Watts and the best we could do was about four days off Grid in a summertime test situation. With the effective doubling of our solar power supply we will re-run this test next summer (2015) to see how much we have extended our off-Grid performance using the solar panels as the generator.

We hooked up the generator in our last off-Grid test as the battery was getting down to a discharged state. The Xantrex charged the battery from the generator (using propane) for about 4 hours and gave us another full day off off-Grid power. During this time the sun did not co-operate fully so the generator was a major source of energy. We have not re-done this test with the new higher powered panels. From the generation results over this past summer we probably could have gone off Grid for some time. Using the panels as the primary battery charger seems to work well for best part of the year.

The following chart demonstrates that this speculation could turn out to be true. These charts are created from our daily database. Our WEB site has charts like this one and many more based upon our daily data readings for every month of the project since January 2007.

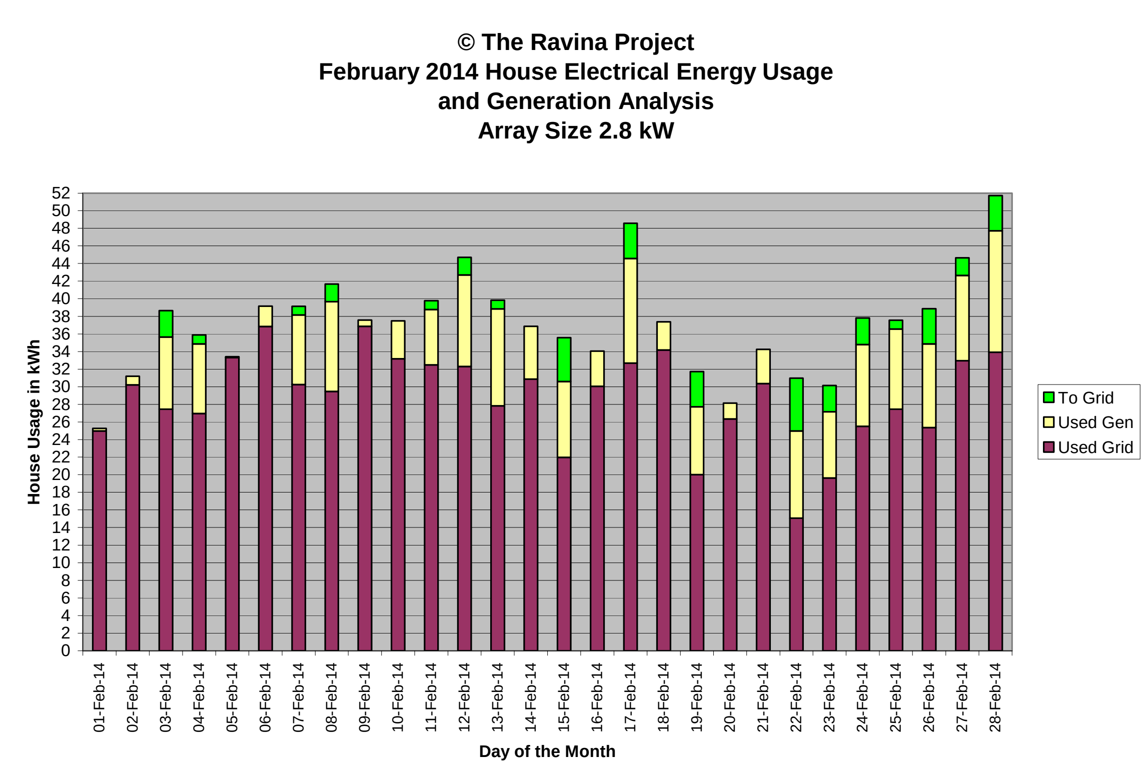
Consider the following chart:



There's lots on this chart so let's unpack it. On the left axis is the household usage in kWh. Across the bottom is the date of each data reading. For each date we plot three values that are stacked on top of each other to give a total for the day in kWh. The rust or darkest colours represent the total amount of Grid energy we used to run the household. This energy is primarily used during the night time when the solar panels were off line. The next colour, the yellow part (like the sun hehe) represents the amount of energy the household used from the total amount of energy generated by the array. As you can see on many days we used more solar energy than Grid energy. This stands to reason because really, other than a fan used for cooling and the refrigerator, nothing else is on line and using energy during summer nights. But during the daytime many more appliances are in operation and hence more energy is used. The top colour (green) in the stacked bar represents the amount of energy sent back to the Grid for neighbours to use. On some days we sent back more energy than what we used from the Grid plus the array.

We could have been off Grid for the month with no problems due to lack of power or discharged battery. In fact, the solar charge controller, our Outback MX-60 would have shut down the panels during some days because the battery would be near being overcharged. That is one of the purposes of a solar charge controller, to protect the battery. The Grid is our outlet valve for extra energy we cannot use.

Contrast this generation with a February chart below.



As you can see winter time here is ugly for solar energy harvesting even with increased harvesting power to a very conservative 2,800 Watts. Note also the increased electrical energy use. We use space heaters plugged directly into the Grid and not to our protected distribution panel. Our heaters are the ones that look like little radiators and are filled with oil. Why? We use them because we heat our house with fossil fuel which produces 100% carbon release whereas our Grid electrical energy has only about 5-10% carbon content. We are a special case here in Ontario, Canada. In a stressful situation these heaters would not be used because the Grid would be off line. The point here is to show that even solar, for long times of the year at this latitude, would only sustain us for a extra day at best over and above the stored energy in our battery.

That of course meant we needed another layer of Grid resilience. We were not happy with the fact that all our work and treasure only bought us a few days of Grid resilience at the wrong time of the year. We were not impressed when the data came in.

Generator Addition

We have added a tri-fuel 2,800 Watt generator to the mix. It can be fuelled from natural gas, propane or petrol. With the addition of the generator we finished the generation part of the Grid resiliency upgrade.

Grid Resilient House 'Lite'

So it seems that our experiment here in household Grid resilience is working out quite well. That's all well and good. But we now must take our setup, strip it down to the essentials and design on paper another house that is Grid resilient. Why? Well as with everything else in R&D the prototype embodies many things including proof of concept. We built it and it works. So our next design will take what we have learned and apply it all to a design practical for many households.

As with most everything else Grid resilience comes in many flavours. Our flavour is full blown Grid resilience maxed out to provide Grid power even if the Grid goes down for days or weeks. But not everyone can afford to or even want to do what we have done.

What are the solutions then for other households who want some kind of Grid resilience? What are the 'must haves' when designing a house's protected circuits? That is, are all circuits the same or is there a hierarchy? Is there a design cheap enough for most householders, that is, is there a Grid resilient household design "lite"?

The House as an Appliance

We are all familiar with electrical appliances. They all have a power cord terminated with a plug. The plug is inserted into a wall socket which makes the connection between the internal mechanisms of the appliance and the Grid that is, the appliance is directly connected to the generators many miles away through the Grid infrastructure. When we switch the appliance ON, the appliance uses the Grid power to do work for us.

Could a house be an appliance?

To be an appliance, the house would have to have an external plug in a waterproof box placed on an exterior wall within reach by a person standing on the ground. An extension cord could be attached to this plug and connect the house to a power source.

The external plug is not all that needs to be done to make the house into an appliance. The house also must have internal modifications to its wiring so that it can accept power from an external power source that is not the Grid plus at the same time disconnect from the Grid. When the wiring and modifications are completed, the house becomes a big appliance. We thank Mr. Mark Brilliant, our neighbour, for this design.

Essential Protected Circuits

Firstly, we must to look closely at the number of circuits we have in the house and determine the ones that need protection.

What we did initially was to make a list of all the household appliances that absolutely **must** have power in an extended Grid outage situation. Do we need a TV or Internet or maybe a radio? How about lighting and lighting on how many floors or rooms? Do we need circuits in a particular room which may be home to a loved one who needs power to keep them alive? The list is really endless and every household will have its own unique list of 'must have' appliances which will run on a unique set of 'must be ON' circuits.

For the purposes of this paper we look at the household and our meaning of resilience which is rooted in the idea that the household must remain, that is, the house remains in a livable condition and the people who inhabit it can carry on living there. With this in mind we can start discarding items on our ‘wish list’ of appliances we want to continue working in the house. We need the furnace … that is a ‘must have’ here at 43 Latitude. A cold house with no heat and burst pipes is not a place to be. So what else is essential? Well we need to keep our refrigeration during a blackout. Our food, especially in the summertime, must not spoil. And of course, we need cold beer to cheer us up during a trying time. So what else do we need? A few elements working on our gas stove would be nice too if the stove needs the Grid to fire up its stove top burners. We need at least one circuit for lighting and wall sockets. We can run extension cords and power bars around the house to ensure we have lighting on every floor. For us this provides a fundamental level of electrical power that will allow us to stay in our house no matter what the season.

Making a house into an appliance

This process is actually much simpler that what we first thought. It seems a new panel can be wired with a switch such that it connects the protected circuits to the external plug on the side of the house and disconnects the entire house from the Grid. The only limitation is that the house must require no more than 1,000 Watts maximum with the average much less when it is operating in the ‘appliance’ mode.

All this work can be done using a licenced and experienced electrician who knows the local building codes. As well, your insurance provider may appreciate being ‘in the loop’ on this issue.

Household Appliance’s Electrical Energy Sources

Here in what follows is a short list of possible energy sources for the resilient household.

Neighbour’s house

In many neighbourhoods, wintertime cold requires that the householder’s vehicle be plugged into an electrical power socket located on the outer wall of the house. The car plugs into the house … or more exactly, the engine block heater plugs into the Grid through the household wiring. In a similar way a house that has been converted into an appliance can be plugged into a neighbour’s house just like a block heater. The limitations placed upon the maximum power use of 1,000 Watts ensures the fuse or breaker in the neighbour’s house will not trip under maximum power usage.

Community Generator

A generator of a 1000 Watts capacity can provide plug-in power for the house. Note houses close together could run their extension cords to a common location where they could be attached to a generator of an appropriate size. Note that the generator can be a smaller capacity that just the sum of each house’s requirements. All the houses would not draw their maximum power at the same time. A 5,000 Watt generator may have eight or more houses attached to it at the same time.

Another way of looking at the generation condition is to imagine a cold winter's night and every house that has generation can heat itself using natural gas. The connection time could be limited to let's say one hour in every four to six. During the connected time the household has a chance to charge the batteries in their phones and computers and to heat itself using the furnace. If the house has a natural gas powered domestic hot water heater which uses nominal electrical power, hot water can be re-heated as well. Note that an electrical hot water tank would not be included in this plan because of its large use of electrical power. Some tanks have 2,000 Watts of heating elements in them and work on 220 Volts.

One neighbourhood generator used intelligently could maintain the heat and livability of many groups of houses. Note that a car type battery of 12 V and a small inverter of about 300 Watts allows several small appliances to be used including many low power CFL bulbs even though the generator is not attached to the house. One of the appliances powered by this method may be the Internet router and access point. This would allow laptops and the like to maintain contact over the Internet with loved ones. This of course would or could occur if the utility that provides the physical Internet hookup to the house has enough power to keep its infrastructure operational over the course of the blackout.

House Insulation and Household / Neighbourhood Resilience

The discussion above drives home the very important point that insulation makes the house easier to keep warm in the winter time and keep cool in the summertime. We have certainly documented in this essay the increase in our household wintertime heating efficiency due to, in the largest part, increased insulation.

So what does this increased efficiency have to do with household Grid resiliency? In the scenario above where houses that have been converted to being appliances, the amount of time the furnace must be ON heating the house over an extended time decreases. Why? It's because the house cools much more slowly than a poorly insulated house. This insulation bonus provides a huge advantage to the overall neighbourhood energy management budget. In the case of using generators that are multiplexed across many houses spending only an hour or so at each location every 4-6 hours, the amount of energy use drops as each house requires less electrical energy to heat itself. When the generator returns to the housing cluster, each house's internal temperature on average has fallen less over the no power time span.

In the summertime the exact opposite occurs. The well insulated house warms much more slowly so the temperature in the refrigerator rises more slowly. It takes less energy to restore the refrigerator and its freezer to their normal operating temperatures.

When one looks at the big picture, whether the electrical energy source is the neighbour's house or an itinerant generator making the rounds, less energy will be required just because houses are better insulated. If the householder has invested in low energy appliances and furnace/water heater then so much the better. The impact through an extended outage will be that there will be more fuel left in the generator's tank at the end of each day. That tends to extend the time to fuel exhaustion and therefore increases the neighbourhood's overall resiliency to Grid outage.

Of course the fuel of importance is the fuel in the gas mains. During a power outage this fuel may not be repressurized by the utility. It itself may have an economy associated with its use and therefore may be limited in its supply. Using less because of better household insulation makes the insulation do ‘double duty’ as it were, saving on generator fuel and natural gas.

We have shown in other papers available on our WEB site, the value of insulating your house. It is by far the best way to save energy. It is by our calculations many times better to insulate than it is to harvest one’s own household energy using any technology you can name. And of course insulation provides the energy savings in perpetuity without using any further energy input or carbon release for the lifetime of the house.

The future of Grid resilient households

Grid resilience is something added to our house. At the time we designed our system there were many bits and pieces available on the market but nothing that was sold as a systems integrated package, guaranteed to work together plus work with all the other electrically powered devices in our house. For us, systems integration has been a major activity. We have all kinds of electronic controllers that would use the AC power created by the Xantrex 4048 Inverter. Even though the sine wave coming out of the inverter is very close to a smooth analog sine wave it is still a digital approximation of a ‘real’ one. Some devices have power supplies that are sensitive to these types of simulated sine waves. So far we have been impressed with the results. The few issues we found have straightforward workarounds. For instance our gas stove does not like the change over from Grid power to battery power. However, be that as it may, it objects by beeping when we have a power outage. We reset it and it’s happy again.

We have been satisfied that our design is the correct one and that the performance, which is of course the gold standard for evaluation, has been superb.

Global Warming and Grid resilience

One might question the insertion of Global Warming here in this paper which is centered upon the household. There is a connection.

In many of our papers where we have evaluated the technical feasibility of using renewables like wind and solar to power our high energy civilization, we have come out in favour of renewable energy plus something else. That is, we have demonstrated that here in Canada renewables alone cannot provide the energy density that our civilization requires. We argue that new, safer technologies that unlock the most energy dense resource we have, the Atom, are required to carry us forward into an even higher energy use future. The Atom is 1,000,000 times more energy dense than fossil fuels.

However, the future use of the Atom as a civilizational power supply is in doubt at this moment in time. There are societal movements, which have huge environmental protection credentials going back decades that are working against any further use of nuclear power. They argue that any upgrades to extend nuclear plant lifetimes should be scrapped, all current nuclear plants must be shut down and any research and development into future nuclear plants must be terminated. Nuclear power is the enemy in their view.

These social movements are substantial and many large populations of voters agree with their goals. It is not therefore unreasonable to speculate that they might win the political battle that currently rages (at this time of writing) over the use of civilian nuclear power plants. With that political win we are left with the usual suspects: wind, solar PV, geothermal, Hydro and the like. Our papers show that solar PV here in the southern most region of Canada is not a viable option for about half of the year. We have shown that the ability to harvest energy using solar PV panels is directly proportional to the sun angles upon the collecting surface. Here at 43 degrees Latitude our angles are better than 99% of the rest of Canada. If solar PV is useless for battery charging for 92 days a year and marginally useful for another 92 days then it is pretty clear that it is much worse than that in the rest of Canada. This argument is also valid for a huge swath of the U.S.A. because much of the northern part of the US is north of us here in southern Ontario.

So where does this line of argument lead us? It leads directly to electricity rationing for the household.

Global Warming as we all know is caused in a major way by having too much CO_2 in the atmosphere, so much that it changes the energy balance the whole earth has with space. The imbalance is caused by the earth being unable to radiate to space the same amount of energy as it gets from the sun, which is about 240 Watts per square meter over the whole of the earths' surface. There will be a time in the future when it is obvious to all that this imbalance is an existential threat to civilization. Laws will be passed and the use of carbon based fuels will be strictly limited. Since we heat our homes with fossil fuels there will be limitations upon the use of fossil fuels at the household level. At the Provincial/State level there will be limitations upon the generation of electricity by fossil fuels. We will be forced to use and depend upon renewable energy for our electricity. We know that renewables do not have the same capacity factor as our current suite of power generation so renewables will be unreliable as a constant source of electrical energy.

The bottom line is we will require that whole sections of the Grid be disconnected during times of the day depending upon how much energy the renewables are generating and of course the amount of energy left in the batteries that service the Grid. At the household level we'll have a choice to either modify our household to be Grid resilient for several days or we structure our lives so that we can live without the Grid for several days at a time.

So we arrive at Grid energy rationing as a result of several related factors. The first is the political win for the nuclear abolitionists. The second is the public acceptance and realization that Global Warming caused by human made CO_2 is an existential threat to our civilization and the third is the fact that renewable energy alone including Hydro dams cannot supply the quantity and quality of electrical energy our civilization requires.

Most of the argument above has been focused upon political events making the Grid unreliable and what we can do at the household level to make ourselves resilient to that stressor. Let us overlay another stressor from the natural world, the increased damage to our infrastructure from Global Warming. When combined, the natural and man made, the argument for household Grid resilience becomes even more compelling.

And finally, the nuclear abolitionists need not have a clean win to induce Grid unreliability; all they need is to delay any kind of massive nuclear research policy under the rubric of: "First give renewables a try and if they don't work out then we can develop nuclear energy or some other ‘magic bullet’”. This assumes we have the luxury of time to dither and see what happens. This assumption is false in the extreme.

Conclusion

Over the course of writing this paper we have had several nasty storms of both rain and ice that have devastated parts of the Greater Toronto Area. Other parts of Canada have suffered from many Grid failures for extended periods of time. This is occurring, or it seems to be occurring with more regularity. All projections into the future strongly suggest that climate change will tip the atmospheric energy balance, pushing naturally occurring strong storms into infrastructure killing, nasty ones.

Reliable electrical energy distribution via the Grid otherwise called electrification has been a boon to our civilization. It is seen as a necessity for those who want to modernize their cities. Grid power must both be reliable and in quantities enough to provide everyone on the Grid with enough power to run their lives and businesses. In the future as more people around the world live in large urban areas, the quantity and quality of Grid will become even more the defining feature separating first, second and third worlds.

In the first world, Grid failure can paralyze whole cities. The response teams can be overwhelmed when hundreds of thousands of utility customers are without Grid power. When cold weather is overlaid on top of the Grid failure, restoring power becomes a household saver for many and in some locations, for most. The Grid resilient house allows responders the luxury of time before it must be serviced. Grid resilient neighbourhoods would be like ‘gold’ to the responders allowing them much more latitude and flexibility in their response planning and operations.

During the last great ice storm here in our neighbourhood, streets of houses were without power yet the next street over had power. Grid resilient houses would allow those without power to plug into powered houses across their back yards.

And finally, we may as a civilization be forced to decarbonize rapidly over a 20 year period because of CO2 pollution. This is a possibility that must be considered as a viable and reasonable future scenario. From the household point if view, it means converting to electrical heating from natural gas. Our optimized house used over 33,830 kWh of energy last year from all sources with 67.4% coming from natural gas. Where will the energy come from if we are forced to convert? A solar array delivering 33,830 kWh to us over the year would have to be 128.5 square meters in size. For 100,000 homes it would be 12.9 square kilometers of 20% panels at a yearly average capacity factor of 15%. For a million homes, we would clear the trees from 128.5 sq km of land for the arrays.

All renewables are diffuse energy sources and as such require huge collectors to harvest the amount of energy required by our society. Hydro dams and solar PV arrays especially require many resources to build and take up large areas on the earth’s surface. Dams flood vegetation that rots and are becoming today a major source of methane, a greenhouse gas more powerful than CO2. Solar PV requires huge swaths of treeless agriculturally unproductive countryside for the arrays of panels. We’ll cut down trees that absorb carbon from the air and turn agricultural land into waste land full of herbicides to control the weeds that would grow around the panels and block the sun.

Is this the future we want?

Appendix - Calculations

We have made some calculations in this paper.

Here's how we got the numbers we did.

Calculating total energy usage 2014 from all sources (using our data collected daily):

Total electrical energy harvested: 3619.6 kWh
Total electrical energy sent back to Grid: 1486.0 kWh
Total electrical harvested that was used: 2134 kWh
Total electrical energy used from the Grid: 6,175.7 kWh

Total natural gas used: 2,466 cubic meters (m3)
Gas to energy conversion factor is 1 m3 = 10.35 kWh
Total natural gas energy used: 2,466 m3 x 10.35 kWh/m3 = 25,520 kWh

Total energy used from all sources: 25,520 kWh + 2,134 kWh + 6,175.0 kWh = 33,830 kWh

Calculating array size for 33,830 kWh yearly generation.

This calculation will ignore the size of battery required to make this collected energy useful and any space between the rows of array panels. We focus only on the surface area of the panels required. Large arrays with a square kilometer or more of collector area may occupy surface areas twice as large given the spacing between the rows of panels and the like.

Calculate the nameplate capacity of the 100% capacity factor generator that will supply our house with 33,830 kWh over the course of a year.

Number of hours in a year is 24x365 = 8,760 hours.

Size of generator with capacity factor of 100% matching the above specifications: 33,830 kWh / 8,760 hours = 3.861 kW

Efficiency is calculated as the number of Watts generated per square meter of panel surface when 1000 Watts of light energy are shone upon it.

A 20% panel has a nameplate capacity of 200 Watts per square meter of panel.

One kW of 20% efficient solar panels will require 5 square meters of surface area.

Our 2014 average monthly capacity factor is 15.0% (calculated from our daily data). The January to December average monthly capacity factor percentage data is detailed below:

7.4, 12.7, 14.6, 18.3, 20.5, 23.2, 21.7, 20.7, 18.2, 10.9, 7.0, 4.7

Size of 20% panels at capacity factor of 15.0% to produce 1 kW of output at 100% capacity factor for a year is: 5 square meters / 0.15 = 33.3 square meters.

Size of the panels above required to generate 3.861 kW on average for a year continuously is: 33.3 square meters/kW x 3.86 kW = 128.5 square meters.

Calculate array size to supply 100,000 and 1,000,000 electric homes:

100,000 homes x 128.5 square meters = 12,850,000 square meters or 12.9 square kilometers.

1,000,000 homes x 128.5 square meters = 128.5 square kilometers.

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

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