A Reasoned Analysis

For a New Distributed-Generation Paradigm

The Inflow & Outflow Mechanism

A Cost of Service Based Approach

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Abstract

Net Energy Metering (NEM) is a balancing method that allows electric utility customers the ability to generate on-site intermittent renewable resources, like rooftop solar PV, that deviate significantly from the customer's actual electric load: but receive credit on their utility bills as if the grid was a giant battery, storing and releasing net excess generation as needed. NEM is intrinsically a subsidized balancing service, and customers whose generation output is nominally equal to the customer's annual electric load can obtain essentially free grid-services.   In contrast, the Buy all – Sell all method that is often considered as a replacement, errors in the opposite direction, overcharging customers for their actual grid usage and over-crediting the same customer for the portion of generation that is injected into the utility grid. The *Inflow & Outflow* mechanism is the only regulatory alternative to Net Energy Metering that is a true cost-of-service based approach. The *Inflow & Outflow* mechanism is uniquely simple, being based upon actual metered power-inflows from the grid, and actual metered outflows to the grid. The *Inflow & Outflow* mechanism requires a bi-directional meter (smart meter). The method results in a rate structure that can yield accurate price signals inducing optimal operation, especially when the distributed generation is combined with battery storage, or advanced inverters allowing for demand response services. Finally, pursuant to the *Inflow & Outflow* mechanism, traditional rate design and cost allocation methods, procedures, and principles, can be used to establish rates.

The principles and analysis of this paper were first presented to the Michigan Public Service Commission in February, 2016, and to the Michigan Public Service Commission Stand-by Working Group, in June, 2016.

The Interface of Distributed Generation Mechanisms and Renewable Energy: Introduction

It is well known that the market share for customer sited solar photovoltaic (PV) has increased dramatically over the past five years. Rapidly declining costs of panels combined with federal tax credits have resulted in a mushrooming of installations on rooftops across America. However, behind the scenes, the almost universal availability of net-energy-metering (NEM) may be nearly as significant to the growth in customer sited distributed generation (DG).

NEM's influence on the rate of installations should not be underestimated. The reason is simple: due to declining costs, the economics of customer sited-solar steadily improved, but absent NEM, rarely provided a full economic-payback over the expected useful-life of the systems.

That solar PV's growth in market share was dependent on utility rate-subsidies was known from its inception. For that reason, many states, Michigan included, set a cap on the aggregate level of net-metering, typically 1% of a utility's retail load. NEM worked remarkably well, and as intended, functioned as a market accelerant, jump-starting the struggling solar PV market.

As installation costs declined, the regulatory mechanism created a positive net-present-value (NPV) for many customers. The improved economics are a direct result of the kWh netting process inherent to NEM. This netting process also facilitates a nearly ideal customer experience, since the local utility takes responsibility for balancing the generation output (which is variable and intermittent) with the customer's load profile.

As the level of NEM approaches (and for some utilities, exceeds the 1% cap), a re-examination of the mechanism is in order.

Re-examination must begin by exposing the regulatory limitations that were germane to the analog-metering world of the early solar-PV industry. The inability to independently measure a distributed generation (DG) customer's power flows to, and from the grid, gave regulators little choice but to capitalize on a technological quirk of old fashioned analog-meters – they could run backward. This ability is the essence of the NEM mechanism. Utilities were thus able to provide a monthly bill that reflected the net difference between a customer's base usage, and the monthly generation output. Unfortunately, it also provided regulators little flexibility, in the way of utility rate-design, to recover the cost of providing NEM services. Fortuitously that defect worked in NEM's favor.

In contrast, modern digital meters, i.e. "smart meters", are unconstrained, being able to **independently and instantaneously meter power-flows in both directions.** For this reason, the focus of our reexamination of NEM must be directed toward understanding the actual power flows created by DG customers, and how that knowledge can be used to design a true cost-of-service rate structure.

The common characteristic of all DG customers is that that their generation system is interconnected and operating "in parallel" with the utility grid. However, the power flows to and from the utility grid are not independent variables, they are a by-product of something more essential and basic to the operation of a DG system. Inquiry into this interplay is the thrust of modeling and analysis behind this paper.

We define the energy output of a DG system that is directly consumed by the customer, as “onsite usage”. Onsite-usage constitutes a direct and physical load-loss to the utility. The level of onsite usage varies on an hourly basis throughout the year, especially with variable and intermittent renewable resources, but modeling can extract the more obscure mathematical relationships needed to make progress on DG program design.

Because onsite-usage can be quantified by reference to smart-metered power flows, it is the key to unlocking past barriers to implementation of cost-of-service based DG tariffs.

As we will see, the netting process inherent to NEM has the practical effect of expanding onsite-usage to include the entire solar output of a customer’s DG system, with a commensurate increase in lost utility-revenue. This is a critically important attribute of NEM.

Unlike small power producer programs, such as under the Public Utility Policies Act of 1978, Pub L No. 95-617, 92 Stat 3117 (PURPA), NEM programs generally limit DG capacity to the customer’s annual electric load. Such regulatory limits reflect the essential purpose of DG programs – to allow customers to self-generate their electric requirements. In light of this purpose, the sale of excess power to the utility is never an end-goal of DG operation, but rather a reflection of sub-optimal system operation.

Under NEM, a system sized to meet the nominal annual customer-load can, in theory, result in a total load (and revenue) loss to the utility. In such a case, the revenue impact to the utility is nearly identical to that of a customer that is physically disconnected from the grid, and for this reason it can be said that NEM can create a “virtual” grid defection.

This might seem like strong language, but the lost-sales impact of NEM goes well beyond the commonly suggested issue of non-participating customer subsidies for uncompensated grid-services.

NEM hits at the core of an investor owned utility’s long-term financial objectives, in particular the objective to grow rate-base through system expansion or replacement. It is this characteristic that has seized the attention of utilities across the country.

State regulatory and legislative bodies are responding to utilities’ outcry by considering a patchwork of disparate replacement programs. Unfortunately, it is clear that an ad hoc regulatory-approach is developing, rather than coalescence toward a new dominant regulatory paradigm. Various forms and combinations of modified NEM, minimum bills, demand charges, and “buy-all sell-all” (BASA) mechanisms are being proposed to restore utility revenues.

The Inflow & Outflow Mechanism: Analysis

As a regulator having a core stake in the controversy, the author asked a fundamental question: would it be possible to develop a new regulatory framework that is cost-of-service based, simple, and can be applied universally?

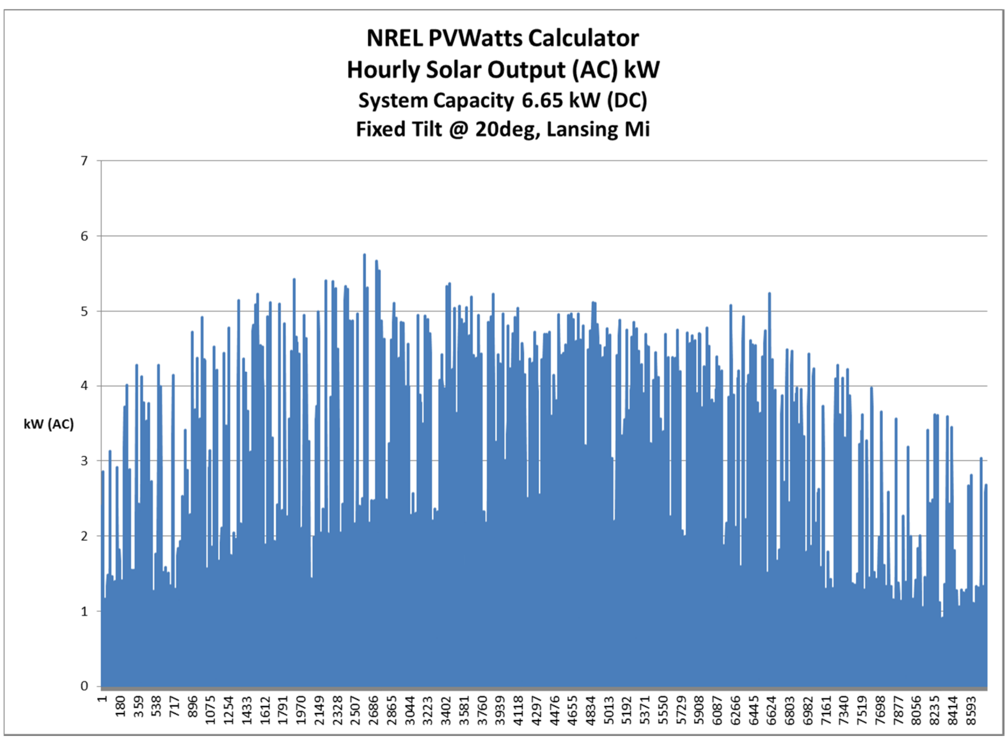
This core question was answered through modelling and analysis, combined with extensive real-world experience developing regulatory mechanisms. **The resulting thesis of this paper, and the opinion of the author, is that the only regulatory mechanism that has all the necessary attributes to qualify as a new paradigm for electric utility DG programs is the Inflow-and-Outflow (I&O) mechanism.** The basis for this mechanism will be reviewed thoroughly in the body of this paper.

Regulators have learned that a little bit of modeling can go a long way toward suggesting an optimal regulatory framework, and distributed generation programs are no exception. A proper characterization of grid usage requires an 8,760 hour model.

Without having to reinvent the wheel, analysis incorporated hourly solar output based on the National Renewable Energy Lab's (NREL's) PVWatts Calculator [for Lansing, Michigan]; and the residential hourly load distribution was derived from the DOE/NREL System advisor Model (SAM) [for Lansing Capital City Airport (TMY3)]. Hourly load data was adjusted so that the cumulative monthly usage matched the historical-average residential consumption for Consumers Energy (CE), of 8,307 kWh, during calendar year 2010.

Chart (1) shows an example of the hourly data for a solar PV system of 6.65 kWh (DC). The aggregate annual generation output of this system size is equivalent to the average-annual residential consumption of 8,307 kWh. Such a NEM customer would effectively have a net zero annual electric bill (excepting the CE access charge of $7.00 per month).

Chart 1



The hourly consumption and solar output data generated by the SAM and PV Watts models, was uploaded into an Excel spreadsheet, allowing for extensive sensitivity analysis both upstream and downstream of the utility's billing meter, e.g. changes in installed solar PV capacity, power inflows, power outflows, onsite usage, netting, and battery-storage impacts. Rate impacts incorporated CE's most recently approved residential standard and dynamic pricing tariffs.

Although the Excel model was relatively simple, the results proved outstanding, clearly revealing fundamental principles useful to regulatory program design. So let's begin by looking at the development of the model, and then follow up with the interpretation of the results, economic analysis, and future DG program design.

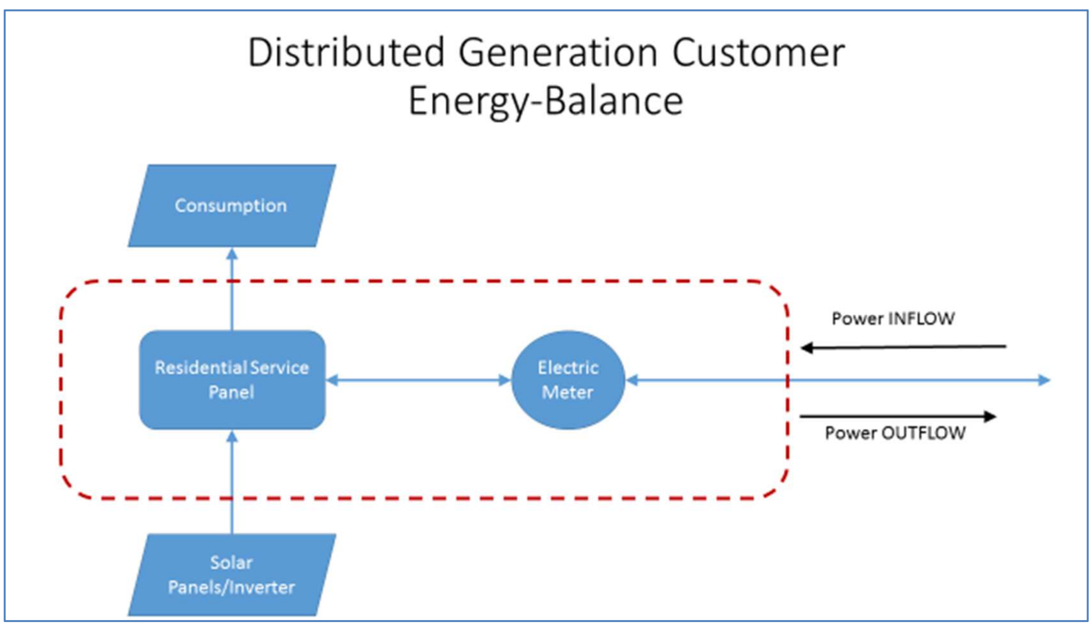
The two fundamental parameters representing grid usage are power-inflows and power-outflows. In the context of DG program design, and operation, both terms are defined from the point of reference of the customer. INFLOW is power taken off the grid; OUTFLOW is power put onto the grid. Inflow and outflow are exceptionally useful in quantifying grid usage and understanding grid impacts, thus these parameters are the focus of DG modeling efforts.

Importantly, inflow and outflow must be derived since the model input consists of hourly solar generation and consumption, not power flows. The derivation of the mathematical relationships between generation and consumption, and power inflows and outflows, starts with an energy balance:

[Energy In = Energy Out] **Equation (1)**

The energy balance is written to encompass the customer's service panel and the utility meter, as in Chart (2) below.

Chart 2



Inserting all energy flows intersecting the energy balance boundary [dashed line in Chart (2)] into Equation (1), yields an exact relationship between the model's key input variables, generation and consumption, and the desired grid parameters, inflow and outflow; i.e.

[Generation + Inflow = Consumption + Outflow] **Equation (2)**

Or alternately stated;

[Inflow – Outflow] = [Consumption – Generation] **Equation (3)**

Since the model input consists of hourly values for consumption and generation, the net quantity, [Inflow – Outflow], can be derived on an hourly basis via Equation (3), but independent values for inflow and outflow during each hour are indeterminate. This is where modeling diverges slightly from the actual operations.

Strictly speaking, modern digital smart-meters measure hourly inflows and outflows by integrating the instantaneous power flows. Over the course of any particular hour, then, both inflows and outflows may take place, and be measured.

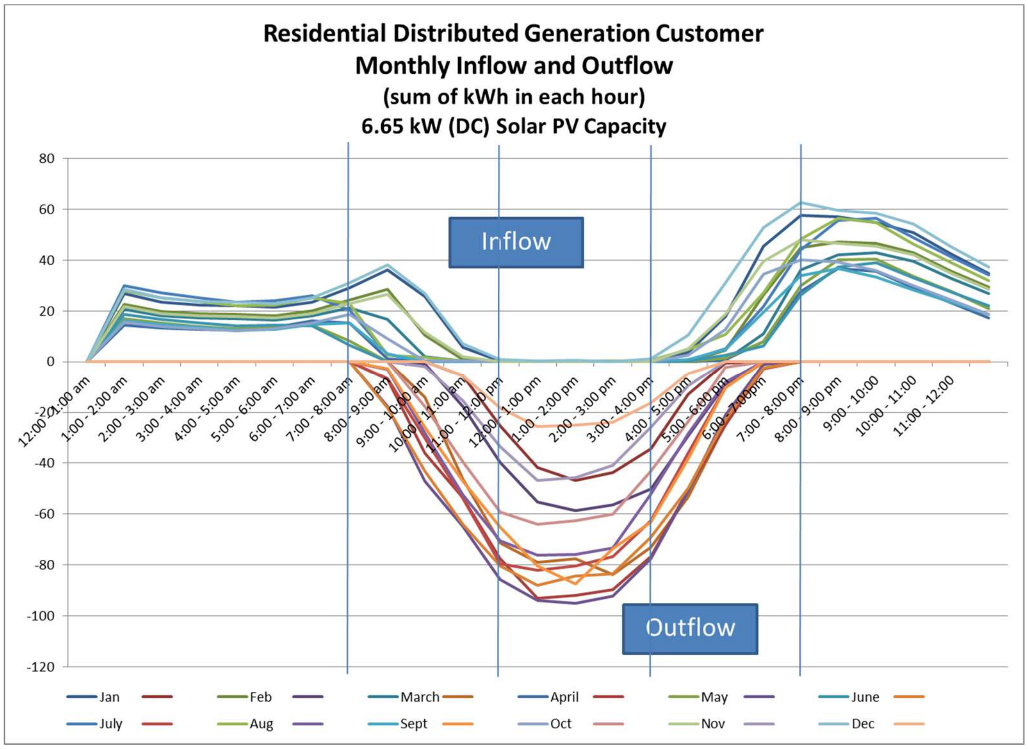
At this point a simplifying assumption must be made for modeling purposes. Since consumption and generation data-output by the SAM and Solar PV models are limited to hourly values, the energy balance is limited in its ability to derive independent [integrated] inflows and outflows during each hour.

A simplifying assumption may be made that a net positive value of [Consumption – Generation] over the course of an hour represents a practical estimate of the integrated hourly inflow for that period. In such cases, the outflow for that hour is defined as zero. Conversely, a net negative value of [Consumption – Generation] represents an hourly outflow (of excess generation).

In this manner, a stream of 8760 (hourly) inflows and outflows are developed from consumption and generation data. Each hour has an inflow or outflow, but not both.

Chart (3) below, reveals the trend in inflow and outflow values over the course of a 24 hour period and from month-to-month over the course of a year. Inflows peak in the morning and evening, and outflows peak during the mid-afternoon.

Chart 3



It was previously asserted that onsite-usage is fundamental to analysis of DG operation, and that too can be derived from an energy balance. Rearranging Equation (3) yields two identities:

[Generation – Outflow] = [Consumption – Inflow] (Equation 4)

These mathematical identities are recognized as representing the "onsite-usage" portion of the generation output.

The identities provide a means to derive onsite-usage, once hourly inflows and outflows have been estimated. Thus, in any given hour:

Onsite usage = [Generation – Outflow] (Equation 5)

Or if outflow is equal to zero in such hour:

Onsite usage = [Consumption – Inflow] (Equation 6)

Although for modeling purposes Equations (1) through (6) are used to calculate hourly values, the reader should note that because these equations flow from an energy balance, they are valid over any timeframe. They can be used on an instantaneous basis, or cumulatively, in any given hour, month or year.

We now have means to calculate the core parameters needed to model any type of regulatory DG mechanism. The next step is to restate Equations (5) and (6) into a form that reflects cause and effect, rather than modeling convenience. In this way, additional insight into onsite-usage can be obtained.

Noting that onsite-usage constitutes generation output (kWh) that is immediately taken up by the customer's electric-load, it is clear that it is an independent variable vis-à-vis the downstream (from the customer's meter) power flows; inflow and outflow. The physical flow of power upstream of the utility billing meter thus suggests that onsite-usage is actually a function of generation and consumption, as opposed to the form of Equations (5) and (6). To be specific, if generation is greater than, or equal to, consumption, then onsite usage is equal to consumption. If generation is less than consumption, then onsite usage is equal to generation. Mathematically these concepts can be stated as follows:

If Generation ≥ Consumption: Onsite-usage = Consumption (Equation 7)

If Generation < Consumption: Onsite usage = Generation (Equation 8)

Thus, the physical electrical system suggests that Equations (5) and (6) be rearranged to a form in which inflow and outflow are the dependent variables:

Inflow = [Consumption – Onsite Usage] (Equation 9)

And:

Outflow = [Generation – Onsite Usage] (Equation 10)

This restatement, yields a profound and nearly intuitive relationships between a customer's effective draw of power from the grid (i.e. inflow or outflow), and the level of generation consumed on-site.

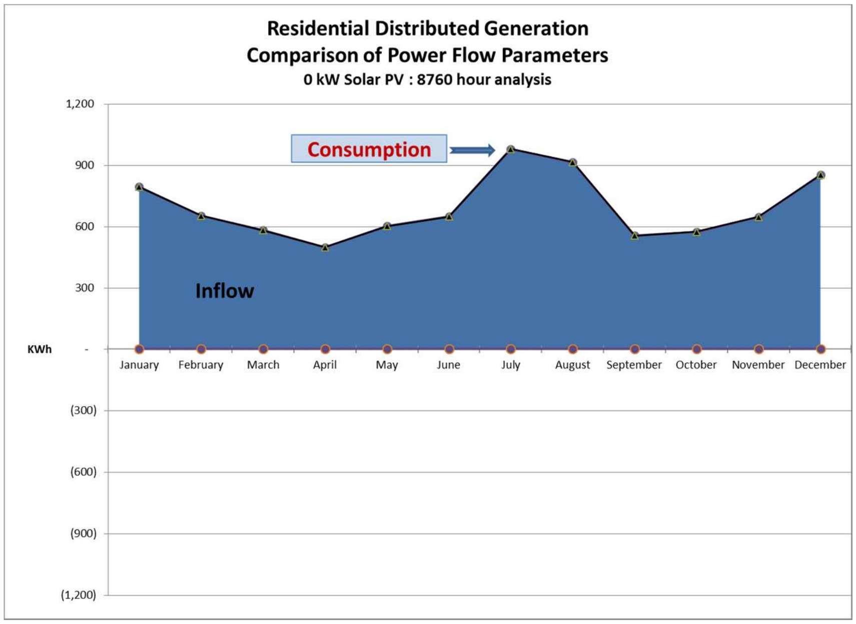
These concepts can be visualized by reference to Charts (3) and (4) below which reveals how onsite-usage modifies the power flows resulting from interconnection of a customer-sited DG system to the utility grid.

We start by looking at power flows created by a residential customer prior to having deployed a solar PV system. In this case, it is obvious that without generation, both onsite usage and outflow are zero. Absent a generation source, the energy balance, Equation (2), collapses to the simple identity:

Consumption = Inflow Equation (11)

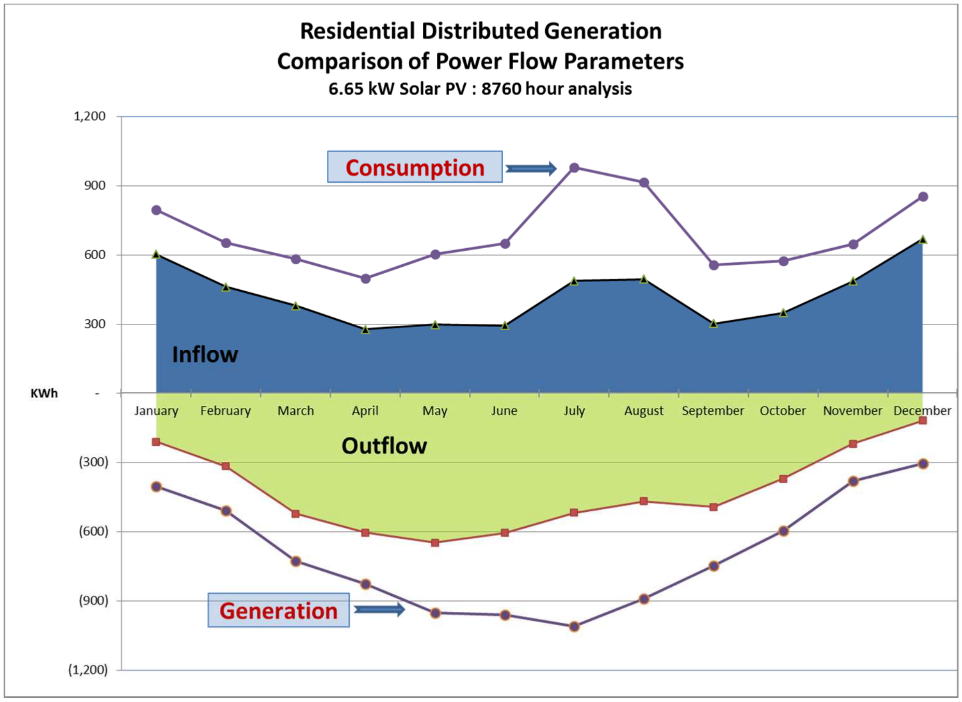
This identity can be seen in Chart (4) below, as the merging of the consumption and inflow curves over the course of the year.

Chart 4



Turning to Chart (5) below, we see how power inflows are affected by the addition of a 6.65 kW solar PV system. Cumulative monthly data graphed in Chart (5) represents the four foundational parameters; consumption, generation, inflow and outflow.

Chart 5



Referring to Chart (5), the top and bottom lines represent consumption and generation. The banded blue and green areas represent power inflows and outflows resulting from the consumption and generation profiles. In contrast to Chart (4), notice how the inflow curve is disengaged, and at a lower level from the consumption curve.

Onsite usage is not directly plotted in Chart (5), however, it is clearly evident and consistent with Equation (9), which takes the form: Inflow = [Consumption – Onsite Usage]. Similarly, Equation (10) states that: Outflow = [Generation – Onsite Usage]. From these two equations it can be inferred that the two white bands separating consumption from inflow, and generation from outflow, denote the customer's actual onsite-usage.

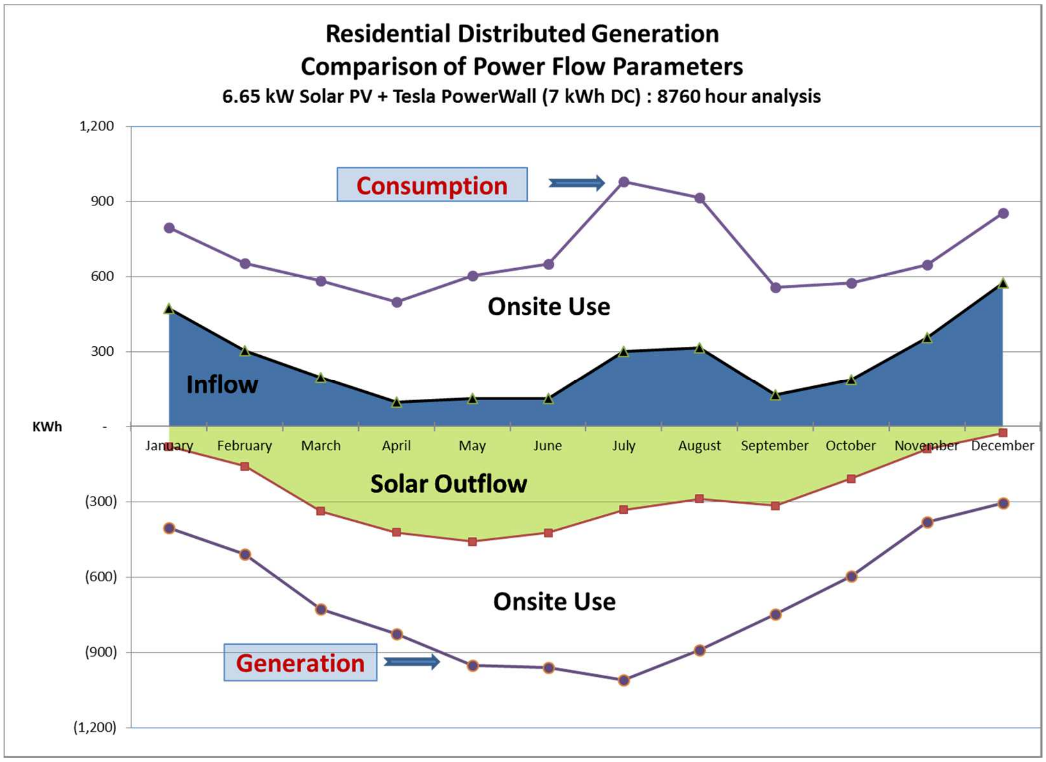
Chart (5), above, creates a striking visualization of how onsite-usage modifies the power flows between an interconnected DG customer and the grid: first, by reducing the draw of power from the grid; and second, by reducing the level of "excess" generation injected into the grid. Both reductions are equal to the level of onsite-usage.

It is logical to conclude that if the level of generation physically used on-site could be increased, then to that extent, more efficient operation of the DG system would be achieved.

Taking this concept to the limit, it can be deduced that **optimal operation of grid-interconnected DG systems occurs when onsite-usage is maximized**. It follows that optimal operation, as thus defined, by minimizing the purchase of energy from the utility, would as a result, simultaneously minimize "excess" generation (i.e. power outflows). The reduction of retail purchases of energy from the utility, is, after all, the primary reason customers install DG systems. This is consistent with the previous assertion that the purpose of a DG customer program is to allow the self-generation of customer's electric-load.

A noteworthy example of a change in customer operations, that yields an increased level of onsite-usage, is shown by Chart (6) which adds a 7 kWh Tesla Powerwall to the 6.65 solar PV system represented by Chart (5). The end result is a commensurately increased level of operational efficiency.

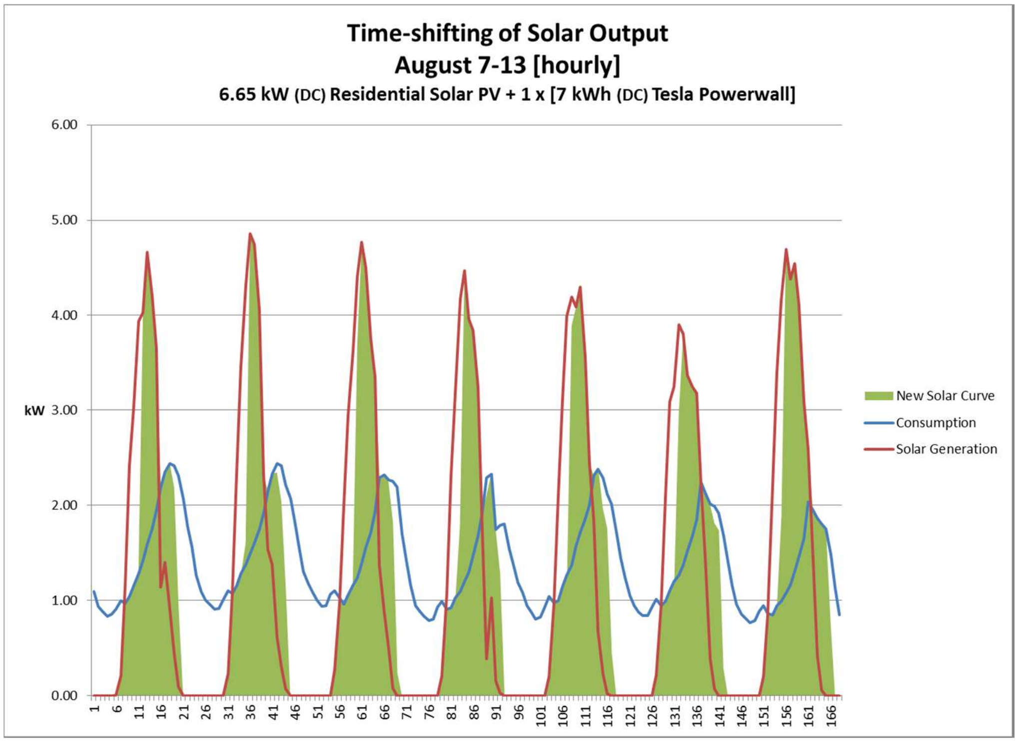
Chart 6



Notice that daily cycling of the battery yields a significant reduction in power inflows vis-à-vis a stand-alone solar PV system as seen in Chart (5). The reduction in power inflows is a direct result of increasing the level of onsite-usage, by charging the battery during periods of excess generation, and discharging during periods of insufficient generation.

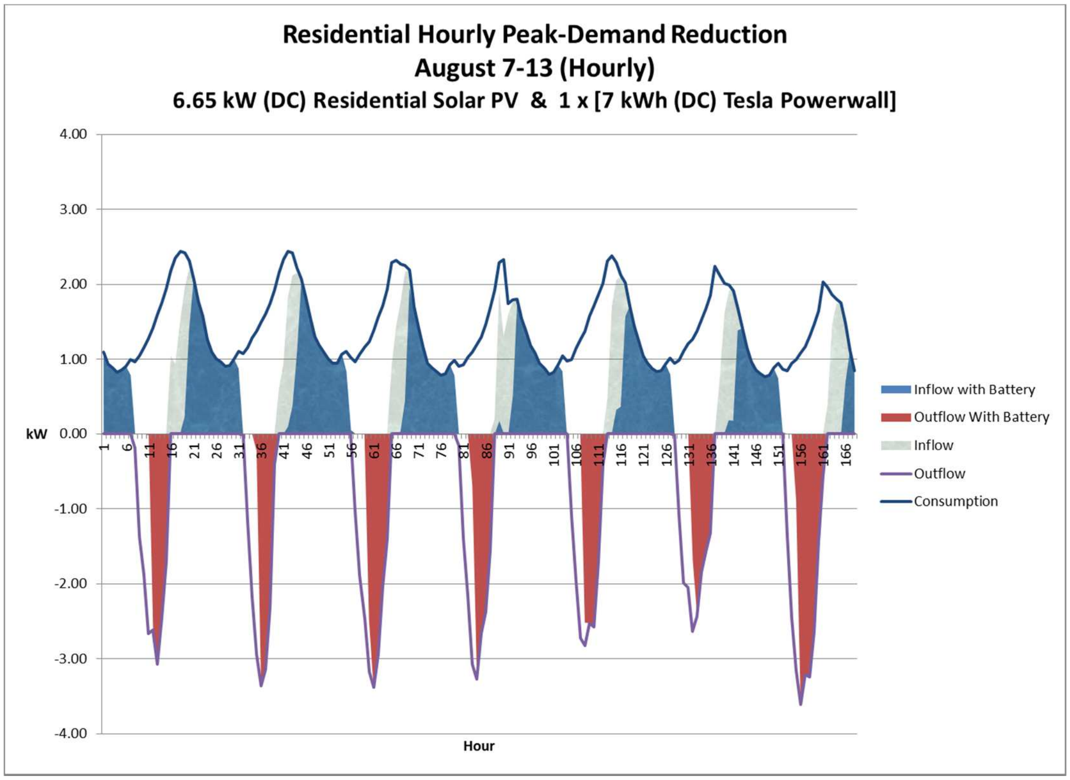
The cause and effect relationship between increased onsite-usage and efficient operation can be seen in more striking detail by graphing the *hourly* power flows of the above residential solar/battery customer, as seen in Chart (7) below. Chart (7) plots consumption and generation on an hourly basis, during the week of August 7-13. The blue line is consumption, the red line is generation. What is of most interest is the "new solar curve" plotted in green.

Chart 7



The new solar curve constitutes a time-shifted generation profile, consisting of hourly solar-output less battery charge, plus battery discharge. Notice that the new solar-output curve begins to follow the consumption curve, especially during the daily peak-demand periods. **The merging of solar/battery output with consumption is a clear indication of enhanced operational efficiency, since it will result in an increased level of onsite usage**. The timing of this occurrence is also a factor leading toward operational efficiency. Chart (7), thus, hints that the draw of power from the grid during the peak-demand period (inflow) should decline in step with the time-shifted generation output, and this can be seen in Chart (8) below, which is a plot of pre and post-battery inflows and outflows.

Chart 8



Notice in Chart (8) the decreased inflows resulting from inclusion of a battery system. The white areas under the consumption curve represents the reduction in inflow stemming from the solar PV system itself. The light blue areas represents further reductions in inflow as a result of the battery storage operations. The relatively small dark-blue areas are the remaining power-inflows resulting from the solar/battery combination. The net difference between the base residential consumption and the remaining hourly inflow is onsite-usage, [as originally seen terms of monthly values in Chart (5) as the white band separating inflow from consumption].

Having now conclusively demonstrated that **the key operational driver toward efficient operations is the level (and timing) of onsite usage**, it behooves both lawmakers and regulators alike to design the regulatory construct for DG programs so that it provides economic benefits to customers who increase their level of onsite usage.

It is entirely rational to use this observation as a test of any proffered DG regulatory mechanism. It can thus be asserted that: **if the economic payback to a customer under a particular regulatory mechanism is indifferent, or nearly indifferent, to the actual level of onsite-usage, then such mechanism is inherently flawed.**

Because efficient operation tends toward the expansion of onsite usage at the expense of bill credits for excess power, DG program structure should be designed so that the displacement of utility purchases (via onsite usage) should create the majority of the cash-flow needed to make the investment in customer-sited generation economic over the lifecycle of the system. Bill credits for the "sale" of excess power are merely secondary manifestations of optimal operation. This proposition can also be useful in evaluating the merit of alterative DG mechanisms, such as the Buy all – Sell all (BASA) mechanism. In practice, increasing the level of generation consumed onsite requires active customer involvement.

So, how does a regulatory mechanism promote customer involvement? By providing appropriate economic incentives to DG customers. It can be thus stated unequivocally that **a necessary precondition for achieving appropriate economic incentives is the implementation of a regulatory rate-design that incorporates power-inflows and power-outflows as billing determinants.**

It is highly relevant that cost-of-service ratemaking principles applied to retail DG program design result in the greatest potential for achieving public policy goals associated with "the new power industry" structure. It is the author's opinion that with respect to DG programs, the *Inflow & Outflow* (I&M) mechanism constitutes the most fundamental platform for cost-of-service ratemaking.

Why is that? The answer is simple, inflows and outflows are the only measured parameters associated with DG operation that inherently reflect the customer's actual onsite usage. **Without measurement of actual power inflows and outflows, it is impossible to deploy a DG program that unlocks the full potential of customer-sited generation resources**. Unfortunately this truth is often misunderstood or neglected by both regulators and utilities alike.

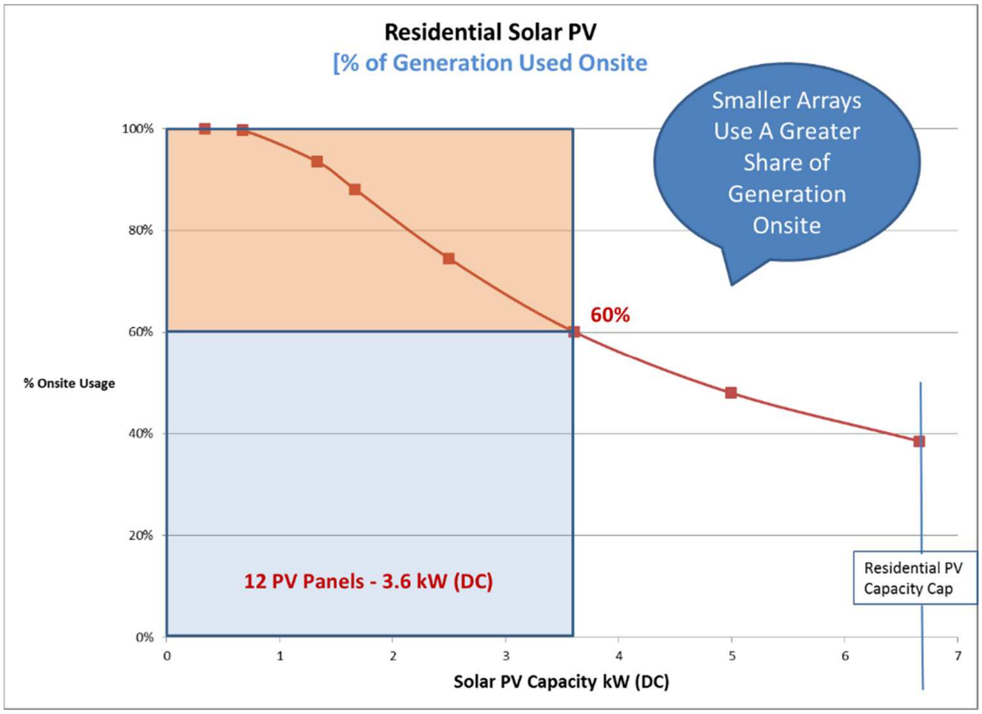
Since recognition of onsite-usage (via metered inflows and outflows) in DG tariff structure is so critical to the achievement of sound public policy objectives, the concept of onsite-usage needs to be explored in more detail.

It should be noted that a pertinent finding derived from modeling residential solar PV is that **the level of onsite usage is an inverse and non-linear function of system-size relative to the customer's base-load**. Small systems (relative to load) result in very high levels of on-site usage. For example, if an average residential customer install only one, or two solar PV panels, modeling demonstrates that nearly all of the power generated is used onsite. Conversely, large systems relative to base-load, result in a lessor, but still significant level of onsite-usage.

The regulatory implications from this finding are noteworthy. It was previously asserted that any DG mechanism that fails to incorporate measured power inflows and outflows as billing determinants, will by its very construct deviate from cost of service. It is further noted by this finding, that this deviation from cost of service is *accentuated* for those customers installing relatively small solar-PV systems (vis-à-vis their base usage).

In the typical NEM tariff, customer-sited generation-capacity is limited to that level producing an aggregate energy output equivalent to the customer's nominal annual-load (i.e. prior to installation of the DG system). This equates to approximately 6.65 kW (DC) for the average residential solar-installation in Michigan. Chart (9) below, reveals how onsite-usage increases dramatically when installed solar PV capacity falls below the effective residential system-capacity cap.

Chart 9



Due to the high installed cost of a solar PV system, many customers install PV capacity at a level below their base-usage. This results in a significantly greater level of onsite usage than would be expected with a system designed to output at the maximum qualifying cap. Twelve panels (about 3.6 kW (DC)) or less has been common in Michigan. It is acknowledged that the practice of under-sizing PV systems is expected to diminish as the solar industry continues to bring installed costs downward. However, it is this author's opinion that there will always be customers who cannot afford a luxury system. Albeit, in light of expected future cost reductions, solar PV capacity will tend to drift higher, toward the cap. The resulting decline in the nominal onsite utilization-rate will approach a minimum of approximately 40% (for solar PV customers similarly situated to Michigan customers).

In view of the desirable phenomenon of onsite usage, it is instructive to consider customer-sited DG as comparable, in effect, to the installation of an energy efficiency measure. Similar to energy efficiency, the reduced demand for grid energy caused by onsite-usage results in two effects: a reduction in retail energy (kWh) purchases by the customer (resulting in lost utility sales) and a commensurate reduction in grid usage associated with utility delivery of such energy.

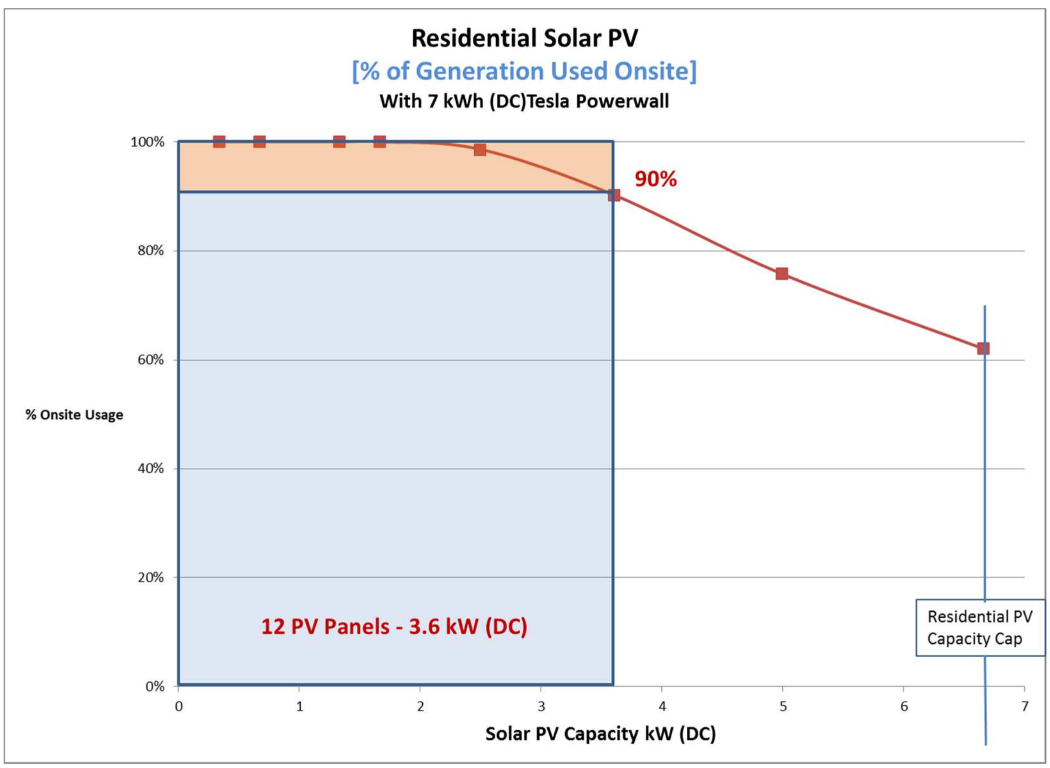
Clearly, the principal distinction between an energy-efficiency measure and customer-sited DG, is the problem-child of excess generation (outflow), due to inability to completely match system output with consumption. This is a key operational issue with customer-sited solar PV.

Load modification, panel tracking systems or orientation adjustment, can yield nominal improvements in onsite usage. However, the only practical solution to completely eliminate excess generation [outflow] is to install a complementary energy-storage system. For residential solar PV, increasing the level of onsite usage to 100% [without extensive load modification] necessarily requires a large and (at this time) prohibitively expensive energy-storage system, and so this would not be an economic choice for a grid-connected solar PV system.

Fortunately, even a relatively small battery system substantially increases onsite usage, and has other demand response benefits as well that could be extracted from any contemplated program design.

Chart (10) shows how the addition of a relatively small battery, a 7 kW (DC) Tesla Powerwall, affects the level of onsite usage for various levels of residential solar PV capacity.

Chart 10



By comparison to Chart (9), it can be seen that the level of generation consumed onsite increases from 39% to 62% at the tariff-specified generation capacity cap of 6.65 kWh. With a smaller solar PV system (consisting of 12 panels), the utilization rate increases from 60% to 90%. Both results are remarkable, considering the relatively small size of the battery [7 kWh] vis-à-vis an off-grid PV-battery system. The calculations are based on an 8,760 hour analysis, with operational objectives to: (1) time the daily battery charge and discharge cycles in a way to unload the battery during the late-afternoon peak-demand period; and (2) maximize use of the energy capacity of the battery.

In order to better understand how *battery-size* effects grid usage, the author modeled the effect of a progressively increasing battery capacity on both cumulative power inflows and outflows, for a typical residential customer having a solar PV system of 6.65 kW. See Chart (11), below.

Chart 11

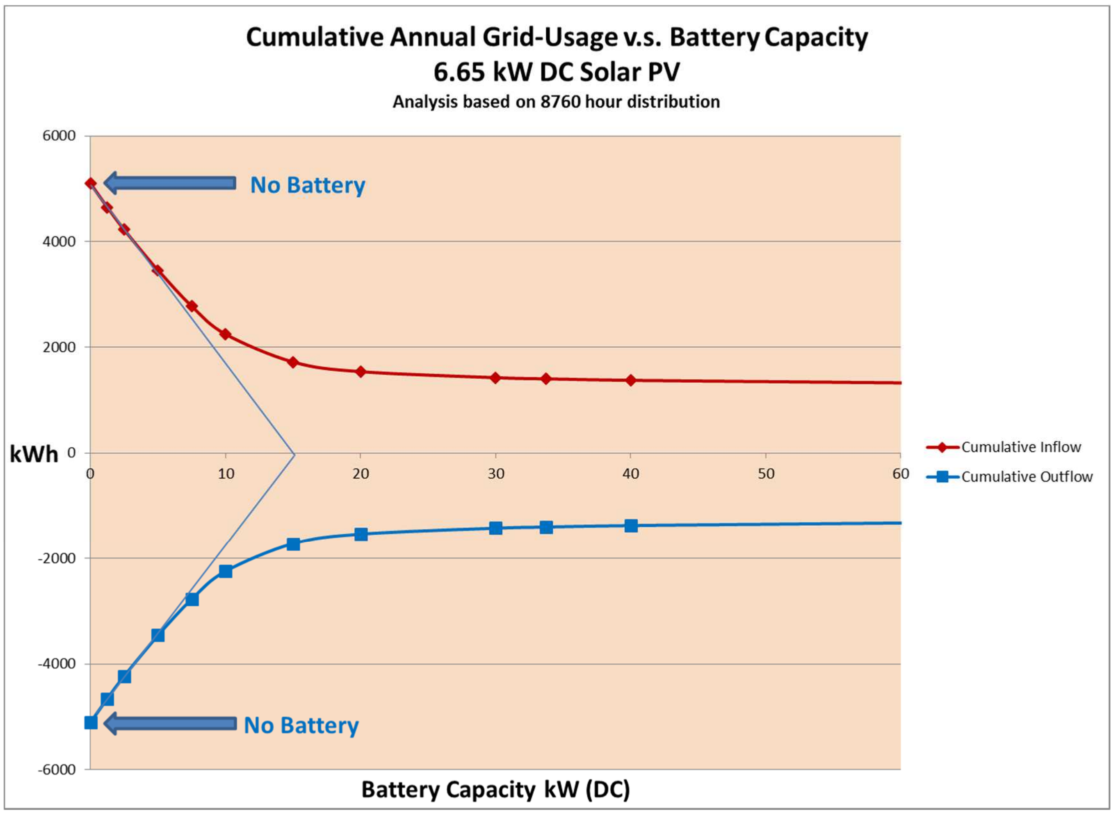
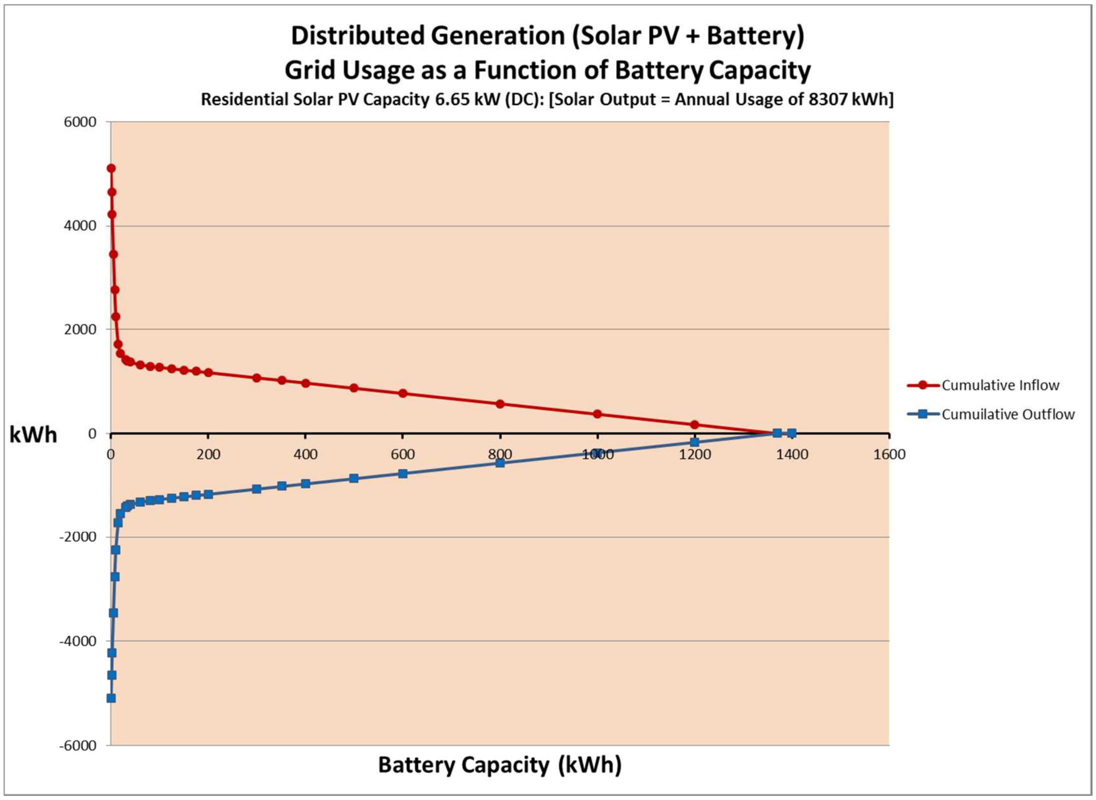


Chart (11) demonstrates that the reduction in power inflows and outflows, with increasing battery capacity, is a steep linear function for small battery sizes. At a battery capacity of approximately 10 kW, the slope of the inflow and outflow curves flatten substantially, indicating a rapidly declining impact of additional battery capacity. At this point, the Law of Diminishing Returns asserts itself, as battery capacity increases to the point that both cumulative inflows and outflows are reduced to zero. In light of this information, **for residential demand-response purposes, one could view a battery capacity of 10kW, or less, as the optimal zone of a grid-interconnected battery/DG system**.

At the other extreme, the state of having zero cumulative power inflows and outflows (over an annual period) is a significant metric because it is the technical requirement for off-grid operation. Chart (12), below, denotes an expanded view of Chart (11) whereby battery capacity is progressively increased until cumulative annual inflows/outflows are reduced to zero.

Chart 12

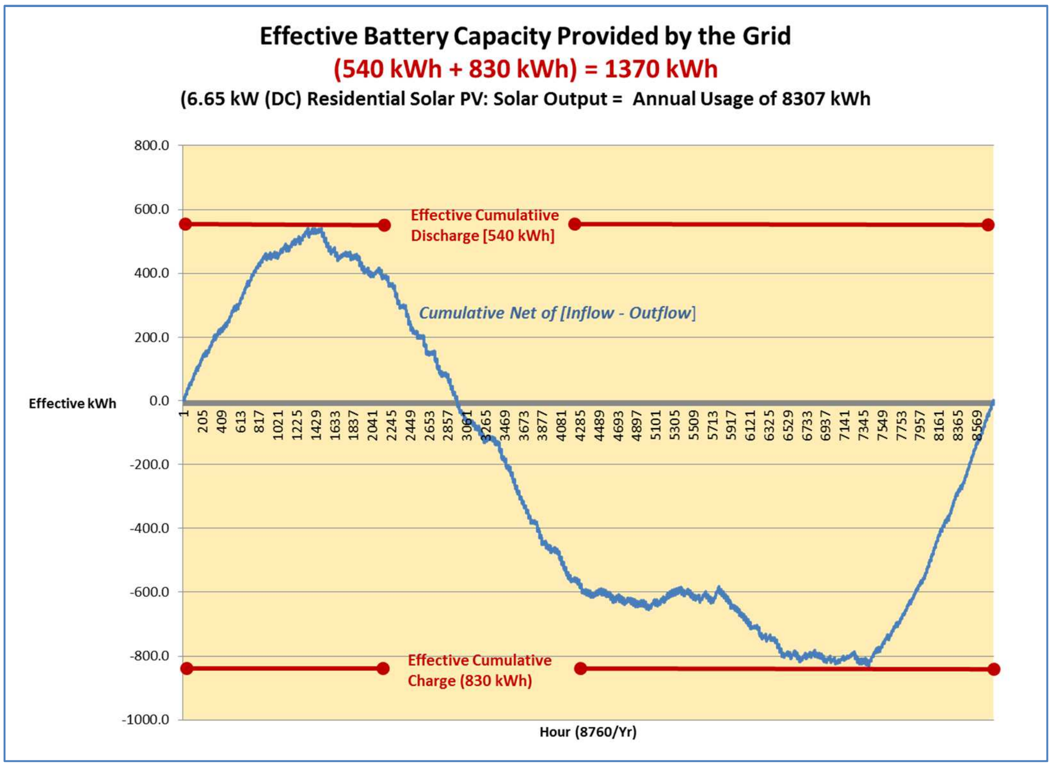


Contrary to popular misconception, the battery capacity needed to reduce power inflows/outflows to zero is very large, given two caveats that are frequently ignored when discussing the grid-defection issue: (1) there is no load modification by the customer, and (2); that no auxiliary generation is used. Given these two conditions, a customer-sited battery capacity of approximately 1,370 kW is necessary to maintain both power inflows and outflows, at zero over the course of a year. With a battery of this capacity, a customer would be “off grid” capable. The required 1,370 kW battery capacity was calculated on the basis of a residential customer in Michigan, having an typical annual load of 8,370 kWh, and a solar PV system with an equivalent annual output of 8,370 kWh (6.65 kW)]. All values, including battery charge and discharge rates, inflows and outflows, and consumption and generation, were modeled on an hourly basis.

This is a surprisingly large required battery capacity. However, given the two constraints imposed, (no load modification or auxiliary generation), this system would be cost prohibitive as an actual off-grid pathway. The modeling exercise, on the other hand, is instructive, because such an onsite battery is equivalent to the *effective battery capacity provided by the grid*, via the NEM mechanism.

Chart (13) allows a direct calculation of such *effective battery capacity* for an average residential customer with a 6.65 kW solar PV system. The chart consists of a plot of the cumulative net of (Inflow – Outflow), on an hourly basis, over the course of a year. Note that the net of (Inflow – Outflow) is the foundational billing determent for a true NEM mechanism. Notice too, that the end-of-year net of (Inflow – Outflow) is zero. Consequently, comparable to the off-grid pathway, the kWh balancing intrinsic to NEM would also result in an effective net-zero utility bill.

Chart 13



Referring to Chart (13), the maximum "positive" cumulative net-metered quantity, (540 kWh), constitutes the cumulative net draw from the grid following the 1st day of the year, up to the seasonal switch to net outflows. But under a NEM mechanism, it also represents the "grid battery" balance needed at the beginning of the calendar year to offset such late-winter power inflows. Coincident with this net "discharge" reaching its maximum point, the virtual battery balance is zero. Later in the year, the point in time that the maximum "negative" cumulative net outflow occurs, (-830 kWh), the virtual grid battery is at its peak capacity. The difference between the two values [540 - (-830] = 1,370 kWh, represents the *effective battery capacity provided by the grid* under the NEM mechanism.

What is striking, but not unexpected, is that this effective battery-capacity is equivalent to the customer-sited battery-capacity, of 1,370 kWh, previously calculated by adjusting hourly charge and discharge rates to yield zero power inflows and outflows, i.e. off-grid operation.

Establishing this equivalency is vital to understanding, and quantifying, the level of grid services being provided by NEM. Clearly, a significant balancing service is being provided by the utility pursuant to a NEM mechanism.

In light of the demonstrated equivalency, we can now say that **the effect on a customer's annual utility bill from the balancing service provided by NEM, is equivalent to the customer's use of an onsite-battery capable of reducing power outflows to zero**. This equivalency holds irrespective of the size of the generation system, as long as its output does not exceed the customer's annual base-consumption. Importantly, **the action of reducing power outflows to zero [by means of an energy storage system] is achieved by increasing onsite usage to the point that it equals the full generation output**.

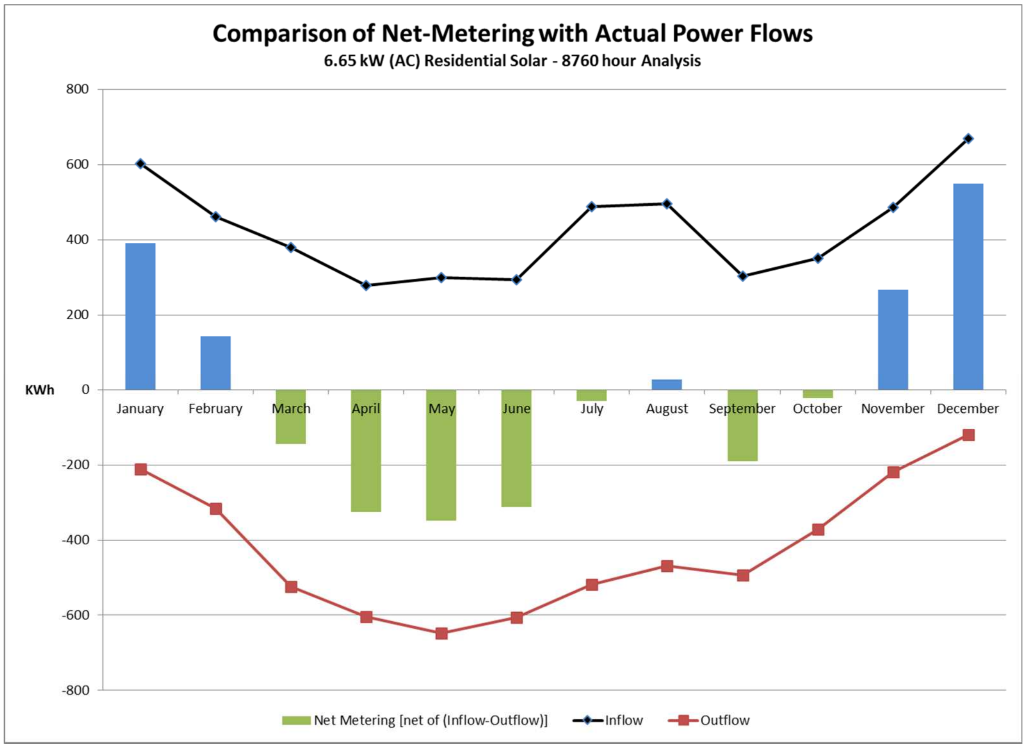
We have now come full circle, having established the basis for the assertion (at the beginning of this paper) that the kWh netting process inherent to NEM has the same effect on customer bills (and utility revenues) as if the customer consumed the full solar PV output onsite.

For example, a customer that installs a single solar panel, creates a physical load-reduction equal to the customer's actual onsite-usage. However, a NEM tariff induces an additional "virtual" load-reduction, such that the sum of the two (actual pus virtual) is equivalent to the entire output of the single-panel generation-system over the course of an annual period. Similarly, at the other extreme in system size, namely a customer having a generation system that has an output equal to the customer's base annual consumption, NEM can induce a total load-loss to the utility, i.e. a "virtual" grid defection.

It is obvious that regulatory induced load-loss is a core issue with NEM. But the heart of NEM deficiencies can only be seen from an operational-efficiency perspective. NEM heavily distorts pricing-signals that could otherwise drive efficient customer behavior. As a result, the author strongly asserts that NEM cannot be relied upon as a regulatory platform for attaining goals associated with the "future electric-power industry", such as those related to expanded use of distributed generation, customer-sited energy storage, or enhanced demand-response resources.

Chart (14) below, juxtaposes NEM's billing determinant, with cumulative monthly inflows and outflows. The chart reveals strong deviation between the two.

Chart 14

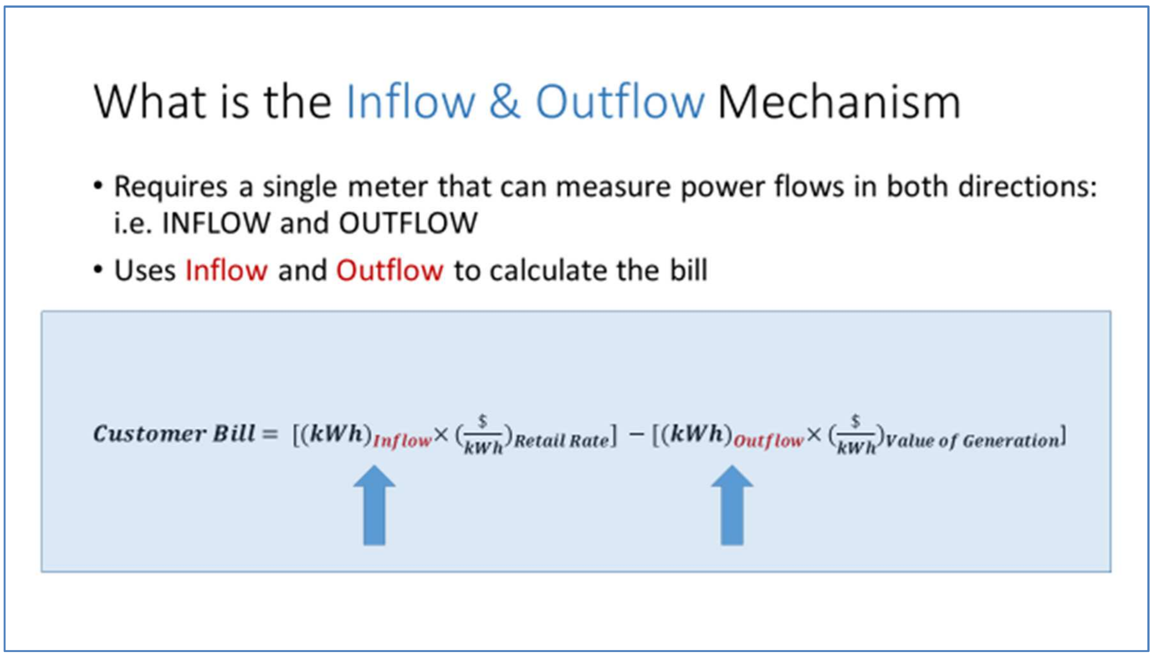


True NEM is implemented by netting over the billing period associated with the customer's retail sales rate-schedule. Obviously, netting over monthly billing-periods thoroughly obfuscates inflow and outflow related price-signals, rendering NEM ineffective as a tool to achieve 21 century energy-policy goals. True NEM cannot be described as anything but "long in the tooth".

Some utilities have implemented a "modified" net metering for commercial and industrial DG customers in which netting occurs over *time-of-use* billing blocks. If the modified NEM takes a step further, and prices carry-forward [from one netting period to the next] at a reasonable value-of-generation, the mechanism could be viewed as an I&O "lite" mechanism. However, seeing that no additional complexity is required to implement a true I&O mechanism vis-à-vis a modified NEM, there exists no real impediment to move directly to a true I&O mechanism, particularly in light of the fact that the modified NEM falls short of providing the full panoply of tools and economic incentives for customers to optimize DG operations, that are derived from a true I&O mechanism.

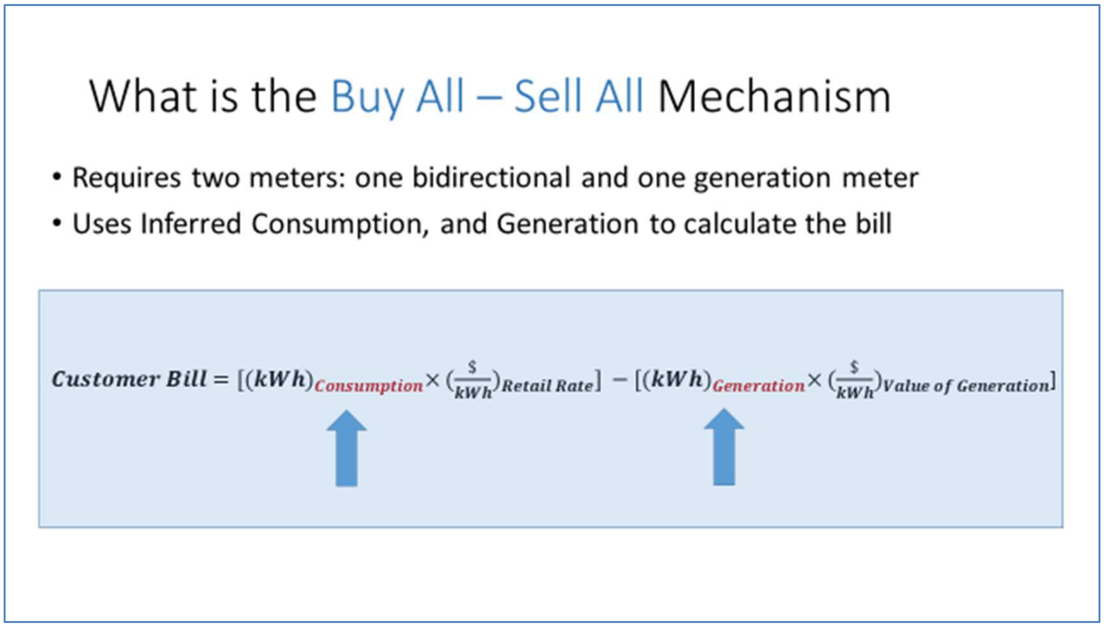
At this point, a fundamental proposition of this paper will be restated: **a DG mechanism that does not use metered power inflows and outflows as billing determinants is in conflict with true cost-of-service principles**. Utility rate schedules may very well include sophisticated elements such as dynamic pricing and/or demand charges, but if the DG mechanism yields customer bills based on: (1) inferred (base) consumption; (2) generation; or (3) the net of [inflow – outflow], it will fail to capture the true cost-of-service, and will convey inaccurate pricing-signals that induce sub-optimal customer behavior. Chart (15) below delineates the Inflow & Outflow mechanism for a simple commodity based rate design.

Chart 15



These findings have implications for regulators considering the Buy-all Sell-all (BASA) mechanism as a replacement for NEM. The BASA mechanism, similar to the NEM mechanism, does not reference actual (metered) power inflows or outflows in the calculation of charges and credits, and thus is invariant to changes in the level of onsite usage in the calculation of retail rates. Like NEM, the BASA mechanism fails to transmit price signals that drive efficient operation. Chart (16), below, defines the mechanism for a simple commodity-based rate-design.

Chart 16



The BASA mechanism is based on a deeming process. All generation is deemed to have been injected into the utility grid, and likewise, all consumption is deemed to have been served by utility system-supply. As a result, the rate structure of the BASA mechanism requires two utility meters. This enables the calculation of two billing determinants; metered generation, and inferred consumption.

Metered generation is invariant to the level of onsite usage on its face. For example, a solar PV system would be interconnected to a utility generation-meter (typically at cost to the customer) directly downstream of the inverter, and as a result reflects gross AC output. It is logical that the customer's base consumption is also invariant, since it constitutes the actual electric-load sans generation offset, (i.e. sans onsite usage).

Unfortunately, a DG customer's actual electrical load cannot be physically metered, and must be inferred by quantities that can be metered. There may be some question as to whether or not "inferred" consumption is also invariant, and it can be shown that it is, as follows.

The process of inferring base consumption is a calculation, based on the energy balance:

[Generation + Inflow = Consumption + Outflow] **Equation (12)**

Rearranging:

Consumption = Generation + [Inflow – Outflow] **Equation (13)**

Equation (13) is used to infer consumption, using the two metered quantities: generation and [inflow – outflow]. Depending on whether or not the BASA mechanism uses time-based pricing, the latter variable can be measured by a vintage analog meter, or a digital smart meter. The sum of the two metered quantities constitutes the customers actual electrical load, and is used as the "consumption" billing determinant.

Regarding Equation (13), it has previously been shown that:

Inflow = [Consumption – Onsite Usage] **Equation (14)**

And:

Outflow = [Generation – Onsite Usage] **Equation (15)**

It is clear that by subtracting Equation (15) from Equation (14), that onsite-usage cancels out of the term [Inflow – Outflow]. Thus the net-metered quantity [inflow – outflow] is itself invariant to the level of onsite-usage. The upshot being that the overall mathematical expression for "inferred" consumption is invariant to the level of onsite-usage.

The BASA mechanism's deficiencies can be visualized by referring to Chart (17) below.

Chart 17

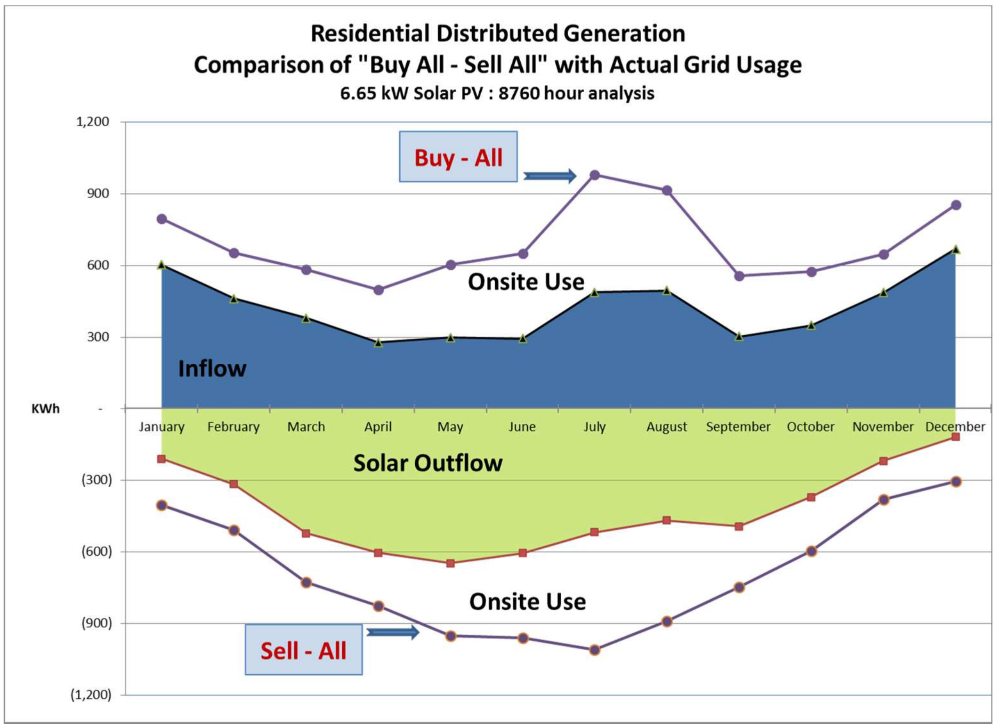


Chart (17) is the same as Chart (5) except that it has been relabeled. The BASA billing determinants can be seen as the top and bottom lines, which are consumption and generation, respectively.

With reference to Chart (17) It is apparent that the BASA billing determinants [consumption and generation] diverge from the cost-of-service based billing determinants, [inflow and outflow], by the (kWh) level of onsite-usage (the white bands) separating the two sets of billing determinants from each other. It is clearly apparent that the net customer bill is calculated from the BASA billing determinants as if none of the generation was consumed onsite. **The BASA mechanism overstates the consumption bill (which should be based on the smaller metered inflow) and likewise overstates the credit (which should be based on the smaller metered outflow)**.

Although Chart (17) conveys the existence of these two deviations from cost-of-service, it provides insufficient information to understand the combined impact on a BASA customer's bill, especially considering that the two errors interact from opposite directions. For this, it is necessary to take a mathematical approach as follows.

First, we assume that the full (per kWh) retail rate for both the inflow and consumption are identical, since technically they are both "inflow" from the perspective of utility grid operations. It is also assumed that the same energy and capacity credits ($/kWh and $/kW) for utility purchases of excess generation applies. These assumptions are made to simplify the expressions, and have no impact on the conclusions reached.

With these assumptions, under the BASA and I&O mechanism, typical residential customer bills are respectively:

Customer Bill under the Buy all – Sell all (BASA) mechanism: ***Equation (16)***

$$= \boldsymbol{Customer\ Charge} + (\boldsymbol{kWh})_{\boldsymbol{Consumption}} \times \left(\frac{\$}{\boldsymbol{kWh}}\right)_{\boldsymbol{Full\ Retail\ Rate}}$$

$$-\ (\boldsymbol{kWh})_{\boldsymbol{Generation}} \times \left(\frac{\$}{\boldsymbol{kWh}}\right)_{\boldsymbol{Value\ of\ Generation}} - \boldsymbol{Capacity\ Credit}_{\boldsymbol{BASA}}$$

Customer Bill under the Inflow & Outflow mechanism: ***Equation (17)***

$$= \boldsymbol{Customer\ Charge} + (\boldsymbol{kWh})_{\boldsymbol{Inflow}} \times \left(\frac{\$}{\boldsymbol{kWh}}\right)_{\boldsymbol{Full\ Retail\ Rate}}$$

$$-\ [(\boldsymbol{kWh})_{\boldsymbol{Outflow}} \times \left(\frac{\$}{\boldsymbol{kWh}}\right)_{\boldsymbol{Value\ of\ Generation}} - \boldsymbol{Capacity\ Credit}_{\boldsymbol{I\&O}}$$

Subtracting Equation (12) from Equation (11) results in an expression equivalent to the BASA deviation from cost of service:

BASA Deviation from Cost of Service **Equation (18)**

$$= [(kWh)_{Consumption} - (kWh)_{Inflow}] \times \left(\frac{\$}{kWh}\right)_{Retail\ Rate} - [(kWh)_{Generation} - (kWh)_{Outflow}] \times \left(\frac{\$}{kWh}\right)_{Value\ of Energy} - [Capacity\ Credit_{BASA} - Capacity\ Credit_{I\&O}]$$

By means of the energy balance: [Consumption - Inflow] = Onsite Usage; and [Generation – Outflow] = Onsite Usage, the deviation from cost of service, Equation 18, can be simplified to:

BASA Deviation from Cost of Service **Equation (19)**

$$= [(kWh)_{Onsite\ Usage} \times \left(\frac{\$}{kWh}\right)_{Retail\ Rate} - [(kWh)_{Onsite\ Usage}] \times \left(\frac{\$}{kWh}\right)_{Value\ of Energy} - [Capacity\ Credit_{BASA} - Capacity\ Credit_{I\&O}]$$

Equation (19) constitutes the deviation from true cost-of-service associated with the BASA mechanism. However, the relationship between the capacity credits can also be expressed in terms of onsite usage as follows

For a solar PV system the effective capacity (kW) provided by the DG system is a function of the system's nameplate capacity and its *effective load carrying capacity* (ELCC).

$$(kW)_{Effective} = (kW)_{Nameplate} \times ELCC$$ **Equation (20)**

Under a BASA mechanism, the entire generation capacity is "sold" to the utility. Thus, capacity credits are readily calculated as:

$$Capacity\ Credit_{BASA} = (kW)_{Nameplate} \times ELCC \times (\frac{\$}{kW})_{Value\ of\ Capacity}$$ **Equation (21)**

Capacity credits under a BASA mechanism are necessarily larger than under an I&O mechanism since the former reflects gross-generation capacity, and the latter reflects actual power outflows, which are necessarily smaller, since onsite usage needs to be netted from gross generation. The difference between the two can be approximated through application of an additional fractional multiplier:

$$[\frac{Cumulative\ Outflow}{Cumulative\ Generation}]$$

Thus:

$$Capacity\ Credit\ _{I\&O} = [Capacity\ Credit_{BASA} \times \frac{Cumulative\ Outflow}{Cumulative\ Generation}]$$ **Equation (22)**

or

$$= \left[(kW)_{Nameplate} \times ElCC\right] \times \frac{Cumulative\ Outflow}{Cumulative\ Generation} \times (kW)_{Value\ of\ Capacity}$$ **Equation (23)**

Inserting Equation (21) and Equation (23) into Equation (19) yields:

BASA Deviation from Cost of Service **Equation (24)**

$$= [(kWh)_{Onsite\ Usage} \times \left(\frac{\$}{kWh}\right)_{Retail\ Rate} - \left\{ [(kWh)_{Onsite\ Usage}] \times \left(\frac{\$}{kWh}\right)_{Value\ of Energy} + (kW)_{Nameplate} \times ELCC \times \left[1 - \frac{Cumulative\ Outflow}{Cumulative\ Generation}\right] \times \left(\frac{\$}{kW}\right)_{Value\ of\ Capacity} \right\}$$

Simplifying Equation 24:

BASA Deviation from Cost of Service **Equation (25)**

$$= [(kWh)_{Onsite\ Usage} \times \left(\frac{\$}{kWh}\right)_{Retail\ Rate} - \left\{ [(kWh)_{Onsite\ Usage}] \times \left(\frac{\$}{kWh}\right)_{Value\ of Energy} + (kW)_{Nameplate} \times ELCC \times \left[\frac{Onsite\ Usage}{Cumulative\ Generation}\right] \times \left(\frac{\$}{kW}\right)_{Value\ of\ Capacity} \right\}$$

Pursuant to a BASA mechanism, **the entire deviation from cost-of-service is related to generation used onsite.** Equation (25) demonstrates that the cost-of-service errors associated with the BASA mechanism combine in such a way that the net deviation is equivalent to the utility charging-back each DG customer the full retail rate for reduced (i.e. lost) utility revenues associated with that specific customer's actual load reductions, offset by the capacity value of generation used onsite. Thus, the DG customer is both overcharged and over-credited.

Clearly, Equation (25) demonstrates that the BASA mechanism necessarily results in **utility lost sales [i.e. onsite usage] being charged-back directly to the distributed generation customer that reduced their retail electric purchases**, rather than being recovered in a general rate proceeding as an allocation to the customer class as a whole (e.g. the residential customer class). This explains the large divergence in customer bills between the BASA mechanism and the I&O mechanism (i.e. cost-of-service).

Advocates of the BASA mechanism, with good intention, intend to address the core issue of the NEM program: that participation in NEM program results in significant reduced utility revenues associated with utility load-losses. Unfortunately, the BASA solution to restore revenues goes beyond parity with cost-of–service and violates a longstanding regulatory principle related to retroactive ratemaking, i.e. the direct billing of lost-revenues to a customer.

It was previously mentioned that onsite-usage may be thought of as analogous to energy efficiency, in that it results in a direct reduction in retail (kWh) purchases by the customer and commensurately reduced power inflows from the utility distribution grid. The generally accepted regulatory method of dealing with energy efficiency program lost-revenues is through a general rate case, or possibly via a decoupling mechanism, such as a lost sales tracker. In fact, both methods could be used to make a utility whole from DG induced lost revenues, **but in either case lost-revenues are never billed back to individual customers**.

Regarding compensation for "excess" generation, the development of principles leading to a fair "value-of-generation" (including mathematical algorithms for quantifying) is a distinctly different matter than the issue of laying a foundation for DG program structures, and will not be addressed in this paper. Suffice to say, it is the author's opinion that efforts to establish a fair compensation are necessary, but premature if the regulatory mechanism being considered is not a cost-of-service based foundation.

Thus, the determination of the "value of generation" remains as a controversial issue, even if the I&O mechanism is selected to replace NEM. However, the I&O mechanism is the only regulatory alternative that limits the impact of mispricing generation credits to the actual power outflows injected into the distribution grid. Any error in setting of a "value of generation" credit is compounded by a DG program structure that does not use metered outflows as billing determinants.

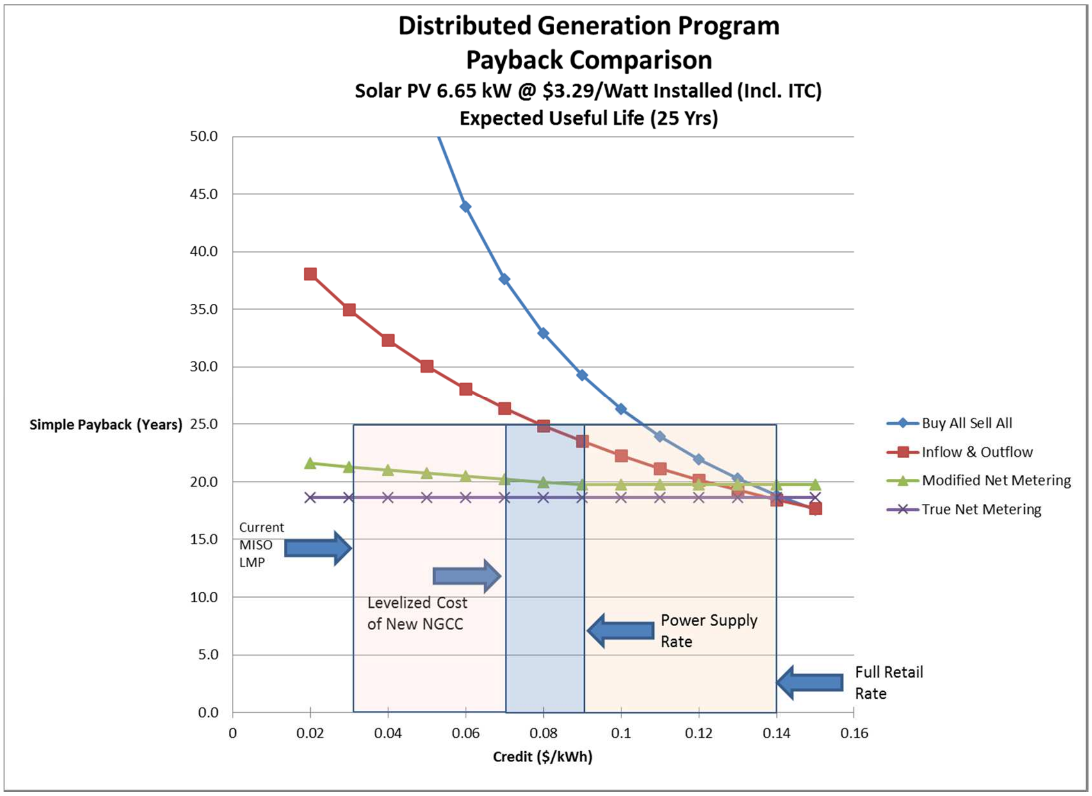
With non-cost-of-service based DG programs, such as the BASA mechanism, the net bill, in practice, needs a significant adjustment to the fair "value of generation" credit, to encourage customer-sited DG installations, and this adjustment is the direct result of overstating grid usage by equating it to inferred consumption.

An example of this adjustment was the initiative in Maine to determine a value of generation, with an incentive adder to improve customer payback. The Maine proposal, proffered by the Maine Public Service Commission incorporates a well-reasoned effort to determine the value-of-generation. However, since the credit is inserted into a BASA rate structure [that necessarily overstates inflow and outflow via the use of imputed consumption and total generation], the proposal resorts to incentive payments for the "sale" of DG generation output in order to make some semblance of economic payback for customer-sited solar.

This underscores the BASA mechanism's focus on bill credits for generation. Economic incentives under a BASA mechanism is singular. The only financial incentive exclusively related to efficient operation of the DG system is the incentive to maximize output, and to do so at the time periods where the "value of generation" is priced the highest. Therein lies the hitch. The mechanism distorts the innate measure of operational efficiency - which is to reduce power inflows, and to do so at the times of highest retail rate. It is true that a BASA customer can modify their load profile. However, since the consumption bill is the same as any similar situated non-DG customer, the financial incentive to do so is identical to that of a full-requirements customer.

The author has modeled the various forms of DG programs to see how they compare on a simple payback basis for various levels of value-of-generation. Chart (18) below delineates the result.

Chart 18



Referring to Chart (18), the box represents a viable range of simple paybacks, recognizing that the nominal expected useful life of a residential solar PV system is approximately 25 years. It is bounded on the left, by the current average (energy only) MISO wholesale electric rate. The upper bound is the full residential retail rate for Consumers Energy. Significantly exceeding the full retail rate generally requires the recognition of external benefits and was not modeled. The I&O mechanism can be considered cost-of-service, and thus the standard for comparison.

All DG mechanisms converge (approximately) with true NEM at a credit equal to the full retail rate. As expected, true NEM, is invariant to the level of credit, because it is a kWh balancing structure. It results in the shortest payback periods. Modified NEM has marginally longer paybacks, closer to the cost-of-service DG structure, because it converts the monthly carry-forward to a dollar based credit, thus mimicking the pricing of power inflows in a I&O mechanism. It was also assumed that Modified NEM also limits credits to the following month's Power Supply Cost Recovery (PSCR) charges, resulting in a bend in the curve at the PSCR. It can be seen that the BASA mechanism results in substantially longer paybacks than resulting from cost-of-service, especially with credits at or below the levelized cost of a new Gas Combined Cycle Power Plant (NGCC).

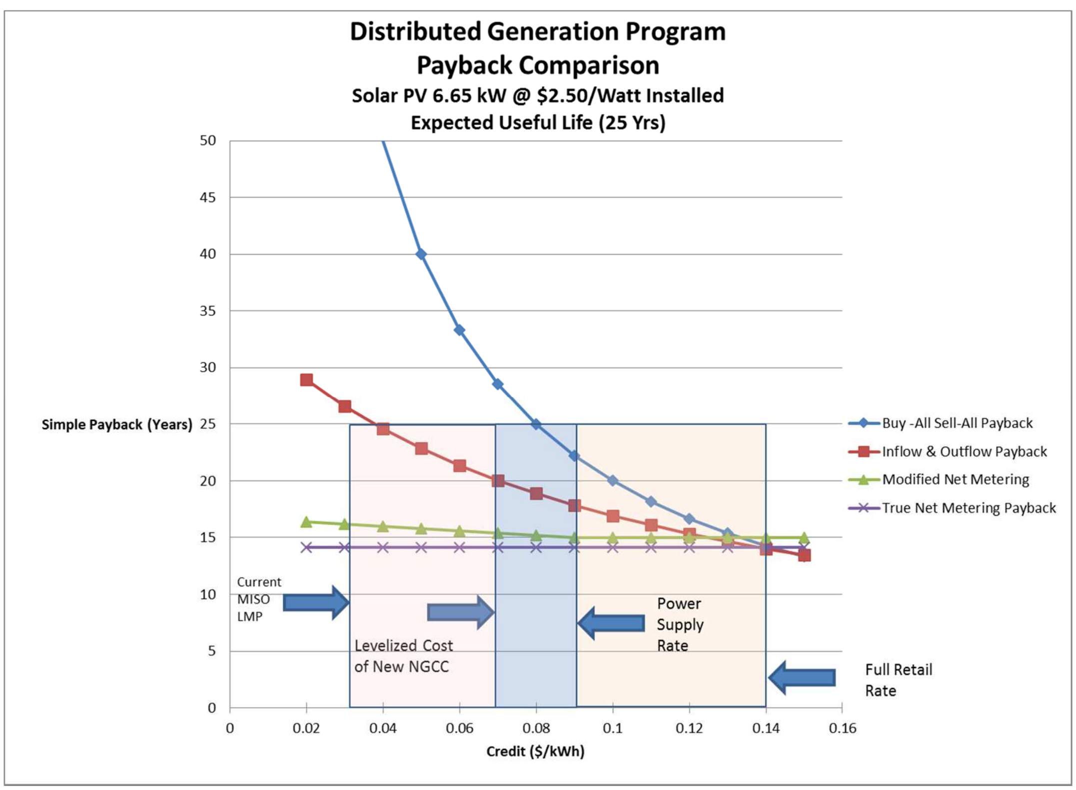
Surprisingly, the I&O mechanism did not result in a valid payback at a credit level near the proxy plant credit. This is a near miss, but significant nonetheless. The proxy plant method, is a foundational pricing method often used for DG sales pursuant to PURPA, and which can be viewed as a simple analog for long-term wholesale market prices. The failure to pay back at the proxy plant rate, using a cost-of-service DG mechanism, is clearly a manifestation of the difficulty of residential solar PV to compete with retail electric rates in Michigan - at this time. With continued reductions in the all-in cost of solar PV, cost of service based distributed generation programs should provide a positive net present value.

Referring again to Chart (18) the BASA mechanism, in contrast, is so far out of bounds that it would essentially collapse the emerging residential solar PV industry in Michigan (and those states similarly situated). At the proxy plant credit level, the simple payback for BASA is approaching 40 years. Even at a credit level approximately equal to the total Consumers Energy PSCR (including fixed capacity costs and transmission costs) of approximately 9 cents per kWh, the BASA mechanism results in an untenable payback of near 30 years.

A lower installed cost of solar PV (at $2.50 per watt) was also modeled, and the I&O mechanism demonstrated a solid payback. An I&O based DG mechanism should be expected to be a long-term solution, helping to drive down installed solar PV costs. If necessary, regulators could transition to a cost-of-service based DG mechanism by including a limited-term adder to the value-of-generation.

See Chart (19) below for solar PV payback at the lower installed cost of $2.50 per watt.

Chart 19



With a credit at the current levelized cost of a new NGCC plant, of approximately 7 cents per kWh, the I&O mechanism results in a reasonable payback of $20 years. However, irrespective of the numerical value of the fair value-of-generation, both Chart (18) and Chart (19) suggest that the I&O mechanism lies in the sweet spot, midway between NEM and the BASA mechanism. It is the author's opinion that the I&O mechanism could be a reasoned compromise between those wanting to retain NEM, and those advocating for a BASA option.

The Inflow & Outflow Mechanism: Conclusion

It should be clarified, that though the I&O mechanism has been referred to as a compromise regulatory structure, this does not imply that the BASA mechanism is merely a matter of preference. The BASA is a failed regulatory mechanism. It is fundamentally inconsistent with the actual grid usage of DG customers and cannot yield a cost-of-service based DG tariff. It is difficult, if not impossible for BASA mechanisms to get both cost and compensation right. Because it intrinsically over-estimates billing determinants, it necessarily leads to efforts to substantially overcompensate for the value of generation. If incentives are needed or desired to stimulate developing markets for customer-sited renewable energy, then it is the author's opinion that the logical starting point to quantify such incentives is the true cost-of service, and that cannot be determined without reference to a DG customer's power inflows and outflows.

Several undesirable outcomes prevail when NEM alternatives are created without a proper understanding of the relationship of power inflows, outflows and grid usage. Without true cost-of-service principles as a starting point, arbitrary rate designs ensue; examples include minimum bills, or arbitrarily large deviations from reasonable value-of-generation credits.

Principles of good rate-design dictate that minimum bills always be a last choice, when no other options are workable. Customers fall into a bell curve, and those at the tail are significantly impacted by minimum bills. Without reference to actual grid usage, measured as power inflows, minimum bills constitute an arbitrary proxy to recover the cost of grid services uncompensated by NEM.

Demand charges only applied to residential DG, but not to full-service customers are another pitfall, since such approaches create a tilted playing field. This is another arbitrary method of recovering the uncompensated cost of grid services associated with NEM.

This paper started with a discussion of the recent flurry of activity to replace true NEM with a DG mechanism that corrects for revenue losses being incurred by utilities, and that are being borne by non-DG customers. The NEM related revenue losses seen by electric utilities are the result of complex interactions. We have seen that breaking DG system dynamics into its components is the only way to understand the deficiencies of NEM, and the road to developing a workable replacement. The Inflow & Outflow Mechanism strikes the best balance, and is inherently a cost-of service based DG program foundation.