To Wash or Not to Wash?
Framework for Making an Informed Decision

By David Young
Vice President, Solarrus Asset Management

First Presented Publically at Solar O&M: North America, San Francisco March 25 & 26, 2014

Within the solar O&M community, much debate has been focused on whether or not solar array cleaning can be economically justified. With field service experience on over 1GW of installed solar assets, Solarrus and our subsidiary, True South Renewables, have developed an objective approach to analyzing the economic value of washing solar panels on commercial distributed generation and utility-scale installations.

During the last year, we have read that some experienced solar operators have given up on determining a proper washing frequency and now operate under a "no wash" policy. More often we hear of operators that budget and proceed under a simple low risk policy of washing once a year just before the summer "money maker" months and would never consider skipping the yearly wash or adding an extra wash, regardless of the actual soiling or the peculiarities of the weather that season or year. At True South Renewables we advocate a more nuanced approach that acknowledges there are circumstances where washing frequency can be dictated by the numbers. There are also circumstances where the wash schedule is a result of a gut feel on the prospect of future rains – similar to a farmer's call on when to harvest his crops.

Let me illustrate an example of where adhering to the numbers to determine washing frequency really does work. First, we need to start with the math that explains the optimal washing frequency at a solar site. We need to first work with a set of simplifying assumptions. For this illustration we assume:

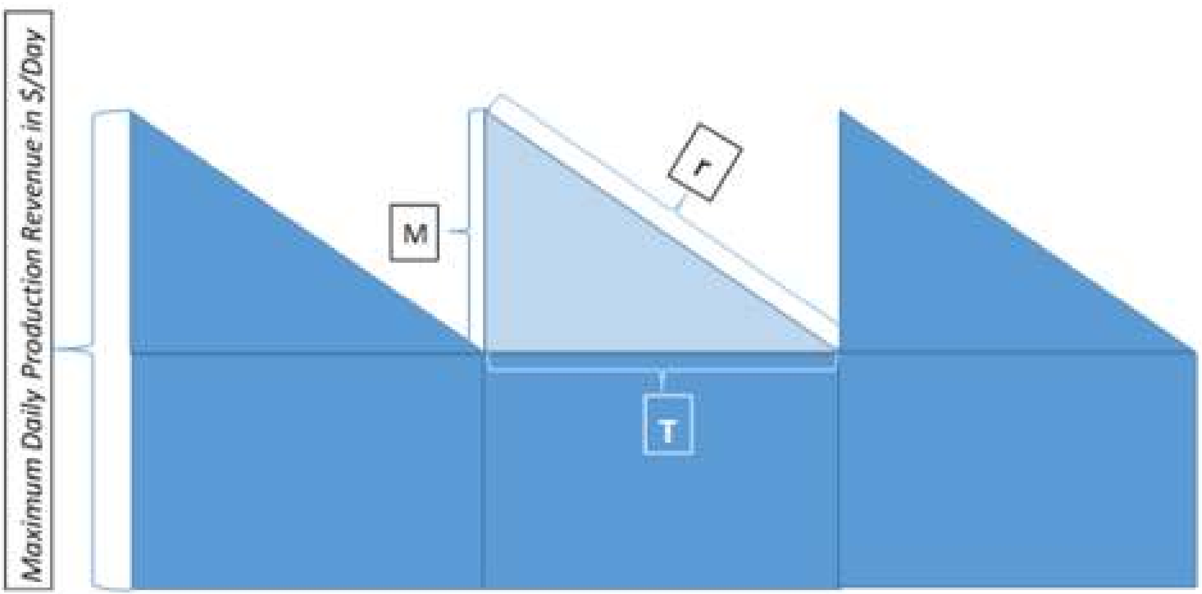
- The loss of power generation and revenue due to soil accumulation occurs at a constant rate
- Washing is paid at the time of service in a lump sum and instantly restores power generation to 100% of its theoretical output;
- Seasonal and weather affects are not considered; and
- There is no output capping

Now before you argue that the world is not as simple as these assumptions and therefore the conclusions drawn are invalid, understand that models are frequently constructed for a simplified world in order to understand the basic relationships between variables. Later, the complications of reality are added one by one through adjustments to the model to make it applicable to more situations. Nevertheless, the initial simple model is highly instructive and generally reflects the overriding principles at work in the process.

In the case of soiling and general rules on washing frequency, we can also assume we know:

W: the Cost of Washing in $
M: the Maximum revenue production increase just after washing in $/day
r : the Rate of revenue lost due to soiling in $/day^2
T : the Time between washes in days

Regardless of any complications that can be added to the decision rule, between washes we always want to maximize the production revenues less the cost of washing. Graphically this looks like:



This simple geometry repeats indefinitely, so we need only consider maximization over a single triangle. Without going into the details of the mathematical derivation, we can find the optimal washing time by writing out the equation describing rate of net revenues, and setting its derivative with respect to time equal to zero. We find that the number of days between washings that maximizes the energy production revenues less cost of washing is:

$$T = \sqrt{\frac{2W}{r}}$$

This formula matches our intuition that the time between washes should decrease if the rate of soiling increases, and should increase with the cost of washing. To fully explore this relationship among these three variables the following table was constructed based on the above formula and with **r** values where soiling causes a daily drop in production revenues ranging from \$100 to \$800, and **W** values where a washing costs between \$40,000 and \$80,000. You can see that the optimal washing frequencies ranged from a low of every 40 days (when a washing cost \$80,000 and the daily revenue loss due to soiling was \$100); to a high of every 10 days (when a washing cost \$40,000 and the daily revenue lost due to soiling was \$800).

Optimal Days Between Washings

r = daily rate of declining revenue due to soiling

increasing rate of revenue decline (\$ / day^2) →

W = cost of washing

W	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800
\$ 40,000	28	23	20	17	16	15	14	13	12	12	11	11	10	10	10
\$ 45,000	30	24	21	18	17	16	15	14	13	12	12	11	11	10	10
\$ 50,000	31	25	22	20	18	16	15	14	14	13	12	12	11	11	11
\$ 55,000	33	27	23	20	19	17	16	15	14	14	13	13	12	12	11
\$ 60,000	34	28	24	21	20	18	17	16	15	14	14	13	13	12	12
\$ 65,000	36	29	25	22	20	19	18	16	16	15	14	14	13	13	12
\$ 70,000	37	30	26	23	21	20	18	17	16	15	15	14	14	13	13
\$ 75,000	38	31	27	24	22	20	19	18	17	16	15	15	14	14	13
\$ 80,000	40	32	28	25	23	21	20	18	17	17	16	15	15	14	14

increasing cost of washing decreases the optimal frequency of washing

increasing the rate at which daily revenues decline due to soiling increases the optimal frequency of washing

For the skeptics, try a couple of examples to convince yourself that the formula really does solve for the optimal time between washes if W and **r** are known. We prepared our own test based on a +20mW plant located in the Central Valley of California, where during the Summer **W** = \$60,000 and **r** = \$240/day. Based on the above formula the optimal washing frequency is:

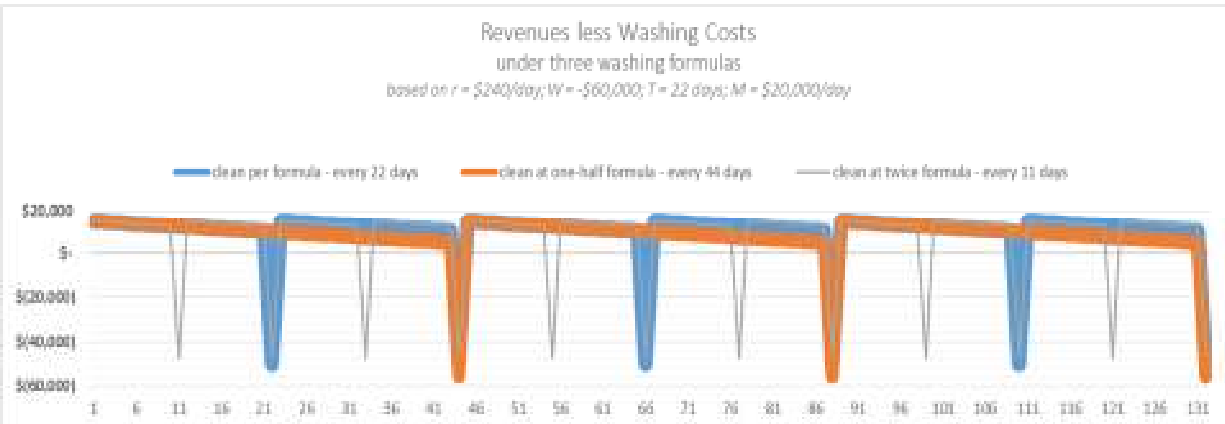
$$T = \sqrt{\frac{2\ x\ 60{,}000}{240}}$$

$$T = \sqrt{\frac{120{,}000}{240}}$$

$$T = \sqrt{500}$$

***T*= 22 days**

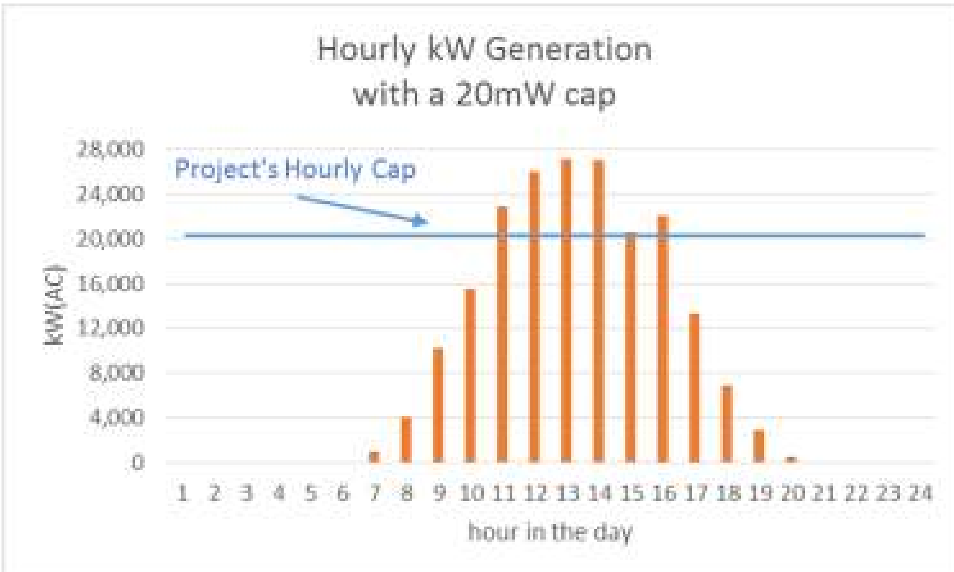
At this test plant M = is $20,000. As a result we can plot out three varying washing scenarios to determine if the formula really does produce the optimal washing frequency. In this case we projected the energy revenues less washing expense if: i) we followed the formula and washed each 22 days; ii) washed at one-half the optimal frequency or every 44 days; and iii) washed at twice the optimal frequency or every 11 days.



You might expect that in the case where the plant is washed at one half the optimal frequency, as indicated by the formula, we would generate a greater net revenue since you are avoiding one-half the washing expense, but in reality the loss of revenue from the soiling actually is greater than the savings in washing frequency. In fact the formula did indeed indicate the solution that generated the greatest net revenues. In our test the optimal washing frequency actually produced at least $168,560 in greater net revenues after the cost of washing than the next best scenario after 6 washing cycles under the optimal formula and 3 washing cycles under the next best scenario.

Now let us outline some of the possible shortcomings of this simplified formula and decision rule.

Capping is a frequent justification for dropping any serious consideration of a more sophisticated analysis of module washing. To be clear, there are cases where solar facilities have been so overbuilt in relation to the maximum energy the off taker will agree to purchase, that soiling and a number of standard preventative maintenance procedures are rendered unnecessary.

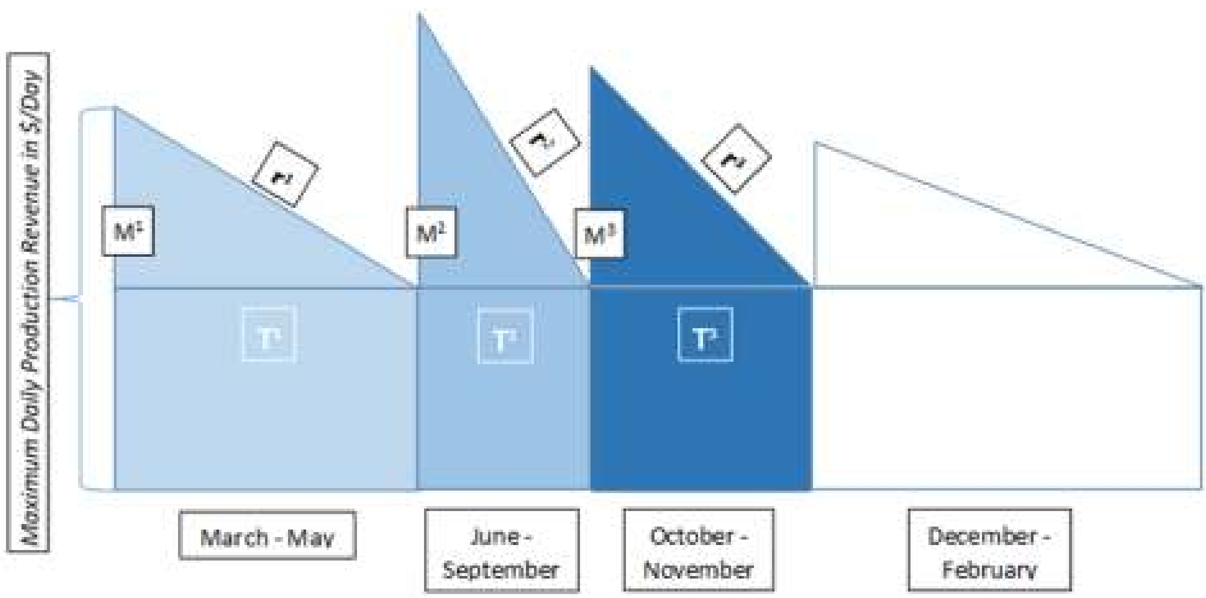


These plants replace good O&M practices and procedures with brut excess capacity. In the not so distant past, when lenders and investors treated all productivity assumptions with suspicion and when production subsidies were generous, this strategy of overbuilding made some sense in the short run. But in the last several years, even with dramatic drops in equipment costs, plants are increasingly being built with much less excess capacity. The Central Valley plant we cited and used in our illustration was put in service within the last 24 months and we have observed capping during the relevant 2nd and 3rd calendar quarters in only 27 of the 2,541 daylight hours. This is less than 1.1% of the hours of operation and we therefore have comfortably ignored this issue when setting washing policies for this project and others like it. So while capping may well be a needed adjusting factor for older projects, it should not dictate washing policy for newer solar generators.

A constant rate of revenue loss due to soiling over long periods of time does seem unrealistic. Note that our variable **r** is actually composed of three factors: i) the physical rate of soiling; ii) the revenue rate being earned for each kWh being generated; and iii) the irradiance each day. We know each of these factors varies over time. Soiling varies due to prevailing winds, soil moisture in the area, and human activity in the area that causes soil or other particulates to be kicked up and carried by the winds. Revenue rates on many PPAs have seasonal and time of day adjustment factors that generally make kWh's generated in the middle of the day and the middle of the summer more valuable than other times of the day and year. Irradiance follows a predictable pattern throughout the year at each point on the surface of the earth in terms of total sunlight hours and its intensity with the usually random factor of clouding complicating these predictable patterns.

While this list of complicating factors to the rate of revenue loss due to soiling appears daunting, these factors often have fairly regular and predictable patterns at least during parts of each year. In fact in certain areas, like our example plant in the Central Valley of California, all three of these complicating factors vary widely throughout a year but vary more or less in unison and in predictable/seasonal patterns. Therefore, we adjust our washing decision rule for this plant by preparing one formula calculation for the June through September months, a separate calculation for October and November, and another calculation for March through May. For the rest of the year at this site [December through February, or California's rainy season] we have determined that a formula-based washing decision rule is just not justified since the occasional rains cause revenue losses due to soiling to be unpredictable. Even without rains, washing during this period is unlikely due to the relatively low rates of soiling, revenues, and irradiance.

So the adjustment to the decision rule to take into account the potential changes in the rate of revenue losses due to soiling is to generate additional calculations for the variable **r** throughout the year as needed.



Rainfall is often cited as a factor that invalidates any systemic approach to wash timing. We certainly concede that in locations where rainfall is relatively frequent and randomly timed, our approach has limited value due to the high volatility of our **r** variable. However, there are numerous locations where rainfall has a fairly regular pattern or has seasonality where rainfall is a factor for only part of the year. For example, much of California has a fairly well defined rainy season from late November through February. Rain can occur outside this period, but it is unusual and the quantities are minor. As a result, our formula-driven decision rule is dropped during California's rainy season and we resort to the "gut feel" if a module washing is proposed during this period.

Obtaining reliable values for r. Obviously a formula-driven decision rule is not useful if one of its variables is hard or impossible to measure. **W** is simply the cost of washing and while it may vary throughout the year, it is a fairly direct process to obtain a cost estimate or quote from qualified vendors at any point throughout the year.

The current rate of production revenue lost due to soiling as measured in $/day, or what we call **r**, is not so readily available. The most reliable method we have found to measure **r** is to set up a control array on the site in question that is washed frequently (often weekly, but depends on the extent of the soiling rates). We also select a matching array to the control array. The selection of the control array and matching array must be done carefully to eliminate any other factors that may cause a differential in output between the clean control array and the matching array with its soiled modules.

The rate of change in the different output rates between the control array and matching array is then compared and translated to revenue. For example:

	Control Array "the clean one"	Matching Array "Soiled like the rest of the plant"	Δ between Control & Matching	Δ in $ *(assume average rate of $0.12/kWh)*	**r** in $/Day²
Day 1 output	100kWh	90kWh	10kWh	$1.20	
Day 8 output	100kWh	80kWh	20kWh	$2.40	$0.171
Day 15 output	90kWh	60kWh	30kWh	$3.60	$0.171
Day 22 output	110kWh	70kWh	40kWh	$4.80	$0.171

Extrapolating the result across the entire 20mW plant and noting a washing cost of $50,000 we can calculate the optimal number of days between washes:

512 arrays X $0.171 = $87.55/Day² = **r**

$50,000 = **W**

$$\sqrt{\frac{2 \ x \ 50{,}000}{\$87.55}} = \mathbf{T}$$

$$\sqrt{\frac{100{,}000}{87.55}} = \mathbf{T}$$

$$\sqrt{1{,}142.2} = \mathbf{T}$$

±34 days = **T**

The above data was from our example plant and done just after completing a wash at the beginning of the second formula calculation period, which ran from June through September. The owners had only budgeted one wash for the year so the formula-driven decision rule was ignored. This "wash once-a-year at the beginning of the summer season" is a standard wash rule but we can demonstrate how suboptimal it really is. Just looking at this second period from June through September we can calculate the lost revenue from only washing once at the beginning of this 102 day period instead of 3 times per the formula:

	Adhering to Formula based Decision Rule	No Washing for the Next 102 Days
Days 1 – 34		
Lost revenue due to soiling	$52,092	$52,092
Days 35 - 68		
Lost revenue due to soiling	$52,092	$153,300
Washing Expense on day 35	$50,000	
Days 69 – 102		
Lost revenue due to soiling	$52,092	$254,508
Washing Expense on day 69	$50,000	
TOTAL LOST REVENUE & WASH EXPENSES	**$256,276**	**$459,900**

Overall lessons learned: From our initial work on formula-based washing decision rules, we have learned that in those circumstances where decision rules work well, optimal washing frequency is often much greater than current practice. It is a common practice among solar operators to wash only once or twice a year whereas there are periods during the year that the formula-based decision rule could call for washing every 20 to 40 days!

-o0o-

About Solarrus Corporation

Solarrus Corporation is dedicated to developing, maintaining, and operating infrastructure that supports a wide range of alternative energy technologies. At the core of the company, Solarrus provides residential, commercial, and utility scale design, operations and maintenance (O&M), and asset management services for solar installations and electric vehicle charging stations. By incorporating our nationwide footprint and our O&M protocols, Solarrus not only brings experience and confidence to our customers' projects, but also our services remain an asset for the entire lifetime of the projects. For more information, please visit our website at www.Solarrus.com.

About True South Renewables, Inc.

True South Renewables, Inc. (TSR) is the leading independent solar O&M services provider in North America and is a wholly owned subsidiary of Solarrus Corporation. TSR operates both distributed generation and utility scale solar electric facilities across the US, with over 1GW under O&M, Asset Management, and field service contracts. The company's national headquarters is located in California and has regional offices in Texas and New York. For more information about True South Renewables, visit www.TrueSouthRenewables.com.

For any questions or comments, or if you wish to arrange an analysis of the optimal washing frequencies for your solar project contact:

Solarrus CORPORATION

David Young
Vice President Asset Management

Corporation Offices
5406 Bolsa Avenue
Huntington Beach, CA 92649

Main: (949) 333-0899
Direct: (949) 954-8178
Email: DavidYoung@Solarrus.com

WWW.Solarrus.com