Solar PV Operation & Maintenance Issues

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Background
Before one addresses the issues of solar photovoltaic (PV), one must understand the nature of solar PV O&M first. The common belief is that solar requires very little to almost no maintenance at all. This statement turns out to be true, but at the same time can be very misleading. In the past utilities have dominated the energy industry and more or less have supplied all the electricity to residential and commercial customers. You pay for the energy you consume per month and that’s it. Why would one consider solar, then? A typical answer might be because it is cleaner than coal or natural gas. This is true, but ultimately it comes down to money, and if solar is the cheaper option. This is where the central idea comes from in order to understand PV O&M. Solar is an investment that is likely to last you 20-25 years. How can one know if converting to solar will save them money, especially if initial capital costs are very high? In order to calculate an accurate return on investment, one must account for O&M issues, as well as understand them as to develop procedures for dealing with these issues in the most efficient and cost effective way. This is why the statement that solar requires little maintenance can be misleading. If one has very low margins to convert to solar, and does not accurately create a return on investment report, economically the results could be disastrous. In this article O&M issues are addressed and references are given as to provide a better understanding of solar PV.

Issues
Natural Degradation
All solar cells naturally degrade over time, regardless of the environment they are in. This is called natural degradation, and is completely normal for all solar cells to experience once in operation. As seen in figure 1, for silicon (Si) panels, both mono crystalline and poly crystalline, degradation rates on average are around .7% a year, with a median value of 0.5% a year [12]. This difference is significant because it appears by the trend of the graph that outliers are skewing the data to the right. Manufacturing companies such as Jinko Solar, Solar World, and Q Cells offer warranties if degradation rates exceed certain amounts. One qualifies for panel replacement or compensation if degradation values exceed 0.8%, 0.7%, or 0.6% respectively for each company. As one can see, these values align with the data provided by figure 1. What this also tells you is that a higher quality panel will have less natural degradation. This data was
collected in 2011, and with the exponential growth of solar in the past 3 years, if you had to choose one of these values for use in calculation, the 0.5% median value would be a more accurate choice. Although there are some outliers, typically panel quality improves over time. This statement can be supported by figure 1, as if one looks at the post 2000 degradation rates, there are less outliers, as well as there being a high frequency of panels below the median 0.5% mark. Although natural degradation is not a preventable issue, it is important to understand because it directly affects the power output of your panels. Over time, your system will be outputting less energy, which means you will be saving less money. Adjusting your return on investment with an accurate natural degradation rate is essential to getting an accurate reading of the true amount of energy your PV system will be generating. Amongst PV installers, it is standard practice to do this, but vital nonetheless. Figure 1 was taken from article [12].

Articles [12], [20], as well as this article can be accessed for more information on natural degradation.

End of Life
A large issue, often overlooked, is what to do with a PV system once it is decommissioned. For residential systems, it is not as large as a problem, but for a commercial 1 MW system consisting of approximately 4000 panels, all bolted into the earth with galvanized ground screws, it would take a lot of man power to uproot and dispose of the materials. Not to mention transportation costs, as well as other costs for disposing large, bulky material. Recycling options as well as potential chemical hazards at end of life are discussed.

Recycling
In regards to an end of life plan, recycling would be the best course of action. Unfortunately, it is a very unrealistic option. The reason there is not a huge emphasis on recycling at the moment is because the vast majority of commercial PV systems have been installed in the past 3 years. Twenty years down the line when these systems begin to approach their end of life, it is very likely a strong emphasis will be placed on recycling. The current issue with recycling is that only some parts of the array can be recycled, and separating out these parts takes extra man power and time. PV manufacturers’ main goal is to lower the cost of panels. They do this by using less expensive materials in the panel. But, as the amount of valuable materials

![Figure 1 – Median and Average Degradation Rates pre and post 2000 – Article [12]](image)
decrease, usually more, cheaper materials must be used [2]. The more types of materials in a panel means the harder it is to recycle. This means that large amounts of waste will come from PV systems because there will be no reason to waste money recycling cheap, highly mixed materials. Anctil and Fthenakis predict that, “…it is unlikely that earth-abundant panels that are more complex would be recycled without any policy incentives such as mandatory manufacturer take-back.”[2] As the large flux of commercials installations that have arisen in the past 3 years start to come to their end-of-life, it is possible that policy incentives will start to come up. It is these incentives, or lack thereof, that will either lead to installations being a financial burden and end up in the landfill, or be recycled.

More information can be found in articles [2] and [8].

**Chemical Hazards**

With the disposal of PV materials there is a potential chemical hazard as well. Traditional Silicon panels have no chemical hazards associated with them. CdTe (Cadmium Tellurium) panels, on the other hand, do. Cadmium can be toxic/carcinogen, but through experimentation it is shown that it can only be dangerous through ingestion [6]. The most likely case in which one would consume cadmium from a solar panel would be if the panels were disposed in a landfill, and the chemicals from the cadmium panel leaked into the water bed; however, a certain bulk of Cadmium is needed to institute health risks. In Colorado, one of the largest states in regards to number of PV installations, 20% of its landfills are too small for this volume of Cd to even exist [6]. To exceed the waste volume limit of 5000yd$^3$ to be deadly, a single landfill would have to absorb 680 thousand Cd panels every year for the next 20 years [6].

![Figure 2 – The process of how Cadmium could infiltrate a landfill – article [6]](image-url)
Based on the CdTe market in 2010, that would mean 8% of all panels being made going into 1 landfill [6]. This is beyond improbable of occurring, even with the market continually growing. Also, nearly all landfills have protective lining. It was shown that with lining, CdTe proved to have no risk, regardless of the amount of cadmium [6]. Only 3% of landfills did not have protective lining during the Colorado study. Overall, cadmium panels should be disposed of with care, but ultimately if the panels are professionally decommissioned and handled properly, there should be no chemical hazards. Figure 2 shows a diagram on how Cadmium could infiltrate a landfill.

More information can be found in article [6].

**Grounding and Lightning Protection**

As with any large, costly structure, a lightning protection system is of high importance. As shown in article [5] there are multiple aspects of a PV system that you must account for to create an effective lightning protection system. The first is to create some form of grounding system to redirect the energy from the lightning into the ground, and away from the panels. Table 1 is a chart that tells you what type of material should be used for the grounding system depending on what type of racking system the array uses. If the racking system is galvanized steel rod drilled deep into the soil, galvanized steel or stainless steel should be used for the grounding system. Even with a proper grounding system, a PV installation can still be at risk from lightning. Once the energy from lightning is discharged into the ground, it can still cause a power surge within the array [5]. Because of this, surge protection equipment is needed to fully protect an array from lightning [5]. In some cases if the grounding system is effective enough to reduce the energy dissipated from a lightning strike, it will reduce the need to use more surge protection equipment. Because metals must be used to create the grounding system, the same type of metal should be used to avoid corrosion between different types of metals [5].

<table>
<thead>
<tr>
<th>Type of Foundation</th>
<th>Material for Earthing System Driven into the Soil</th>
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<tbody>
<tr>
<td>1 Galvanized steel directly buried into the soil</td>
<td>Galvanized steel, Stainless steel</td>
</tr>
<tr>
<td>2 Steel profile embedded in concrete</td>
<td>Copper coated steel, Copper, Stainless steel</td>
</tr>
<tr>
<td>3 Reinforced concrete block placed above ground level</td>
<td>Galvanized steel, Copper coated steel, Copper, Stainless steel</td>
</tr>
<tr>
<td>4 Reinforced concrete foundation into the soil</td>
<td>Copper coated steel, Copper, Stainless steel</td>
</tr>
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Note 1: Copper Conductor may be tinned;
Note 2: Aluminum not allowed to be buried into the soil
Article [5] can be accessed for more information on grounding systems, including tested grounding models.

**Component Failure**

**Panels**

As the main component of a solar PV system, maintaining panels is key to achieve an ideal power output. Throughout the life of a PV system, there are multiple issues that can lead to panel failure, or loss of optimal efficiency.

**Panel Cracking**

Panel cracking can be caused from a variety of sources. Physical impacts, oscillation from wind, or manufacturing issues can all lead to cracking. Panels should be inspected on purchase because there could be micro cracks created during the manufacturing or shipping process that will grow into larger cracks over time [7]. Cracks will reduce module energy output and efficiency. This is because the cracking will alter the optical properties of the panel, and cause light to penetrate the surface of the panel differently. This leads to loss of efficiency because the maximum amount of light is not penetrating the panel. Depending on the amount of cracking, sometimes it is not warranted to buying an entire new panel. Usually extra panels are ordered whenever a system is purchased, and in this case it could be worth utilizing these panels to replace cracked ones. Otherwise, it would not be worth buying an entirely new panel to replace ones with cracks. Figure 3 shows an example of panel cracking.

**Panel Discoloration**

Visual discoloration is a common defect that reduces the amount of sunlight that penetrates into a solar cell. This means solar cells being less exposed to solar irradiation, and generating less energy. The reason it leads to loss of efficiency is because different color panels changes the wavelength of light that can be absorbed. For instance, purple discoloration, such as in figure 4, means that purple light is not absorbed by the
panel. This causes loss of efficiency because not every wavelength of light is being absorbed. Different types of semi-conductor materials absorb different wavelengths. Some examples that cause discoloration are poor encapsulant quality, high temperatures, humidity, and if a PV system is located near an ocean: ocean salt [7]. Similar to panel cracking, there is not much you can do to reduce the effects of discoloration once it has occurred, other than replacing the panel entirely. Higher quality panels will become discolored less easily. There is not an exact method to see how much power is lost, other than comparing the energy output before and after discoloration has occurred.

More information can be found in article [7].

**Hot Spots**

It is a common misconception that solar panels are the most efficient in the highest temperatures. Solar cells do not gain efficiency based on temperature, but instead based on the amount of solar irradiance. On the other hand, high temperatures can actually damage solar panels, and can lead to hot spots. Hot spots occur when a panel is shaded, damaged, or electrically mismatched [7]. Hot spots decrease power output, and because solar cells are attached in strings, just one hot spot can lead to multiple cells functioning poorly [7]. To solve this problem, all shading should be negated, and electrical connections should be optimized. Depending on the severity of other issues that could lead to hot spots, a panel replacement might be justified. Hot spots can be easily seen with the use of an IR Gun. Figure 5 shows an example of multiple hotspots.

Article [7] should be addressed for more information on panel issues.

**Inverters**

One of the main electrical components to a solar installation, the inverter changes the electricity created by the solar panels from DC to AC. Currently there are 2 inverter schemes that one can use. The first is a single, central inverter. The other is a multi-scheme setup that utilizes 2 or more inverters in a single array. Micro inverters are gaining popularity as well. In this setup, each panel has its own separate inverter. The lifetime of a central inverter is 10 years with a standard deviation of 3 years [9]. This is an older reference, and as such inverter
lifespans have been a huge issue. A large amount of research has gone into improving inverters, though, and newer models are expected to last for the lifespan of the system.

**Monitoring Failure**
Modern inverters usually have monitoring instruments integrated into their build. Typically, both the voltage and the current of the electrical output can be measured. For newer models of inverters if the data link is broken, it could be useful to check the inverter itself to see if the data link is turned on and information is being monitored. For older models though, one must check each individual instrument to make sure the data stream is up.

**Panel Orientation and Grid**
Panel orientation is an issue that must be addressed before a system is installed. It requires due diligence on the consumers part to make sure the installer is taking the proper steps necessary to determine an ideal panel orientation. Now, if the installation is using panels with tracking systems, then the panel orientation is less important. For static panels, though, it is essential to have an ideal panel orientation. Depending on your location, there is a unique tilt angle and solar azimuth angle to optimize energy output. There are many websites that can give you accurate data in regards to panel orientation. An example would be [http://solarelectricityhandbook.com/solar-angle-calculator.html](http://solarelectricityhandbook.com/solar-angle-calculator.html).

Articles [10], [13], [14], [15], and [18] all use extensive methodology to test optimal orientations in different parts of the world. These can be accessed to gain further knowledge on how solar irradiance and other factors affect panel orientations.

**Snow**
A study showed that power losses from snow can be as high as 15% in places like Truckee, CA, or as low as 0.3-2.7% for a highly exposed 28° tilt roof mount system in Germany. Yearly yield losses are averaged around 3% [2]. As one can see, snow is a variable issue, highly dependent on one’s location. Unfortunately, at the moment there are not many ways to deal with it. On residential sized arrays, it could be worth one’s time to simply shovel snow off of a few panels, as long as you do not scratch the array. On a large commercial sized array, this is very impractical. The reason there is little one can do to address snowfall is because it will deal with itself, or one will have no way of dealing with it at all. The first instance happens when the temperature is hot enough to where snow will start to melt and the latter when it is too cold. When it is hot enough out, the bottom part of the snow that is in contact with the array will melt first. Then, if the panel is at an angle, this small volume of snow (now water) will cause the entire block of snow to slide off the array. This will happen fastest when the sun is out (and you are capable of generating power). Now, when the sun is not out, and if it is too cold for the snow to melt at all, the snow will not naturally slide off the array. In this instance, because it is so cold, it is highly likely the sun is not out anyways, and your panels will not be able to
generate power. In this case, it is not worth the effort to get the snow off the panels, because it is cloudy and power output will be low anyways. Spraying water at snow covered panels could get it off, but in the process the water can freeze and damage panels. As one can see, if the sun is out and one is capable of generating power, snow will tend to deal with itself. Otherwise, it is not worth the effort to mess with.

Articles [2] and [16] should be referenced to create an ideal plan for snowfall.

Soiling
Soiling is one of the most prominent issues in dusty environments. It is also very costly, as the only way to deal with it is to clean panels. On a large commercial array, heavy soiling could warrant multiple cleanings a year. At a cost of a couple thousand dollars a cleaning, having to do this every year for a PV systems lifespan can be very taxing, and in many instances can even discourage the switch to solar. One of the best ways one can deal with soiling is to combat it before it even happens. One can do this by performing due diligence and seeing if panel cleaning comes under warranty. Also, according to Mejia and Kleissl, out of 186 sites, each site was found to have losses greater than .01% per day, over double the average. This is because the tilt angles were less than 5 degrees. Tilt angles less than 5 degrees were shown on average to have 5x more soiling than ones that were tilted more than 5 degrees. If you are in a very dusty environment it would be well worth it to consider a higher tilt angle even if maximum solar irradiance is gained from an angle of 5 degrees or lower. This is because over time there will be less soiling, and ultimately you will produce more energy in the long run, as well as not having to clean as often. There is only so much you can do to combat soiling before you have to clean panels. Finding a professional solar cleaning company is the best option when it does come time to cleaning panels. An example would be www.solarmaid.org. Figure 7 shows an example of soiling.

Because rain cleans panels very effectively, it should be noted that soiling effects depend primarily on time since previous rainfall. When rain does occur, it should be noted and panel cleanings should be postponed accordingly.
Additional information can be accessed in articles [1], [17], [19], and [22].

**Wind**

Similar to soiling, wind is a locational issue. Because of regulations, all solar panels must be tested to withstand certain wind loads. Usually the wind loads are significant (~50+ mph), but they do not accurately simulate wind patterns in real life [5]. This is because in testing, a panel will be put in a wind tunnel and blasted with wind linearly from a single direction. In the field, wind patterns are not linear, and can cause damage to solar panels. This occurs when oscillation is induced, and a large enough frequency of vibration is reached that will cause the panels to outright break [4]. As discussed by Banks, many wind patterns are circular (vortexes), and cause lift under solar panels [4]. The most vulnerable part of an array is the corners, and often depending on the orientation of the environment, and the position on the panels, this can be a deciding factor whether or not if your array will survive through the wind over a 20-25 year lifespan [4]. Currently there is no easily accessible way of testing if solar panels can handle dynamic wind loads. It would require accurate fluid dynamics simulations to see if panels are sturdy enough or not. Usually installers are very knowledgeable about wind loads, and through years of experience will be able to tell if it will be an issue. As all installers require an inspection before any building takes place, a professional PV installer will be able to foresee any large issues.

Article [4] can be accessed to gain further knowledge on wind loads on PV systems.

**Maintenance**

**Panel Cleaning**

It is important over the lifespan of an array to maintain optimal energy output. In order to accomplish this, panel cleaning will be necessary. Cleaning early in the morning when the mirrors are wet from dew is probably the best time to clean the panels because dust can easily be rinsed without coating removal or damage [19]. The best technique today in the strategy of high-pressure sprays is a spray with commercial anionic detergents [19]. Effective cleaning solutions employ chemicals which reduce surface tension, lower the cost, are capable of being handled and mixed by automated equipment, and are non-toxic, safe, and biodegradable [19]. Detergent based solutions are normally able to restore the surface to 98% of its original reflectance [19]. High-pressure sprays proved to be a very effective method for cleaning large-scale arrays. A Benchmark of 3-gallon per minute spray at 300 psi (with detergents) recovered up to 90% of reflectance [19]. If you are hiring a professional cleaning service to clean your panels, confirm that they are using the best methods, and that you are getting what you paid for.
Article [19] should be addressed for cleaning tips.

**When to Clean**

Because it is variable how often one should clean, an algorithm should be used to determine when cleaning should be done to be as cost effective as possible. This means cleaning when the cost of energy lost exceeds that of cleaning. In order to calculate this, first one must adjust the actual energy production. This means taking the ratio of the actual solar irradiation your PV system receives to the expected solar irradiation. Once the actual energy production has been calculated, one must compare the result to the expected projection (adjusted for natural degradation). When the cost of energy lost exceeds the cost of cleaning the panels should be cleaned. This is a simple formula to follow, but requires an accurate monitoring system to utilize. This is because every day of the year has a different projection for energy production: The incidence angle changes and solar irradiation varies by day. For short sample records, the result is small enough that it is negligible, but comparing month to month produces better results. However, it is hard to do this comparison without accurate month to month data, which means drawing on data from an installation in operation for more than a year, or using a very accurate prediction tool. An example would be the NREL PV Watts software, which can be accessed at [http://pvwatts.nrel.gov/](http://pvwatts.nrel.gov/). In order to determine when to clean, the cost of cleaning has to be acquired. This can be difficult because cleaning companies require a visual inspection to get an accurate prediction on the cleaning cost. Typically for commercial arrays, the price of cleaning was averaged around $2.50 a KW plus transportation and special equipment costs. This data was compiled from cleaning quotes from seven different companies that can potentially service the Reno area.

Article [23] can be addressed for more information on cleaning.

**Warranties**

It is important to take advantage of warranties to reduce costs. At the time of installation the buyer receives information regarding everything from operation procedures, inverter information, module information, combiner information, racking information, monitoring system, electrical balance of systems, as-built/plans, and maintenance options. Amongst this information are the product warranties for each aspect of the PV system. It is important to utilize this information so that warranties can be enforced. Being able to prove that something has failed under warranty is key to reducing the lifetime costs of an installation. When trying to enforce a warranty, consult the installer of the array first, before the manufacturer. It is often in the best interest of the installer to help you to maintain their reputation. It is difficult to contact the manufacturer directly, and an attorney may need to be involved in order to make sure manufacturers uphold their warranties.
Component Optimization

Panels
The key to keeping panels working at optimal efficiency is to keep them clean, and make sure they were installed in the optimal orientation to maximize power output. Panel cleaning is discussed in the above section, and finding an optimal tilt angle is discussed in the Panel Orientation and Grid section.

Inverter Strategies
In the configuration of a common DC bus, the number of inverters should not exceed 5, as it becomes inefficient [9]. The configuration with a common DC bus is the lowest risk oriented for investors. In the case of a 1 MW case study, the configuration with two 500 kW inverters in parallel connected to a common DC bus had the lowest energy cost [9]. Compared with a central inverter, this configuration is preferable not only because of its higher energy yield and lower cost, but lower investment risk [9]. As seen from this study, a multi-inverter scheme is the most efficient, and because of this the industry is moving in this direction. Through the use of micro inverters, every panel will have its own inverter as to maximize efficiency and minimize issues that would affect entire strings of panels. Another crucial strategy is to use a single inverter for panels with similar orientation. For large commercial arrays, it is unlikely that all the panels will be facing the exact same direction, with the same tilt angle. For each part of an array with a different orientation, a separate inverter should be used. This is because each part of the array with different orientation will have different electrical properties, and electrical mismatch could cause inverter issues and loss of efficiency.

Article 9 should be referenced for more information on inverters.

Conclusion
Looking at 31 articles addressing PV Operation and Maintenance issues, 23 were used to conduct this study. It can be seen that many different issues can affect a solar PV system, and it is crucial to take in account as many issues as possible to reduce costs. In particular, panel cleaning, inverter strategies, and warranty enforcement are crucial to minimizing costs. Amongst all the issues, these are the most expensive, and are very likely to show up in the lifespan of any PV system. Because of this, performing due diligence is a must when converting to solar PV. Checking to make sure the installer orients inverters in the correct way, as well as getting detailed information on all warranties is vital. Also, finding a cost effective cleaning service will save money, and keep your panels working in optimal condition. Overall, becoming knowledgeable about these issues will help one run and operate a solar PV system effectively.
Works Cited


**Other References**

[Soiling Picture 1](#)