The next big step – Optimizing the performance of PV power assets

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ABSTRACT
To achieve project cash flow expectations, it is necessary to operate, maintain and optimize the performance of a PV power asset to meet or exceed the pro forma operating assumptions. To assume as given the achievement of these model assumptions is both naive and risky. Experience in operating the largest fleet of solar PV power plants in the world has demonstrated that project financial hurdle rates can be missed by as much as 25% if the plant is not well maintained and its performance is not optimized. Conversely, an optimized PV asset can generate cash flows 2–10% higher than expected if the optimization approach described in this paper is implemented.

Why PV performance optimization is needed and why now

New technologies typically follow a four-phase maturation cycle as they are being commercially deployed: 1) technology breakthrough, 2) market development, 3) technology build-out, and 4) maintenance and service. This last phase in the deployment of a new technology, the actual servicing of the technology, is the least glamorous of the phases and is often taken for granted by asset owners and investors. Specific operating assumptions, such as plant availability and component degradation rate, are part of every financial model used to finance an asset purchase. But how does the investor know those assumptions are valid and if the projected returns will be realized on their particular project?

What is optimization?

To optimize the operating performance of any system, PV or otherwise, the first order of business is to understand what the term 'optimization' really means. At its most basic level, optimization is the process of finding the 'best available' solution for a system, given a set of operating variables with an accompanying set of constraints. To optimize a system or project, it is first necessary to characterize how it works within a set of physical and commercial limits and the operational degrees of freedom that the owner has to work with.

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The ABC of optimization

A simple way to think about optimization is what has been called the 'ABC' of optimization (Fig. 1). The letter 'A' prompts the question 'What can be **A**djusted?'; 'B', 'What is the **B**est solution?'; and 'C', 'What are the **C**onstraints?' Each of these components of optimization will be addressed.

Before considering how system variables can be adjusted and how they are constrained, however, it is important to understand what is meant by the 'best', or optimal, system solution. Typically, when considering what the best solution to a problem is (also called the 'objective function'), the maximum or minimum result from a set of options is the object of the search.

What can be adjusted?

Controllable parameters, or 'decision variables', are those operational and commercial 'knobs' the operator can adjust to obtain different operating results from the PV power plant. Though PV plants have fewer controllable parameters than other generation technologies, such as fossil and wind plants, there are still more operating degrees of freedom than many owners recognize. For example, most inverter original equipment manufacturers (OEMs) will allow operators to 'over-drive' the inverter beyond its nameplate rating if staying within the limits of the warranty.

Why is this important to know? Many PV power plants are built with excess DC capacity, meaning that the DC arrays can deliver, under ideal conditions, more power than the nameplate rating of the inverters. This extra DC power is often 'wasted' at the inverter because of a factory setting that 'clips' the power so as not to exceed the AC nameplate rating of the machine.

Why waste that power and not realize the potential revenue? Some power purchase agreements (PPAs) and interconnection agreements (IAs) limit plant power to the total inverter AC nameplate capacity of the project, while others allow generation 5–10% above guaranteed capacity. If the project limits generation to the inverter nameplate capacity, it may be possible to negotiate an amendment to PPAs or IAs and obtain written approval from the inverter OEM to increase the factory power limit by several

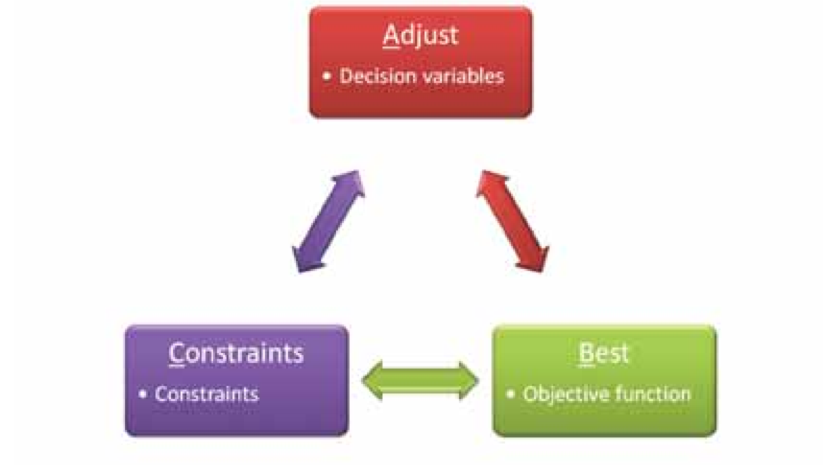

Figure 1. The ABC of optimization.

percentage points. This one modification alone can increase revenues for some projects by 2–10% per year.

What is the best solution?

For a financial asset, such as a PV power plant, the problem to be solved is usually not how to maximize revenues or minimize expenses, but how to maximize revenues while minimizing expenses. In other words, what solution returns the highest profit for the project? This is because, although the goal of maximizing revenues sounds like a good objective, a short-term perspective on maximizing revenue could actually result in suboptimal profits for the project in the long term. For example, the plant operator could ‘over-drive’ the inverters or increase panel-washing frequencies to achieve maximum project revenues while simultaneously adding cost at a higher rate, resulting in reduced project profits. Maximizing project revenues in isolation is therefore typically not what is best for the project.

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Similarly, minimizing project expenses is usually not the right goal either. Taken to an extreme, a good way of minimizing project expenses is to do no maintenance. Is this practice advocated? Certainly not! It is known intrinsically that neglecting a power generation asset, even a fairly low maintenance asset such as a PV power plant, does not result in maximizing long-term project returns. Indeed, inspections have revealed that many rooftop PV power systems which have been neglected or poorly maintained are operating at only 80–90% of their system capability.

The reason why maximization of long-term project profitability is the right goal for a PV power project is that it seeks to find the balance between generating high revenues and making the right investment in the reliability and maintenance of the system.

What are the constraints?

Constraints are the limits imposed on the project’s controllable parameters. Think of the optimization problem for the project as a multidimensional box where the constraints are the walls of the box and the controllable parameters are the ‘room’ in which one has to manoeuvre within the box. A particular corner in one of those rooms in the box is the optimal solution for which project profitability is maximized (Fig. 2).

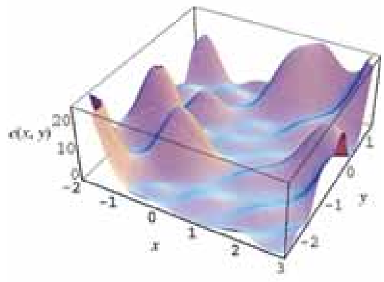

Figure 2. A multidimensional optimization problem.

PV power plant constraints come in three types: 1) physical, imposed by the plant equipment; 2) commercial, imposed by the operating agreements and warranties; and 3) regulatory, imposed by local and national rules and regulations.

Physical constraints are the limits of the plant hardware. For example, a 320W panel can generate 320W of power under standard test conditions (STC), but there is nothing that can be done to make it generate more than 320W of power. More panels can be added to increase the plant’s DC capacity, or a fixed-tilt system can be converted to a tracking system to increase the plant’s capacity factor, but the panels are still only generating 320W of power.

Commercial constraints are those non-physical limits imposed by the equipment manufacturers and operating agreements. For example, though an inverter may be able to generate 5–10% more AC power than its nameplate rating, if the OEM warranty would be violated by over-driving the inverter, the operator is commercially constrained not to do so. Similarly, if the project interconnection agreement dictates that the plant can never deliver more than 25MW at the point of interconnection, the plant will not deliver more than 25MW of instantaneous power, even if it has additional AC capacity available to do so on a sunny day.

Regulatory constraints are constraints imposed by operating permits. For example, some PV projects in the desert of the southwestern USA prohibit owners from using water to clean the plant’s PV modules. Unless a non-water method of reducing soiling is available to the operator, the plant’s performance degradation rate is at the mercy of local environmental and rainfall conditions.

The balance and benefits of optimization

The benefit of optimizing the operational performance of a PV power asset is, of course, the ability to improve project cash flows. The balance in optimizing the profits of the project is to ensure that the best solution for a given set of operating variables and constraints is what is *really* being determined. This is typically not a trivial solution and requires that commercial and technical analysts properly characterize the system and its controllable parameters and constraints. For the most complex analysis, the problem can be modelled using a ‘solver’ software tool to find the best solution from among thousands or even hundreds of thousands of candidates. To accommodate a large data set, a robust ‘data historian’ – such as OSIsoft’s PI System – can be particularly useful when analyzing historical and real-time plant data.

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Exceeding project operating performance

For the asset to exceed its projected operating performance, it is necessary to evaluate which of the pro forma operating assumptions have some available margin, and how sensitive revenue and expense are to changes in those parameters. The first step is to develop a simple table showing which project variables can be adjusted and what the projected profit impact might be (Table 1).

For example, though an owner may be able to generate an additional 2–5% of production from their facility, there is almost always a cost in doing so. The operator could over-drive the inverters to generate additional peak capacity during some hours of the year; however, what impact would increasing the inverter’s operating duty have on reducing the equipment’s life and increasing its maintenance costs? Similarly, an operator could increase the module-wash frequency of the facility and improve the overall electrical conversion efficiency of the modules, but at what cost? To properly determine the ‘right number’ of module washes for a given PV power facility,

Variable	Potential improvement [%]	Profit impact [%]
Production	2 to 5	–5 to +5
Efficiency	1 to 10	–10 to +8
Availability	1 to 2	–10 to +1
Corrective maintenance labour	10 to 50	–5 to +5

Table 1. Adjustment of project variables.

the owner needs to characterize the past, present and future recoverable degradation rate of the modules and the unit cost of cleaning.

Finding the right balance

The above example of finding the optimal module wash frequency for a facility demonstrates why a robust physical and financial model needs to be developed in order to find the optimal solution for each plant operating scenario. Until the relationship between recoverable power, time-of-delivery power rates, module-cleaning effectiveness, historical and projected degradation rates, and cost of module washing is modelled, the optimal solution to the problem cannot be properly determined. Optimization solver technology determines the best answer by setting up a mathematical model of the problem and exercising every option until the best (most profitable) solution is found.

If the resources for utilizing a solver for each scenario to be evaluated are not available, the next best approach is to model the problem using a spreadsheet and then perform a simple sensitivity analysis on the variables that most impact the optimal solution. Once this model has been established, each assumption is varied within a range of reasonable values and the change in profit recorded during this process. It should be possible to quickly identify which variables most influence project profitability.

Figure 3. Soiled solar panels – the case for module-wash optimization.

For the module-wash frequency problem, module soiling rate (recoverable degradation) and power price are likely to be the variables with the highest sensitivity. The best available information for soiling rate, power price, wash cost and other key variables is inputted to the spreadsheet, and the module-wash frequency variable is then adjusted. It will soon be discovered that, as the module-wash frequency is varied from one to two to three washes per year (and so on), the law of diminishing returns kicks in and profits peak, and then drop quickly. The module-wash frequency that returns the best profit strikes the balance between too many and too few washes.

PV power optimization options

As mentioned above, though PV power systems do not have as many controllable parameters as traditional fossil-fuel power plants, there are still quite a few to consider. Some of these are listed in Table 2.

Category	Optimization variable	Comments
Production	Inverter over-drive	Increasing this increases peak capacity but can also increase major maintenance expense. Interconnection agreement may not allow guaranteed capacity to be exceeded.
	Inverter start-up/shutdown control	Adjust inverter control logic to wake up earlier and generate more morning/afternoon energy.
	Under-performing combiners, strings and modules	Repair of these will increase production capacity but may increase O&M labour costs if not performed using automated fault detection software.
	Tracker control under diffuse irradiance conditions	Adjust tracker control algorithms to not directly track the sun under high diffuse irradiance conditions.
	Tracker wakeup/sleep control	Improve early morning and late afternoon tracking algorithm to capture more energy.
Efficiency	Module-cleaning frequency	Recovered power must exceed cost of recovery.
	Inverter-container cooling	Improvement can reduce the high ambient temperature de-rating of the inverter but may have CAPEX and OPEX impacts.
Availability	On-site spare parts or critical spares	Model the component failure rates, availability (production) impacts, parts availability and parts cost.
	On-site staff or pay for contractor response/availability guarantees	Model the current and projected forced outage and de-rating rates and incremental labour/guarantee costs.
	Component failure rates and tracker operation	Estimate the cost/benefit of adding automated fault-detection/ network operations centre (NOC) services.
O&M costs	Corrective maintenance costs	Estimate the reduction in truck roll costs by having real-time component fault codes visible from a NOC and the part available prior to dispatching the service provider.

Table 2. Controllable parameters of PV power systems.

Time to choose

After all the viable decision variables for optimizing performance have been listed for a facility, the economic impact has been estimated, and the commercial and technical constraints have been evaluated, it is then time to begin developing a detailed model and to 'down-select' from the list of options. Some of the performance optimization options will be eliminated, as they are deemed too risky or would require re-permitting the plant or re-negotiating a power purchase agreement. Others will generate return rates and payback periods that easily meet project hurdle rates. All appropriate stakeholders and specialists should be involved in the decision-making process, and it must be ensured that equipment or system warranties are not violated. Prior to implementing the optimization project, quality baseline performance data need to be gathered so that the incremental economic benefit of the project can be measured once it is in place.

Summary

The PV power marketplace has matured and is now approaching 100GW of generation capacity worldwide. To confirm PV as a mainstream electricity-generation asset class, it is time to demonstrate to project stakeholders and to the public and private sector that this is a generation technology to take seriously for decades to come. Optimization of the technical performance of the asset is the next step in making solar mainstream and an attractive investment option.

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PV power systems need to meet and exceed their pro forma economic returns. Performance optimization methods and systems common in the traditional power and wind industries should now be deployed to realize rates of return 2–10% greater than originally modelled during project financing.

About the Author

Steve Hanawalt is a founding partner of Power Factors, LLC – a company set up in 2012 to provide PV performance optimization services. He has worked in the independent power industry since its birth in the early 1980s, and has spoken around the world on the topic of optimizing PV power project returns. Steve received his Bachelor of Science degree in mechanical engineering from the University of California, Berkeley, in 1982, with a specialization in energy conversion.

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