How Does Power Plant Controller Performance Affect Generation Revenue?

Bakhtiar Kabir and Mark Phillips
BlueEarth Renewables

Brian Waldron
Schweitzer Engineering Laboratories, Inc.

Revised edition released November 2025

Originally presented at the
61st Annual Minnesota Power Systems Conference, November 2025

How Does Power Plant Controller Performance Affect Generation Revenue?

Bakhtiar Kabir and Mark Phillips, *BlueEarth Renewables*
Brian Waldron, *Schweitzer Engineering Laboratories, Inc.*

***Abstract*—Operators often discuss power plant controller performance when examining compliance requirements for voltage control or frequency support for generation facilities that are always tied to the grid. However, little discussion is dedicated to how the performance of a power plant controller affects real power revenue for that site. Some sites are generally allowed to operate at their maximum output, which results in real power control performance being irrelevant. However, curtailments are becoming more common, and producing power as close to that curtailment, without exceeding it, is important for maximizing potential revenue. It is becoming more common in the industry for site owners to have a generation facility designed to be approved for a specified amount of power, but then have the site constructed to generate 10 or 20 percent more power than what is approved to be exported to the grid, which helps maximize the potential revenue of the approved export limits for the site. In these situations, real power control performance matters in keeping the site generating the maximum amount of power across all inverters to maximize revenue opportunities.**

In the case of solar generation, when cloud cover is present, the facility may still be able to reach the set point with a non-even distribution among inverters. When cloud cover is gone, returning the site to an even distribution without overshooting the set point is an important aspect of the power plant controller performance. Overshooting or oscillation around the set point may incur operational penalties or, in the worst case, the facility could be disconnected from the grid for violating the allowed export power. The quicker the facility can drive its output to the target set point, the more revenue the site can generate.

In this paper, we explore the benefits, if any, of a power plant controller that calculates set points closer to the limits of the underlying technology and whether this functionality provides any increase in generation revenue for the site owner.

I. Introduction

In this paper, we examine power plant control simulations with the capability to calculate set points at 300 ms, 1 s, and 5 s to see if increased calculation rates achieve any benefits in increased energy generation for the site owner. Each of these performance rates represents standard rates used in power plant controllers deployed currently in the field. Typically, each performance level increase has increased equipment and engineering costs associated with it. We demonstrate the potential revenue differences over the course of a year with these different performance levels under a wide range of irradiance and curtailment conditions. And we examine sites with greater capacity than their approved interconnection limits and sites with matching generation capability to their approved interconnection limit.

For inverter-based power plant controllers, performance requirements are often specified by many factors, such as the utility the site connects to, independent system operators, or the need to comply with regulatory standards, like IEEE Std 1547, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces or IEEE Std 2800, IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems. In many cases, regulatory requirements are sufficiently met when the controller is able to calculate new set points between 1 s and 5 s for the inverters. However, the underlying technology within these controllers can generate set points significantly faster. But once set points are calculated faster than once a second, the additional metering upgrades, additional engineering in the settings of devices, and communication upgrades needed to operate at this faster speed begin to drive up the cost of performance.

II. What Is a Power Plant Controller?

A power plant controller takes a set point from an external source and then measures an aggregate output of generation inverters. The controller compares the total measurement against the target set point and then calculates individual set points for each inverter to drive the total output of the system to the target set point. The measurement point may be far away from the inverters and may include load, losses, and other generation. The power plant controller accounts for all these factors to hit the target set point.

III. Reasons to Support Faster Performance

The following are two primary reasons that generation site owners would want to consider the additional cost of a higher performance control system with the capability of exceeding the minimum regulatory requirements.

1. The ability to participate in ancillary services that require faster responses, like fast frequency response (FFR)—see Section VIII for more about ancillary services.
2. The increase in revenue from exporting more power for a longer period of time due to the controller being able to reach a target set point faster.

The second reason poses an important question for those making the decision whether to upgrade their system—does the additional revenue generated with a faster response translate to sufficient enough additional revenue to warrant the additional costs—such as more communications equipment, the potential addition of metering equipment, additional engineering costs, and the possibility of needing to add personnel with more expertise to do maintenance updates—due to the faster control system?

IV. Simulation Study

To help answer that question, we ran several simulations to see how many additional kilowatt-hours a faster controller produces.

The weather and subsequent irradiance for photo-voltaic panels is potentially different each day. Looking at the different types of irradiance conditions that occur throughout a given day, we identified and ran test simulations using four different irradiance profiles.

A. Tested Simulation Profiles

1) Clear Sky Day

In the irradiance profile for a day with a clear sky, the irradiance increases fairly quickly and then stays steady throughout the day until the sun goes down and the irradiance decreases down to zero, as shown in Fig. 1.

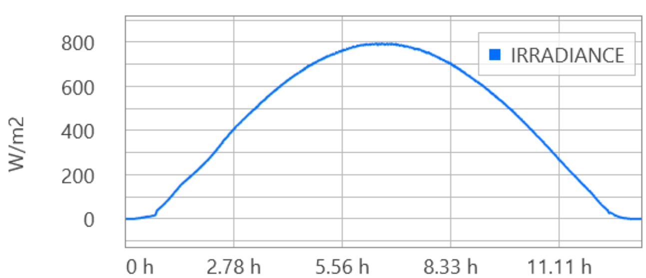

Fig. 1 Clear Sky Irradiance Profile

2) Overcast Day

In the irradiance profile for a day with an overcast sky, the irradiance increases slowly but at a steady consistent rate, reaching a maximum output far below full capacity of the site. There are some fluctuations in the irradiance throughout the day but none of them are fast or have large drops or increases, as shown in Fig. 2.

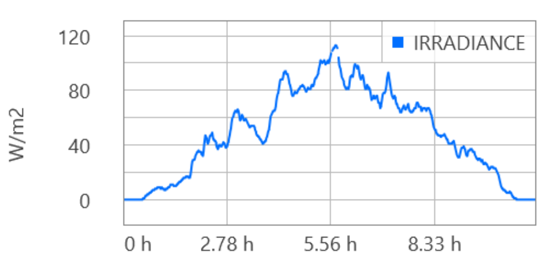

Fig. 2 Overcast Irradiance Profile

3) Variable Day

In the irradiance profile for a day with a variable sky—a partially clear sunny day that has several instances of shade and sun—there are significant drops and increases in the irradiance. In this profile, the controller needs to do some work to limit overshooting the curtailment set point when the irradiance returns, as shown in Fig. 3.

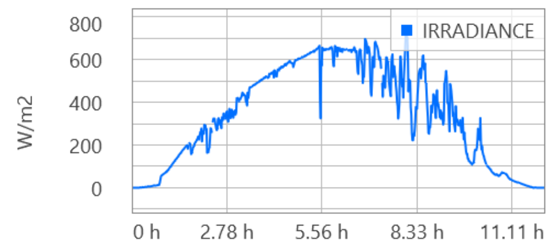

Fig. 3 Variable Irradiance Profile

4) Very Variable Day

In the irradiance profile for a day with very variable sky, the irradiance experiences many large increases and decreases due to highly variable sky conditions. The controller is very active during these conditions, managing set points from different inverters that have different capabilities to produce power, to extract the maximum amount of power without overshooting the curtailment limit of the site, as shown in Fig. 4.

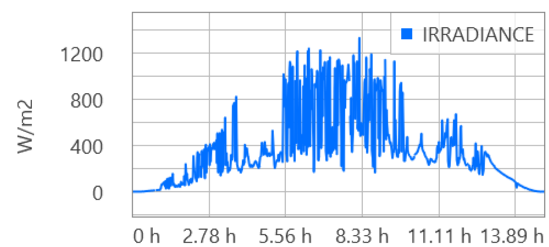

Fig. 4 Very Variable Irradiance Profile

B. Simulated Power Plant

The simulated site we used for testing consists of 24 individual inverters each with a name plate of 3,600 kVA, for a total site nameplate of 86,400 kVA. Each irradiance profile has a set point of 80 percent of the site nameplate to mimic a site that has additional capacity compared to the approved export amount. This is one of the primary use cases where additional performance in the controller may provide benefit.

Each inverter has its own unique irradiance profile, which was acquired from [1]. The irradiance data are acquired by 1 ms measurements that are averaged over a 10 ms period. When the value changes by more than 5 W / m^2 since the last 10 ms interval, the quantity is saved. Then the data are recorded at 1 min intervals. Data between all inverters are time-synchronized by GPS signal and unit-to-unit skew on the synchronization is less than 1 ms. The 24 measurement points have little to no shading due to trees or other large objects that may cast shade [1]. Dips in irradiance should almost all be due to meteorological changes.

During the simulation, each irradiance interval was given a one-to-one time scale, so the simulated inverter received the measured irradiance value for a full minute without any noise or changes within that time period.

V. Results

A. Clear Sky Day

A clear sky day that does not have any significant variation in irradiance provides only one instance during the day when the site approaches the target set point. This means there is also only one instance that provides an opportunity to generate more power than is possible when using slower control settings. Also, because that initial rise is likely slower than the configurable ramp rate, the benefit this one instance offers may not come into play at all. The difference turns out to be less than 0.01 percent between the fastest tested and the slowest tested (see Table I). Therefore, for this type of irradiance profile, there is no benefit to having a faster controller.

TABLE I
ENERGY GENERATED FOR CLEAR SKY PROFILE

Set-Point Calculation Time	Energy Generated
5 s	576,861 kWh
1 s	576,886 kWh
300 ms	576,899 kWh

B. Overcast Day

An overcast day, while it does have some variance in irradiation, is likely to reduce the total amount of power the site can produce in excess of the 10 to 20 percent extra production for which the site is overbuilt. This means that the controller is asking for the maximum amount that the site can possibly produce, but it is still below the maximum that the site is approved to export. The difference turns out to be negligible between the fastest tested and the slowest tested (see Table II). For this type of irradiance profile, there is no benefit to having a faster controller.

TABLE II
ENERGY GENERATED FOR OVERCAST SKY PROFILE

Set-Point Calculation Time	Energy Generated
5 s	40,794 kWh
1 s	40,836 kWh
300 ms	40,841 kWh

C. Variable Day

A day with some significant variance provides more than one opportunity for the site to approach the curtailment or maximum export value. This type of profile is likely to benefit from a faster controller that has more opportunities to bring the site back to a curtailment set point or a maximum export value. The data in Table III show that the 1 s calculation rate offers an approximate 0.5 percent increase from 5 s. But the 300 ms calculation rate only improved by approximately 0.01 percent from the 1 s calculation rate.

TABLE III
ENERGY GENERATED FOR VARIABLE SKY PROFILE

Set-Point Calculation Time	Energy Generated
5 s	451,913 kWh
1 s	454,415 kWh
300 ms	455,237 kWh

D. Very Variable Day

A day that has many significant variances in irradiance also provides many opportunities for a faster controller to bring the site back up to target. This type of irradiance profile also has the greatest risk to overshoot curtailment or maximum export values. For a very variable irradiance profile, there are multiple chances to optimize inverter set points and so there is a significant increase in possible generation when upgrading from 5 s to 1 s controller speeds—an 8 percent increase in kWh. But the increase is only 0.3 percent when going from a 1 s to 300 ms controller speed (see Table IV).

TABLE IV
ENERGY GENERATED FOR VERY VARIABLE SKY PROFILE

Set-Point Calculation Time	Energy Generated
5 s	303,123 kWh
1 s	329,958 kWh
300 ms	330,059 kWh

VI. RESULTS DISCUSSION

Looking at the results for the four different types of irradiance profiles, there is no measurable benefit in generation for the clear day and overcast day with a faster controller. There is some difference identified in the variable and very variable irradiance profiles. The largest benefit comes from increasing the controller set-point calculation rate to one second. The gains beyond one second are minor and would not typically justify the additional cost in metering or engineering effort. And a one-second set-point calculation is a performance level that is often sufficient to achieve many transmission-connected inverter generation regulatory requirements.

A key distinction where performance does show a significant difference in total kWhs produced is in the rate-of-change of the irradiance conditions. The results for the overcast profile show almost no difference between the performance intervals, because the irradiance changes are slow. But the irradiance changes in the variable and very variable profiles, where the irradiance increases are large and quick, offer the best possible environment where increased performance potentially adds benefits by increasing total energy production.

For systems that have set-point calculation rates longer than 1 s, it may be worth evaluating increasing system performance. The results differ significantly based upon the type of irradiance profile, and that the mix of these different irradiance profiles vary over the course of a year based upon geographical location. But if we take an example where each profile represents 25 percent of the year, then a site that calculates set points at 5 s may see up to a 2.25 percent (sunny 0, overcast 0.5, variable 0.5, very variable 8) increase in yearly revenue by increasing calculation rates to 1 s. While many transmission sites are unlikely to have 5 s calculation rates, there are distribution sites where performance due to regulatory requirements is not as stringent, and a 2 percent increase in yearly revenue may make sense to increase the rate at which the power plant controller calculates new set points.

It is important to note that the performance gains in the variable and very variable day profiles will fluctuate within the profile day. There are two aspects which primarily affect the additional generation: the number of variances which occur in a day and the depth of magnitude of a given variance. A variance in the summer may have a peak difference between 400 W/m^2 and 1,200 W/m^2, where a variance in the winter may fluctuate between 400 W/m^2 and 800 W/m^2. As a result, a very variable day in the winter may only represent a 4 percent increase in revenue, while on a summer day it may represent 8 percent increase in revenue. We did not examine the magnitude of variance within a profile day throughout the year of irradiance conditions for this paper.

It is difficult to place an exact dollar amount on the results of these improvements; however, in Table V we provide some rough estimates that show what the potential additional revenue may look like for a site that is allowed to export up to 68.8 MW. For Table V, we assume that each of the four irradiance profiles have equal distribution (we used a leap year because 366 days is evenly divisible by 4 into 92 days for each irradiance profile). For this paper, we did not calculate the typical number of profile days due to wide-ranging irradiance conditions across geographical locations; for simplicity, we instead used an equal distribution of profile days in the following example. We also assume that the results for each day are identical to the test results, not real-world results, but they should suffice for estimating the amount of revenue dollars for this exercise. Each performance category takes the summation of each irradiance profile and then multiplies by 92 to reach the total kWhs for a hypothetical year, which is then multiplied by a wholesale electricity rate of \$.04/kWh [2], as shown in (1).

$$(clear + overcast + variable + very\ variable) \bullet 92 \bullet 0.04 = hypothetical\ yearly\ revenue \quad (1)$$

It is important to note that the price for energy fluctuates significantly based upon geographical location and other factors [2]. For example, (2) shows how we calculated the revenue estimate for the 5 s category.

$$(\$576{,}861 + \$40{,}794 + \$451{,}913 + \$303{,}123) \bullet 92 \bullet 0.04 = \$5{,}051{,}502.88 \quad (2)$$

TABLE V
ESTIMATED YEARLY GENERATION REVENUE

Set-Point Calculation Time	Energy Generated
5 s	\$5,051,502.88
1 s	\$5,159,709.60
300 ms	\$5,166,852.48

For the 5 s to 1 s improvement for a 68.8 MW site, the benefit in increased revenue may be in the range of approximately \$108,000 per year. This paper does not explore what it may cost to increase performance from 5 s to 1 s, but in the authors' experience the potential cost in additional equipment and engineering is likely to be significantly less than the generated revenue for a single year. For the 1 s to 300 ms improvement, upgrading is likely to result in less than \$10,000 of additional revenue. Therefore, the additional equipment and engineering necessary to reach that performance target is unlikely to justify the additional revenue in this case.

VII. PERFORMANCE UPGRADES

We do not cover the full scope of what is potentially necessary to meet various performance standards for the overall system in this paper. There are many factors that affect the rate at which the power plant controller generates new set points [3]. However, here are a few examples of what performance related upgrades may look like.

1. The point of common coupling (PCC) meter is polled at 5 s, updating the polling of PCC meter to 1 s. A new type of poll may need to be configured to adjust for the speed, perhaps deadbands in the meter need to be adjusted, or a small group of data reported to the power plant controller. The increase to certain performance levels may only require settings and engineering work [3].
2. Set points to inverters take 5 s to be distributed over a serial EIA-485 two-wire network shared by 20 different inverters. To make set-point distribution 250 ms or faster, each inverter requires its own dedicated serial line. This increase in performance may require settings work and wiring additional cabling to each inverter from the power plant controller [3].
3. PCC meter is polled at 1 s; update polling of PCC meter to 200 ms. The meter does not support sending new data values at 200 ms. A new meter that supports synchrophasors may be required to send data values at 200 ms. This increase in performance may require a new meter, plus a GPS clock, and additional communication equipment [3].

VIII. ANCILLARY SERVICES

We do not take into account the potential financial benefits of installing a faster control system that can also provide certain ancillary service revenue benefits against the increased cost of said system described in this paper. Common ancillary services include frequency regulation, FFR, reserve capacity (spinning and non-spinning reserves), and voltage support. These additional services may only occasionally be called upon by the generation site in special circumstances. A good example of a service that requires high speed control is FFR. For instance, Electric Reliability Council of Texas (ERCOT) requires that the corresponding increase in real power output be deployed in 30 cycles (approximately 500 ms) after the criteria for FFR are detected.

IX. CONCLUSION

In this paper, we show that once the performance requirements have been met for utility connections, independent system operators, or regulatory requirements, there is likely negligible benefit, in the form of increased generation revenue, to add additional equipment or engineering to the system to further increase the performance of the power plant controller. The exception being systems with set-point calculation rates longer than 1 s. These systems may be worth evaluating for potentially increasing their performance. It is important to note that the overall responsiveness of the generation site is not solely based upon the rate at which the power plant controller calculates new set points. There are a whole host of factors, including metering equipment, communications equipment, the power plant controller, and the inverters, that determine the total system performance. Another important factor, which affects results, is that the variance of irradiance within the profiles highlighted in this paper vary significantly across geographical locations. And it is important to note that the performance numbers highlighted in this paper were from a single geographical location and single-day irradiance datasets recorded across the different types of profiles. The results identified in this paper could vary depending upon these factors. Generation site owners, prior to design and equipment selection, should identify the performance criteria necessary and then design and pick equipment that meets those requirements. Once the equipment has been selected, performance should be maximized, based upon the technology available, to provide a little margin on the specified requirements for the generation site.

X. References

[1] Government of Canada, "High-Resolution Solar Radiation Datasets," January 2025. Available : https://natural-resources.canada.ca/energy-sources/renewable-energy/high-resolution-solar-radiation-datasets.

[2] U.S. Energy Information Administration (eia), "Electricity Monthly Update: Regional Wholesale Markets," June 2025. Available: https://www.eia.gov/electricity/monthly/update/wholesale-markets.php#:~:text=Most%20regions%20east%20of%20the,an%20early%20summer%20heat%20wave.

[3] D. Anichkov and B. Waldron, "Case Study: Phasor-Based Control for Managing Inverter Generation," proceedings of the 57th Annual Minnesota Power Systems Conference, St. Paul, MN, November 2021.

XI. Biographies

Bakhtiar Kabir is a P.E., M.E., and PMP and a senior electrical and project engineer with over 15 years of experience in high voltage generation, transmission, and distribution and in the renewable energy industry. He has been involved with the development, engineering, construction, and operation of over 1 GW of renewables projects across the U.S. and Canada. His expertise includes power system designing and modeling, protection and control, automation, interconnection, and operation oversights. He holds a Master of Engineering in Electrical and Computer Engineering with Energy and Environment Specialization from the University of Calgary.

Mark Phillips is a senior SCADA technologist with over 15 years of experience in the electrical, instrumentation, and automation industries. He has worked across a range of sectors, including renewables, oil and gas, and water utilities, delivering reliable and efficient control system solutions. Mark specializes in the design, integration, and commissioning of SCADA and automation systems that enhance operational performance, improve safety, and support sustainable infrastructure.

Brian Waldron is a senior automation engineer with Schweitzer Engineering Laboratories, Inc. (SEL). He has over a decade of experience in designing and troubleshooting automation systems, communications networks, and distributed energy resource (DER) control systems. He has authored several technical papers, application guides, and teaching presentations focused on integrating automation products. Brian graduated from Gonzaga University with a BS degree in electrical engineering

20251013 • TP7238-01