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Comparing control strategies in curtailment environments

Lab simulation data shows how control system techniques can substantially impact energy yield for utility scale PV projects

by Mesa Scharf, Adam Marshall, and Zac Wenrick

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Mesa Scharf is the Vice President of Product Management at AlsoEnergy. Mesa brings nearly 20 years of experience in the alternative energy industry, including 9 years with Advanced Energy, where he helped design control and monitoring solutions for some of the largest solar plants in North America. Mesa holds a BSEE from Oregon State University, is a member of the IEEE, and has five granted patents.

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Zac Wenrick

Zac Wenrick is a Controls Engineer who has designed and commissioned PV plant control applications for a variety of projects throughout his 6 years of employment at AlsoEnergy. Zac is responsible for developing the core algorithms of our Dynamic Energy Harvest Optimization feature and integrating those algorithms into the existing control model framework. Zac holds a BSEE from the University of Colorado.

The essential challenge of grid-tied utility PV assets is to hit performance benchmarks while managing grid compliance. As curtailments come to more markets, and as interconnection requirements become more complex, this is creating real challenges for owners and asset managers trying to drive project profitability.

Executive Summary

Plant control logic can have a significant impact on energy harvest. This is especially true in markets where curtailments and/or ramp rate limitations are imposed by the utility, and on days where variable weather and cloud cover cause large disparities in the available power among inverters.

AlsoEnergy used lab simulations to compare daily production for a plant built to 26.6MWac capacity. We compared 3 control techniques: inverter-based control, inverter group control at the POI, and AlsoEnergy's Dynamic Energy Harvest Optimization, which enables independent inverter control at the POI. The test environment simulated a typical, mostly sunny day in Hawaii with partial shading as clouds pass by. The plant's real power ramp rate limit was set at 2 MW per minute up to a plant curtailment limit of 20 MWac per terms of the interconnection agreement.

Bottom line ROI results →

In our simulation the inverter-based control technique generated the lowest yields and serves as a baseline for other model results. The POI-based group inverter control technique generated 1.5% more production relative to baseline, corresponding to a $42,000 increase in estimated annual returns (based on $50/MW pricing). Dynamic Energy Harvest Optimization produced the best results, generating 3.7% more relative to baseline, corresponding to an estimated $102,000 increase in annual returns.

Challenges for Utility PV on Today’s Smart Grid

To illustrate the underlying challenge for Utility PV owners, look at some real data from a plant in Hawaii with 5 central inverters:

Fig. 1 Central inverters reacting to variable spatial irradiance. Actual site data, Hawaii

Figure 1 shows the performance of five inverters at a site monitored by AlsoEnergy’s PowerTrack Platform. Shortly past 7 am, all five inverters begin to ramp, producing the start of a typical sunny day. A little after 8 am and then again after 9 am, cloud cover disrupts performance of all five inverters. After 10AM, however, you can see that some central inverters are at or near full capacity while others are dropping precipitously. This indicates variable spatial irradiance, meaning different cloud coverage, and therefore fuel availability, over different parts of the array. Variable spatial irradiance poses a challenge for plant controllers managing more than one inverter.

Since most PV plants are built with excess capacity, some inverters are able to ramp up to compensate when one or more inverters exhibit diminished production. However, when you add in constraints like interconnect limits and ramp rate constraints, and you see how fast the dynamics of cloud cover impact a site like this, it becomes clear that optimizing energy harvest under all conditions can be a real challenge. SCADA system design at the plant controller level governs how the system reacts to this complex challenge.

This can be a particularly difficult issue for owners because control system procurement is typically managed by the EPC. EPCs are not financially incentivized to invest extra time or effort to ensure that the system optimizes performance; on the contrary, because they must satisfy the utility that the project will meet control and curtailment requirements in order to pass the commissioning process, they may be inclined to err on the side of caution, restricting production more than necessary.

How your plant controller addresses this challenge can have a significant impact on project returns. We constantly advise owners that they must get involved early and advocate for their long-term operational interests during the SCADA system design process. Choice of who provides the control system, and how they design it, can have a big impact on energy harvest and overall project returns.

What is Needed

Control integrators have taken several approaches to this challenge over the years. Initially, they would manage real power primarily by hardcoding ramp and capacity limits within each inverter so that the entire system can never exceed the maximum limits defined in the agreement. Though simple on the implementation side, this approach undercuts asset performance. Any time one inverter goes down, the capacity on adjacent inverters can only get to the hardcoded limit of the inverters that continue to run, even if available irradiance allows for better production. The same problem occurs with partial shading. As output drops for one section of the project, or a few of them, rate- limited sections with excess capacity cannot compensate for the loss.

The next level of sophistication is power plant control at the point of interconnection with group set points for a collection of inverters (POI group control). In this case, the project has gained some compensation capabilities. If one inverter goes down, the controller will ramp other inverters up. The controller can also compensate to some degree for partial shade on one of the arrays. However, with POI group control, system design is limited to group set points rather than individual set points for each inverter. As a result, site performance goals still take a back seat in the tradeoff with interconnect limits, limiting how much energy a project actually gains.

Dynamic Energy Harvest Optimization →

What is needed is a flexible control system allowing inverters to ramp independently as fast as technical specifications allow while maintaining systemwide limits. AlsoEnergy has developed this system in the form of proprietary algorithms configured at the plant controller level. We call this control technique Dynamic Energy Harvest Optimization, and it is available with our RTAC based plant controllers.

With Dynamic Energy Harvest Optimization, the power plant controller (PPC) sends a closed-loop control signal to all the inverters to ramp, then measures if each inverter actually ramps as directed. If one responds too slowly for any reason, perhaps due to shading or because it's offline, the controller signals additional capacity for other inverters to increase power output until the system reaches its ramp rate limit. By continually tracking individual inverters, the system delivers an automatic response anytime a single inverter becomes resource constrained. In this case, inverter ramp rate is dynamic.

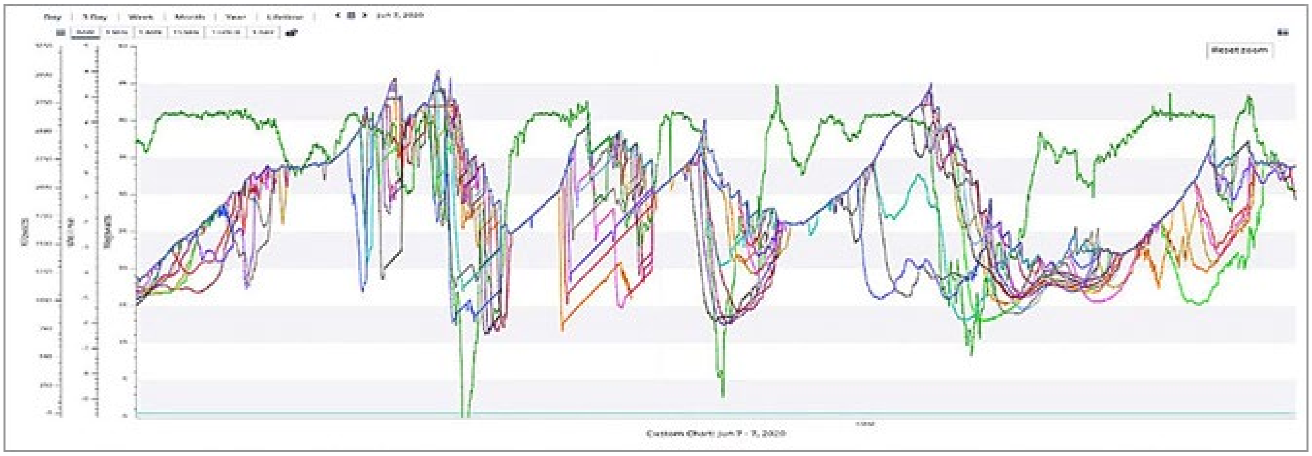

Fig. 2 Dynamic Energy Harvest Optimization: actual site data, Hawaii

The performance impact can be significant. Fig. 2 shows inverter production data from an actual site in Hawaii, where an AlsoEnergy plant controller is using Dynamic Energy Harvest Optimization. You can see the complex range of inverter activity in response to cloud cover. Sudden power drops appear as clouds shade portions of the solar array tied to individual inverters.

The chart shows dynamic ramp rates as inverters with more irradiance ramp faster to compensate for inverters with less irradiance ramping at a slower rate. Steep upward slopes indicate inverters ramping at a very fast rate during periods when a large number of the other inverters are experiencing diminished production. The power curves in Fig. 2 show that ramp rates for individual inverters frequently exceed 200 kW per minute, compensating for diminished production among the other inverters, helping the system maximize generating capacity.

Dynamic programming of power setpoints for individual inverters enables faster ramp rates. Inverter based control and POI group control create rigid restrictions for the power setpoints of individual inverters, leaving the system to run below capacity for longer than necessary, thereby diminishing energy harvest.

Table 1 outlines the major pros and cons for each of the competing control techniques:

	Inverter Based Control	POI Group Control	Dynamic Energy Harvest Optimization
Pro	• Simple implementation • Can be accomplished for simple projects without a plant controller • Control interactions easier to manage	• Straightforward implementation • Compensates for down inverter • Enables optimization to POI (PPA)	• Compensates for down inverter • Compensates for partial shade • Enables optimization to POI (PPA)
Con	• Conservative • Significant impact on • Energy harvest • Down inverter • Partial shading	• Impact on energy harvest • Partial shade • Limited optimization potential	• Non-trivial implementation

Table 1: Comparison of techniques for real power control

Lab Simulation Testing

Using Simulink, a MATLAB-based graphical programming environment, and the simulation tool SIMUL8, AlsoEnergy compared the performance of Dynamic Energy Harvest Optimization, POI group control, and controls hardcoded at the inverter level.

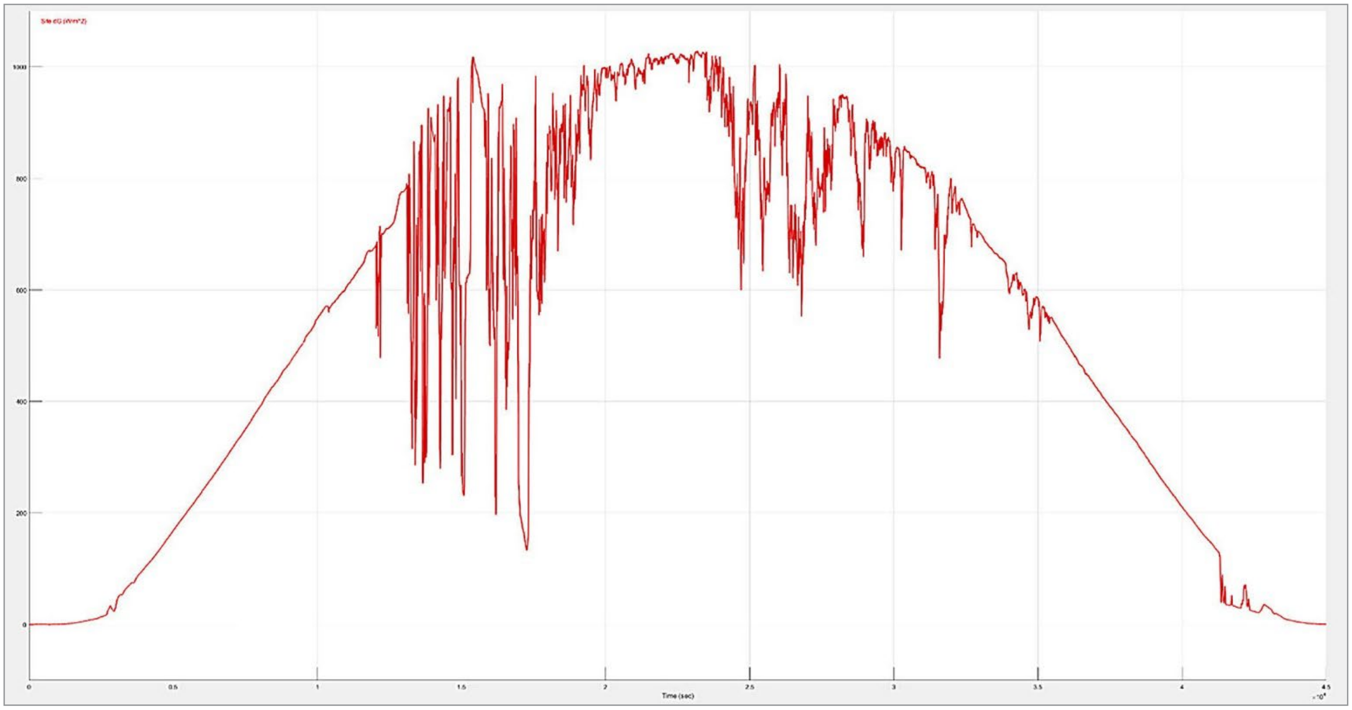

Fig. 3 Irradiance model used for lab simulations

AlsoEnergy's analysis used data from a solar project built to 26.6 MWac capacity, served by seven 3.8 MWac central inverters. Per the interconnection agreement, the plant's real power ramp rate limit is 2 MW per minute up to a plant curtailment limit of 20 MWac. Therefore, the plant setpoint was held at a curtailment limit of 20 MW, or about 75 percent of total capacity.

As model inputs, the analysis used one full day of real irradiance data, taking an average of two metering stations collected from irradiance monitoring stations distributed across the site. The irradiance model for the simulation is shown above.

The test environment simulated a typical, mostly sunny day in Hawaii with an asymmetrical fuel profile representing typical cloud conditions. In the asymmetrical model a region of the PV power plant remains relatively unshaded while partial shading affects one inverter in the shade area more than the others. This scenario allows a full demonstration of the compensation capabilities for each control technique.

Under the asymmetrical load scenario, two inverters receive fixed irradiance (effectively in the sun or filtered sun all day), one at 1,000 W per m^2 and another at 800 W per m^2. This simulates a scenario where there is a relatively unshaded region of a large PV power plant. Additionally, one of the inverters undergoing partial shade according to the profile above is offset in time by 42 seconds from the other inverters The remaining four inverters experience shading with a 4-second delay each.

The asymmetrical model also includes a sequence to test for highly cloudy days with some differentiation in time-staggered partial shade, and some differentiation in irradiance magnitude at some PV arrays. In this sequence, each inverter sees some time delay relative to when the cloud front initially affects unit 1.

The delays and irradiance measurements are as follows:

Inverter	Delay	Irradiance
Unit 1	4 seconds	Fixed 1000 W/m^2
Unit 2	8 seconds	Fixed 800 W/m^2
Unit 3	4 seconds	Nominal irradiance curve
Unit 4	8 seconds	Nominal irradiance curve
Unit 5	12 seconds	Nominal irradiance curve
Unit 6	16 seconds	Nominal irradiance curve
Unit 7	42 seconds	Nominal irradiance curve

Table 2: Cloud effect variables: delays and irradiance measurements across 7 inverters.

Results

Side-by-side comparisons show that under an asymmetrical load scenario, dynamic ramp rate controls outperform inverter controls and group controls.

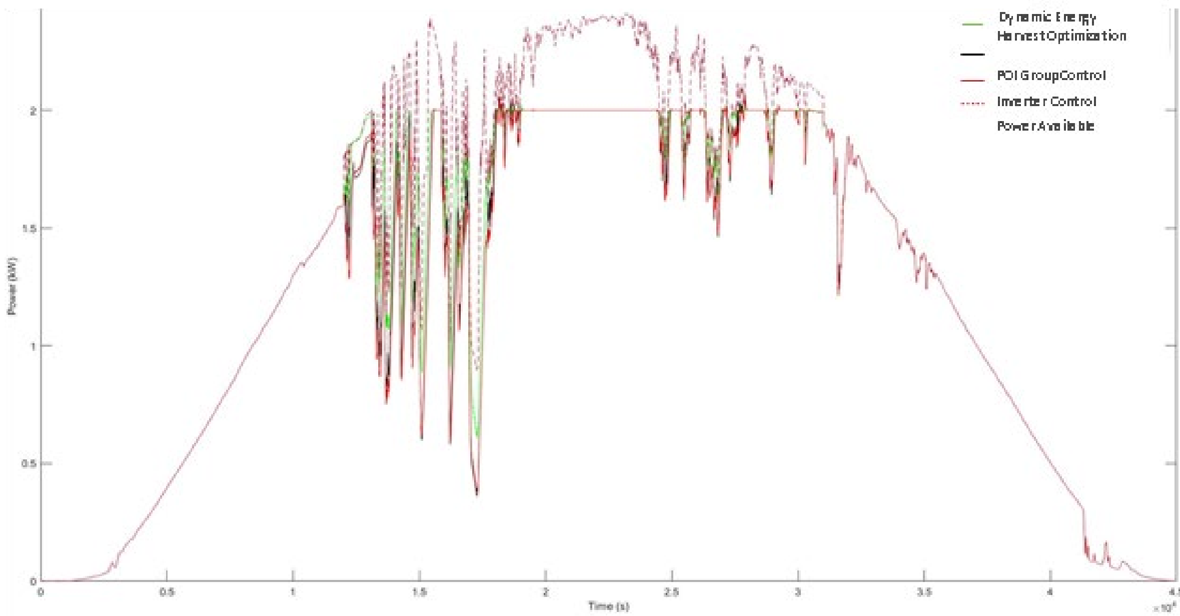

Fig 4: POI Power & Available Power - full day

In the graph above, the inverter control technique is represented by the solid red line. The POI-based group inverter control technique is the black line, and AlsoEnergy's Dynamic Energy Harvest Optimization model is represented with the green line. Total available power is represented by the dashed red line.

Note that during almost all parts of the day when available power exceeds output limits at the POI, the performance among the competing models is identical (the one exception is the brief period after available power climbs above the output limit while inverters adjust to the changing irradiance conditions). At times when there is no significant shading anywhere on the array, there is no need for any inverters to compensate for underperformance in other parts of the system. In these conditions, each inverter is able to contribute their expected portion toward the total allowed output at the POI.

The difference in performance among the control techniques becomes apparent, however, when available power dips below the output limit for the system. During these periods, the yield for Dynamic Energy Harvest Optimization are consistently higher than the yields for the other two techniques. As clouds pass over, some inverters experience diminished production. Dynamic Energy Harvest Optimization allows each inverter to respond independently while ensuring that total system output levels are maintained at the POI. This enables the system to fully leverage the capacity of unshaded inverters to compensate for localized production shortfalls in other parts of the array.

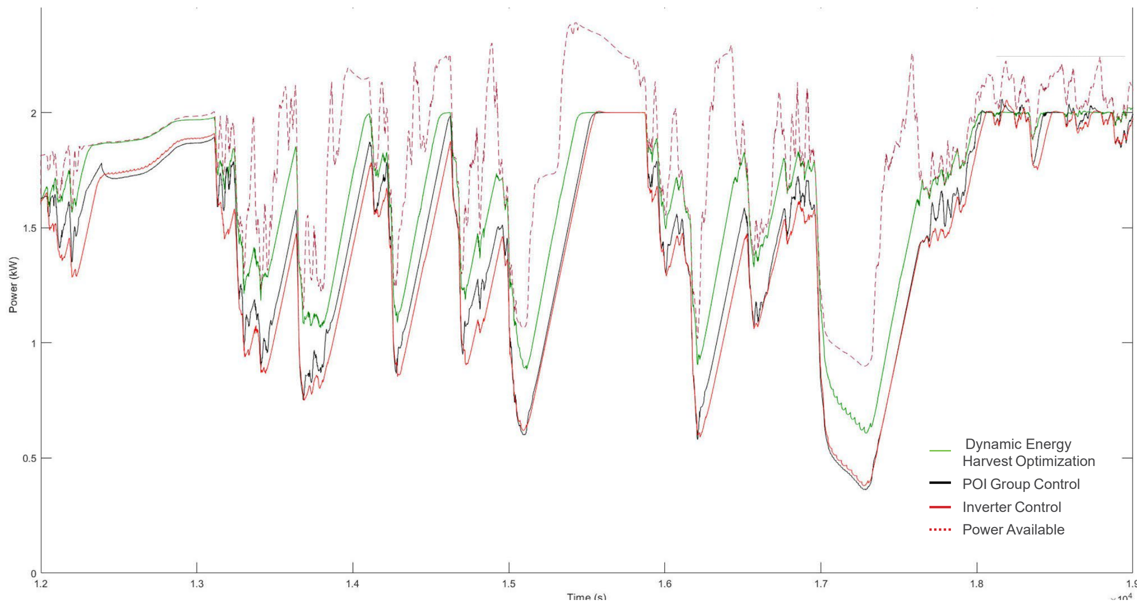

Fig. 5: POI Power & Available Power 12000 to 19000 sec

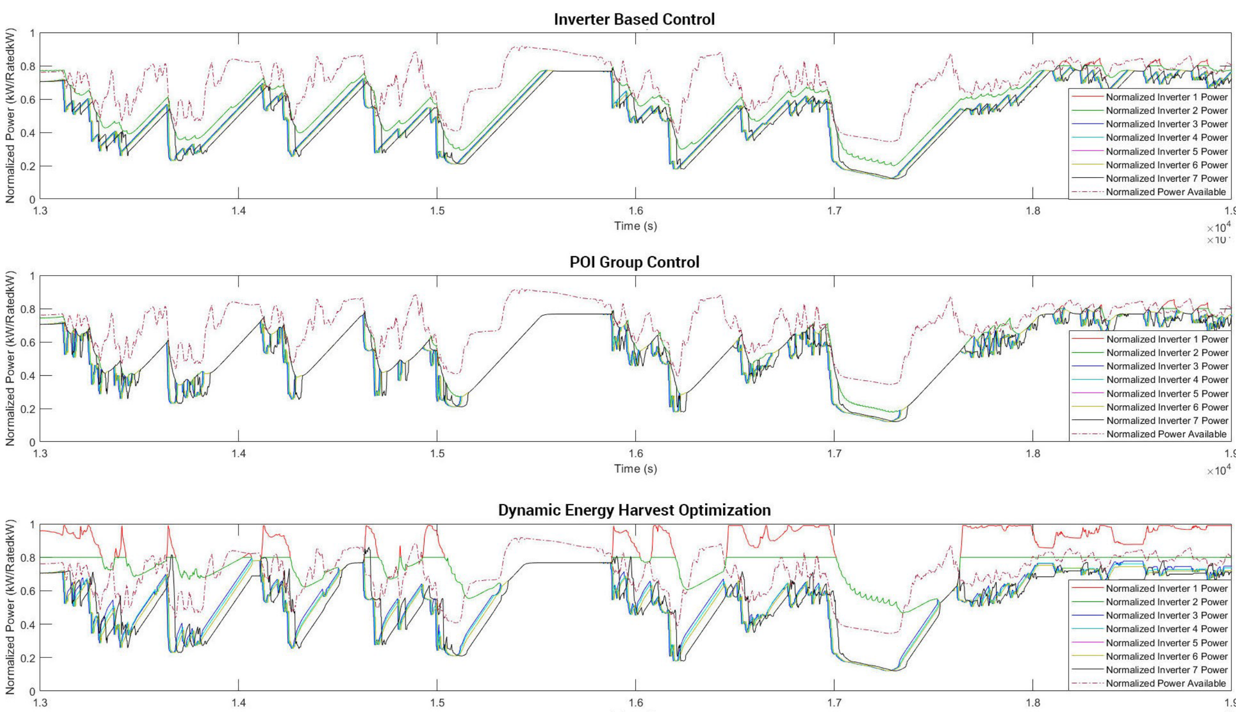

Fig. 6: Inverter Normalized Power and Normalized Irradiance 12000-19000 seconds

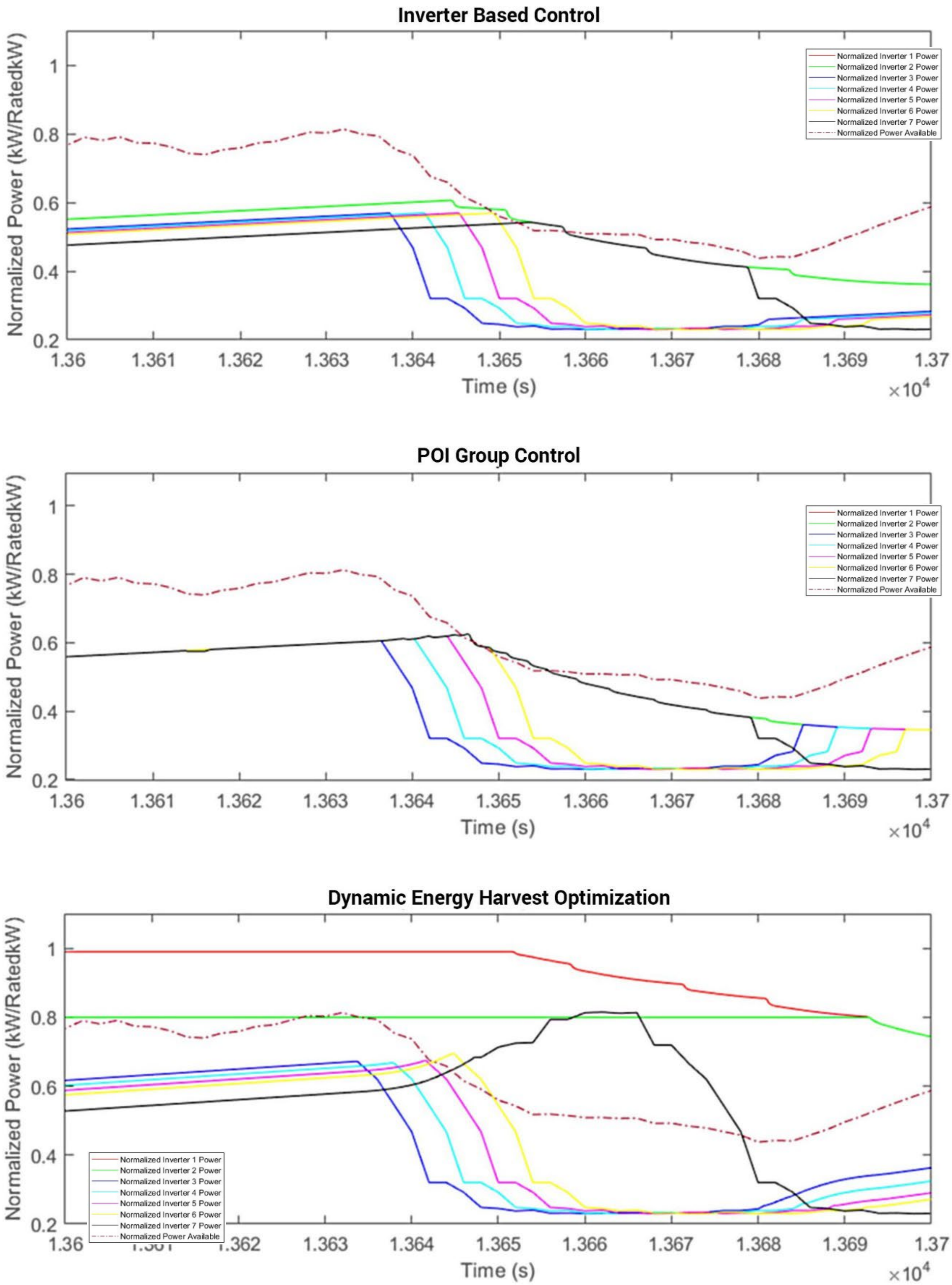

Fig. 7: Inverter Normalized Power and Normalized Irradiance-13600-13700 seconds

The stacked graphs in figure 7 clearly show the variation in inverter behavior among the control techniques. The dashed red line representing normalized power available remains constant across the three graphs, but inverter behavior across the models is very different.

Using Dynamic Energy Harvest Optimization, you can see that inverters 1 & 2 (red and green lines), in the unshaded portion of the array, are in a state of higher production throughout the time window as they compensate for the diminished production of shaded inverters. Within the shaded portion of the array, inverter 3 (black line) has the most available sunlight, so you can see that inverter increasing production as inverters 4-7 progressively experience cloud cover.

The graph below most clearly reveals the impact on your bottom line, showing total system yield over a time window of about 2 hours:

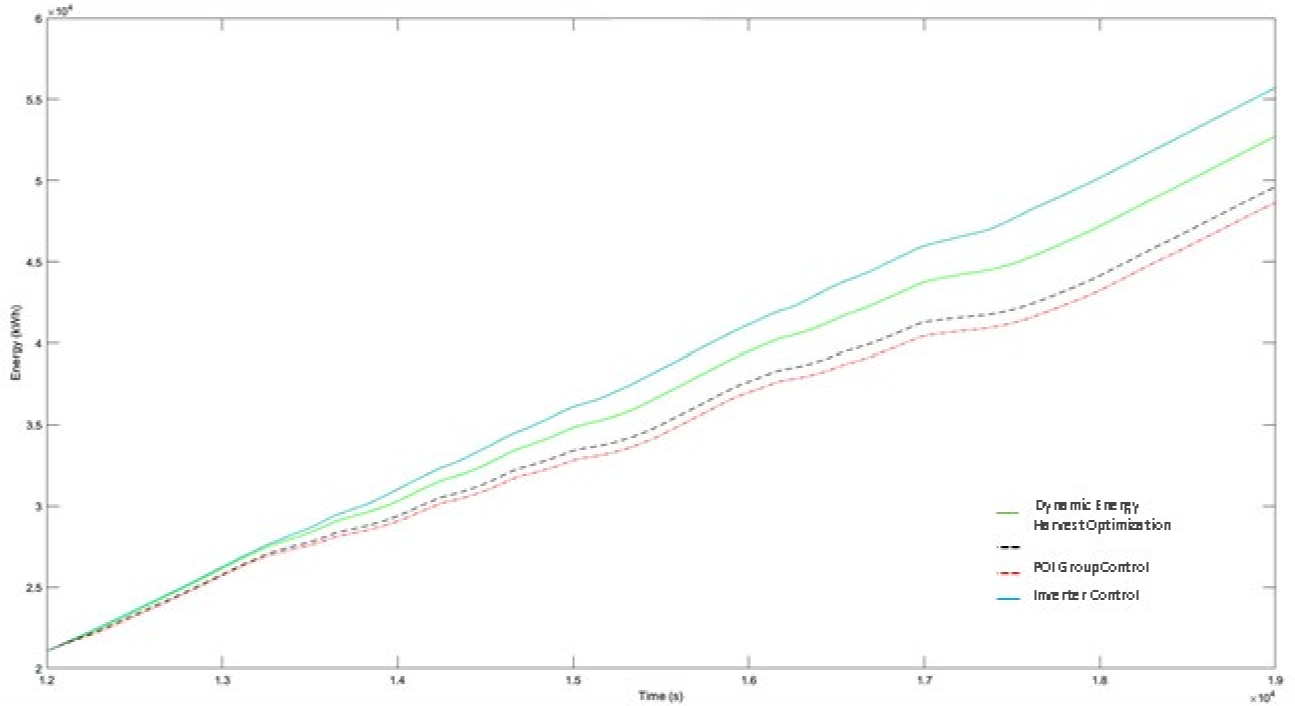

Fig. 8: 12000-19000 seconds

Conclusion

Plant control logic can have a significant impact on energy harvest. This is true for interconnections that have active curtailment and ramp constraints and becomes more pronounced in regions with highly variable irradiance.

Dynamic Energy Harvest Optimization is AlsoEnergy's answer to this problem. The control technique enables inverters to ramp independently thereby providing a means to optimize energy harvest while meeting interconnection constraints. Dynamic Energy Harvest Optimization outperforms traditional inverter-based control and POI group control techniques.

For the 20 MWac curtailed project in this analysis, the added energy harvest gained by switching from inverter-based control to the POI group control model yielded an estimated additional $42,000 per year. Dynamic Energy Harvest Optimization resulted in the best outcome, providing an estimated gain of $102,000 per year.

Method	Daliy energy (MWh)	Yield increase from base case (%)	Incremental revenue vs base case ($50/MWh)
Inverter based control	149.7	+0%	0
POI group control	152.0	+1.5%	$42K/yr
Dynamic energy harvest optimization	155.3	+3.7%	$102K/yr
Ideal	157.7	+5.3%	$146K/yr

Table 3: Simulation results

Note the results of this lab simulation reflect outcomes for a scenario in which the project is overbuilt on the DC side, it is subject to curtailments both for total power output and for ramp rate, and the array is experiencing asymmetrical cloud cover. These are common project conditions in a place like Hawaii, but they do not apply equally to all systems in all locations. To better understand the potential gains your projects can achieve using Dynamic Energy Harvest Optimization, we invite you to start a conversation with our Technical Sales Engineering team.