INVERTER SIZE OPTIMIZATION FOR GRID-CONNECTED CONCENTRATOR PHOTOVOLTAIC (CPV) PLANTS

Xu Chen[1], Jane Melia[1]
[1]SolFocus, Inc., Mountain View, California, USA

ABSTRACT

Concentrator PV systems utilize different part of solar irradiation arriving at the Earth's surface and typically generate different power profiles than traditional flat plate PV or thin film. These factors need to be taken into account during plant design, particularly for inverter sizing strategies, and will result in very different inverter size/ rated DC power ratios than flat plate PV systems.

This paper describes a methodology for sizing inverters for CPV power plants that optimizes the financial return of a project, taking into account energy generation profiles and financial parameters for large scale projects. Using hourly CPV power output throughout the year for a number of locations with high Direct Normal Irradiance (DNI) in southwest US, the optimal inverter size to maximize financial return over the project term is determined taking into account the magnitude and financial value of inverter energy clipping, capital and on-going costs and other project financial parameters. This analysis demonstrates the value of inverter sizing to CPV rated power ratios at or close to 1:1 at CPV standard operating condition (SOC) rating (850W/m2 DNI, 20°C Ambient, On-Sun), or 1:1.25 at standard testing condition (STC) rating (1000W/m2 DNI, 25°C Cell).
Concrete examples of how this methodology was applied to several commercial and planned SolFocus sites are presented.

INTRODUCTION

Concentrator PV systems utilize different part of solar irradiation arriving at the Earth's surface and typically generate different power profiles than traditional flat plate PV or thin film. These factors need to be taken into account during plant design, particularly for inverter sizing strategies, and will result in specific inverter size/ rated DC power ratios different than flat plate PV or thin film systems. The solar project development and investment sector has been evaluating inverter sizing strategy based on the trade-off of lost energy through inverter "capping" and capital expenditure savings through smaller inverter sizing. The same approach can be applied to CPV projects and provide optimization for inverter sizing design.

This paper describes a methodology for sizing inverters for CPV power plants that optimizes the financial return of a project, taking into account energy generation profiles and financial parameters for large scale projects. Using hourly CPV power output throughout the year for a number of high DNI locations in southwest US, the optimal inverter size to maximize financial return over the project term is determined taking into account the magnitude and financial value of inverter energy clipping, capital and on-going costs and other project financial parameters.

DESCRIPTION OF OPTIMIZATION METHODOLOGY

Goal and Steps

The purpose of the optimization is to identify an ideal inverter sizing strategy (e.g. the ratio of inverter capacity over CPV power rating) for SolFocus CPV projects. Inverter sizing impacts a CPV project in the following two ways:

1. Inverter sizing determines the AC power and energy output of a CPV project. When the aggregate DC power output from the CPV systems exceeds the inverter capacity, energy "clipping" or "capping" will happen, resulting in additional loss to the energy output potential. Different inverter sizing ratios will yield different AC energy output for the CPV project, hence impacting the energy harvest and energy revenues over the course of the project term.

2. The inverter is also a significant portion of the capital expenditure required for completing a CPV project. Using different inverter sizing ratios directly impacts the initial capital expenditure amount, hence the financial returns for the project from time zero.

The goal is to identify the optimal inverter sizing ratio that maximizes a project's financial return. This may result in some energy loss due to "capping". In order to reveal the optimization dynamics, a pro-forma financial model is created to reveal the impact of different inverter sizing on financial returns while the energy sacrifice (or "inverter capping loss") is summarized for different inverter sizing ratios. The results from the analysis in terms of financial returns and energy losses are compared for multiple locations in order to extrapolate optimization guidelines.

Sites and Climate Data

Five sites in the Southwest United States are chosen for the financial optimization analysis. A brief description of the six sites is summarized in the following table.

City Name	**Annual Average Direct Normal Irradiation**	**Source of Solar and Climate Data**
Albuquerque, NM	6.7 kWh/m2-day	TMY3 (NSRDB)
Phoenix, AZ	6.9 kWh/m2-day	TMY3 (NSRDB)
Alamosa, CO	7.1 kWh/m2-day	TMY3 (NSRDB)
Boulevard, CA	7.2 kWh/m2-day	Solar Power Prospector (NREL)
Daggett, CA	7.5 kWh/m2-day	TMY3 (NSRDB)
Ridgecrest, CA	7.8 kWh/m2-day	Solar Power Prospector (NREL)

The five sites together are representative of the high DNI regions in the US where CPV will have a very strong performance. For ease of analysis, a generic 1MW-DC SolFocus CPV plant is assumed with a standard square-shaped layout. For each site, either TMY3 or NREL's Solar Power Prospector data are used to model pre-inverter energy output from the generic CPV plant.

Energy Modeling

The pre-inverter power output (DC output) for each site is calculated with the propriety and industry-leading SolFocus Engineering Energy Calculator (SEEC), using the hourly solar and climate data referenced previously. SEEC was reviewed in depth by an independent third party engineering company who concluded that "the SEEC modeling software is a sophisticated tool for estimating energy production from SolFocus systems. It is a more flexible and advanced than most "single point efficiency" models that are currently used in the market [1]. SEEC is tailored towards shading analysis which aids in site layout design." More information on SEEC can be found in (McDonald and Dittmer, 2009).

The hourly pre-inverter energy output data are then gathered in Excel, upon which the inverter "cap" is applied. Consequently a table of annual energy outputs in correspondence with different inverter sizing ratios can be created for each site. The inverter capping loss can be extracted from the ratios of the energy outputs over the output under a non-capping scenario. The following table shows an example:

Energy Performance by Inverter Sizing Ratio (Daggett, CA)	
Inverter Sizing Ratio (Inverter Capacity/CPV Rating)	Energy Performance (% of Non-Capping Scenario)
85%	95.49%
90%	97.76%
95%	99.14%
100%	99.77%
105%	99.98%
110%	100.00%
115%	100.00%
120%	100.00%
125%	100.00%

Financial Modeling

With the energy outputs the financial analysis is conducted based on a typical Power Purchase Agreement (PPA) financial structure with a project term of 25 years. In this structure, a project owner pays the initial capital expenditure for completing the CPV project in returns of 25 years of electricity revenues based on the energy outputs (kWh-AC), subtracting annual O&M and other expenses. For ease of comparison, the financial structure is assumed to be "unlevered" (e.g. no debt financing).

The initial capital expenditure assumptions are based on SolFocus's current pricing for the CPV systems in its commercial and planned projects, as well as the inverter prices currently available to SolFocus and its customers. Generic assumptions on O&M cost, insurance, monitoring, and administrative costs are also included in the pro-forma analysis.

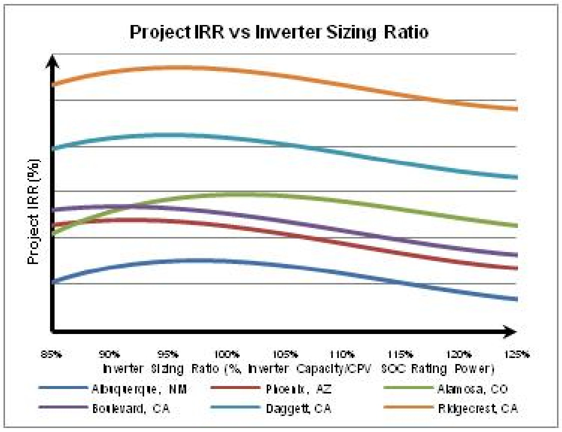
The Internal Rate of Return (IRR) is used as the evaluation metric. As a normalized ratio not directly influenced by the scale of investment, IRR allows comparisons among projects with different initial capital expenditures. IRR is also a better indication of financial attractiveness in a capital-constrained environment, in which the majority of world economy essentially still operates in. For each inverter sizing scenario at each site, the IRR is calculated and tabulated against the corresponding inverter sizing ratio.

OPTIMIZATION RESULTS

By tabulating the financial and energy analysis results, an optimal inverter sizing strategy and guideline can be For simplicity, the analysis results are tabulated based on CPV standard operating condition (SOC) rating (850W/m2 DNI, 20°C Ambient, On-Sun).

IRR Optimization

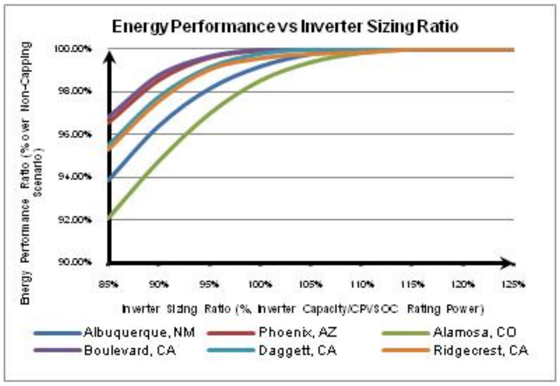
By plotting the IRRs against the inverter sizing ratios for each site, the optimal inverter sizing ratio can be identified where the project IRR peaks. The following chart depicts the IRR curves against inverter sizing ratios for the six sites:



From the chart it is identified that the IRR curves peak within the inverter sizing ratio range from 90% (Boulevard, CA) to 102% (Alamosa, CO). The peak indicates the ideal inverter sizing ratio at which the trade-off between energy “capping” loss and initial capital expenditure hits the balance and the financial efficiency of the project is maximized. It can be concluded from the chart that, in average, a 100% inverter sizing ratio (e.g. 1:1 inverter sizing) is recommended for the best financial returns across a wide range of geography in the southwest US.

A Check on Energy and Performance Losses

The next step to validate the adoptability of the 1:1 sizing is to assess the potential impact of smaller inverter sizing on the power and energy performance. This is also financially relevant due to performance ratio warranty and guarantee generally available for customers and projects. As the following chart shows, by following a 100% inverter sizing ratio, the annual energy loss due to inverter “capping” is generally minimal across the sites, supporting the conclusion made through IRR maximization.



Inverter Sizing Strategy

Combining the findings on the IRR optimization and energy performance loss analysis, it is concluded that the optimal inverter sizing ratio is about 100% based on CPV standard operating condition (SOC) rating. This translates to an optimal inverter sizing ratio of 80% based on standard testing condition (STC) rating. In practice, the availability of commercially available and CPV-compatible inverters in terms of size intervals has to be taken into account. However, a ratio of inverter capacity over CPV rating as close to the optimal ratio as possible will in general provide the best financial returns to the project investors.

SolFocus CPV Inverter Sizing in Practice

SolFocus has been following the optimal inverter sizing strategy for several of its commercial and planned projects. A summary of the projects is presented in the following table:

Project/ Location	CPV SOC Rating (kW-DC)	CPV STC Rating (kW-DC)	Inverter Size (kW-AC)	Inverter Sizing Ratio (%) SOC Rating
A/California	1,041	1303	1,000	96%
B/California	1,238	1550	1,250	101%
C/California	1,136	1422	1,075	92%
D/Arizona	397	497	400	101%
E/California	1,035	1296	1,000	97%

CONCLUSION

By evaluating expected financial returns for CPV projects in high-DNI regions in the southwest US at different inverter sizing ratios, an optimization analysis was done to identify the optimal inverter sizing ratio that allows the project to have the maximal IRR. The analysis results strongly support an optimal inverter sizing ratio of about 100% based on CPV standard operating condition (SOC) rating, or 80% based on standard testing condition (STC) rating. In addition, the energy losses due to such sizing are determined to be minimal, validating the adoptability of the sizing strategy.

REFERENCES

[1] *SolFocus Technology Review Report*, Black & Veatch, March 2010, Section 7.2.

[2] M. McDonald and J. Dittmer, “Accurate Energy Predictions for Tracking HCPV Installations”, *24th European Photovoltaic Solar Energy Conference*, 2009, pp. 4193 – 4198.