APPLICATION NOTE

Conext RL PV Inverters: Superior energy harvest and return on PV system investment

By Prasad Rao and Ranjeet Kuberkar

Abstract

An inverter is the heart of a solar PV installation and it plays a critical role in maximizing energy harvest.

Competitor PV inverters with varying feature sets are available in the market; each with various claims for maximizing energy harvest. However, it is difficult for a home owner to understand what features constitute a truly flexible and efficient inverter that maximizes energy harvest and return on PV system investment.

This application note presents an easy to understand approach to the issue of energy harvest maximization. The approach encompasses design as well as operation aspects of the PV plant. With an analysis of a few typical installation situations, this document illustrates how Conext RL, with its superior feature set, can help harvest up to 10% or even more additional energy when compared to lower quality and lower cost competition inverters.

Introduction

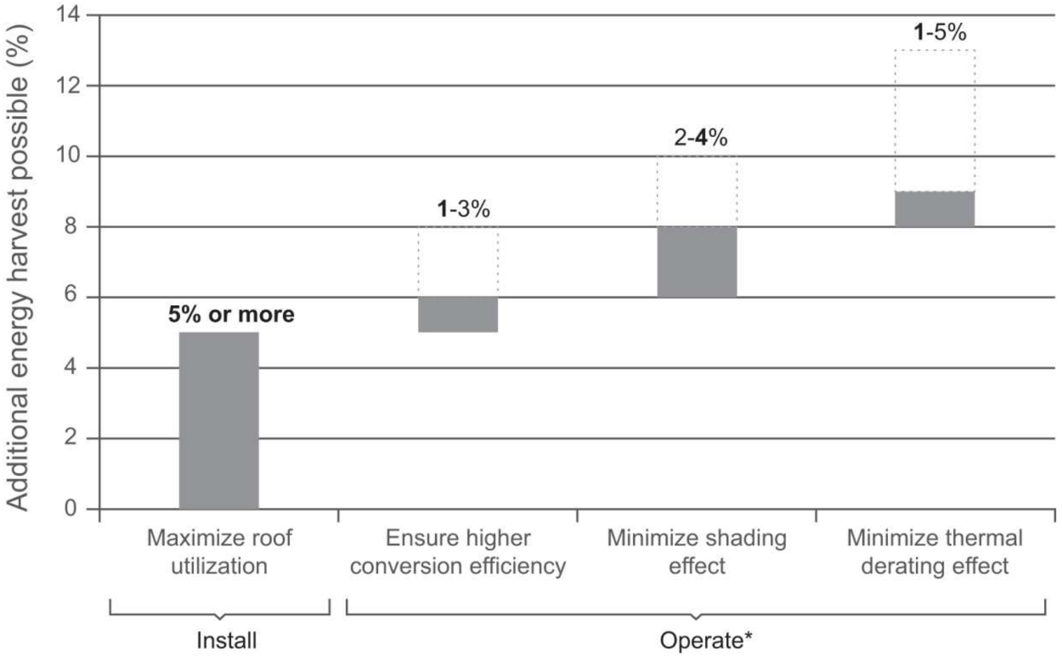
PV inverters are relatively small but critical part of a larger investment in a PV energy generation system consisting of PV modules, module racking, inverter(s), and other equipment. However, the selection of a PV inverter can play a relatively large role in the performance of the overall PV system.

A home owner looking to install a rooftop PV energy generation system can maximize energy harvested and subsequent return on investment in two ways:

- **Install** to make maximum utilization of available roof area
- Select components that **Operate** to ensure high conversion and to minimize negative impact of external factors (e.g., shading, high ambient temperature etc.)

Figure 1 below represents various energy yield increasing factors that help Conext RL to harvest more energy than lower featured competitive inverters in several installation situations. The following section details each factor and illustrates how connect RL’s feature set can often lead to superior economic returns.

Figure 1 *- Factors that contribute to maximize energy harvest using Conext RL from available roof area*



*Definite upside possible thanks to high product quality and service standards from Schneider Electric

Factors that contribute to maximum energy harvest using Conext RL

It is possible to have many system installation variations such as roof structures, orientations etc. and operating conditions such as ambient temperature, shading, insolation throughout the day. The results of Figure 1 are produced by considering some typical installation situations and operating conditions.

A few of the factors represented in Figure 1 might not be an issue at the time of installation (e.g., shading effect). However these might arise during the lifetime of the installation, e.g., after the PV plant installation an adjacent object such as a tree or building might appear up in the vicinity of the PV plant causing a persistent shading issue. If a single MPPT inverter has been installed the shade tolerant performance of the system may be compromised when compared to a multi-MPPT solution. Therefore, it is very important to plan for the maximum energy harvest from the design stage of the PV plant itself by choosing a flexible and efficient inverter. Choice of an inferior quality inverter with limited feature set can considerably reduce the energy harvested over the lifetime of the PV plant.

The following section explains in detail the various factors that contribute to maximum energy harvest using Conext RL:

Factor 1: Maximize roof utilization

For most home owners it's desirable to maximize the utilization of the roof area to harvest maximum possible PV energy. However, not all roofs are uniform with single optimum orientation. Multiple pitched roofs or roofs with structural elements that limit installation are quite common. Two physical limitations are often encountered during the layout design phase of a PV array:

- **Unequal strings:** Due to some structural limitations only an odd number of modules on the roof will fit in order to make maximum utilization of the roof area. An odd number of modules will not perform optimally when split into two unequal length strings on one MPPT input.
- **Different orientation strings:** For multiple pitched roofs each planer orientation of PV modules needs to be on an independent MPPT input in order to maximize system performance.

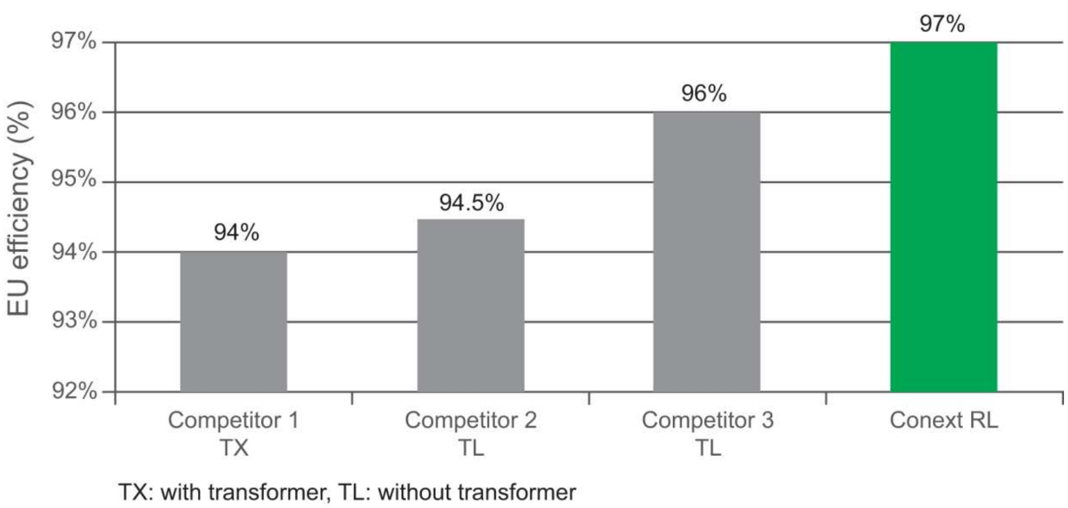
Unequal strings and strings with different orientations have different characteristic PV (power vs voltage) curves and different MPPs (maximum power points). If an inverter with single MPPT (maximum power point tracker), is implemented a considerable amount of energy that could be harvested will be sacrificed – even if the system appears to be performing normally. An alternative is to use two single MPPT inverters to handle such conditions or to use a single inverter with multiple MPPT inputs such as Conext RL.

Refer to **Appendix A** for more details on how Conext RL maximizes utilization of roof area and can harvest more than 5% additional energy than a representative single MPPT inverter in representative installation situations.

Factor 2: Ensure higher conversion efficiency

Conext RL -- with peak efficiency of 97.5% and EU efficiency of 97% -- is one of the most efficient solar PV inverters in the world. With its transformer-less topology it has a distinct efficiency advantage over inherently less efficient transformer-based inverters.

***Figure 2** - EU efficiency of Conext RL and competitor inverters with comparable power rating*



As represented in Figure 2 above, higher efficiency of Conext RL facilitates the harvest of 1-3% additional energy than a representative competitor inverter.

Refer to **Appendix B** for the simulation of a typical PV plant that shows how Conext RL helps improve the PR (Performance Ratio) of a PV plant.

Factor 3: Minimize shading effect

Shading of PV modules is one of the most challenging obstacles encountered when attempting to maximize the energy harvested from residential solar PV installation. The challenges of the shading issue are widely documented in solar installation studies[1] as well as in installer surveys[2].

The shaded part of the solar PV array has different IV and PV characteristics than the non-shaded part. The optimum PV plant design in such cases involves designing different strings for the shaded and unshaded parts and tracking them separately for maximum power point (MPP). Such a design is not possible with a single MPPT inverter resulting in suboptimal energy harvest. Conext RL with dual MPPTs is an ideal inverter for such a situation.

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[1] "Simulation der Abschattungsverluste bei solarelektrischen Systemen," Quaschning V., ISBN 3-89574-191-41996; Verlag Dr, Köster Berlin; "Operational Performance of Grid-connected PV Systems on Buildings in Germany," Ulrike Jahn and Wolfgang Nasse, Prog. Photovolt: Res. Appl. 2004

2 "PV Inverter Customer Opinions & Requirements Survey Dec 2011," IMS Research

Refer to Appendix C for more information on how Conext RL helps you harvest 2-4% additional energy, on a conservative basis, than a representative single MPPT inverter in a typical shading situation.

Factor 4: Minimize thermal derating effect

Conext RL has an exceptionally broad operating temperature range of -20^{0}C to +65^{0}C and a high thermal derating point as shown in Table-1 below.

Table 1 *– Thermal derating points of Conext RL*

Product	Thermal derating point*
Conext RL 3000E	52°C
Conext RL 4000E	52°C
Conext RL 5000E	48°C

**at nominal voltage*

Because of these favourable thermal characteristics, Conext RL is able to harvest full rated power even at high temperatures where other competitor units start derating.

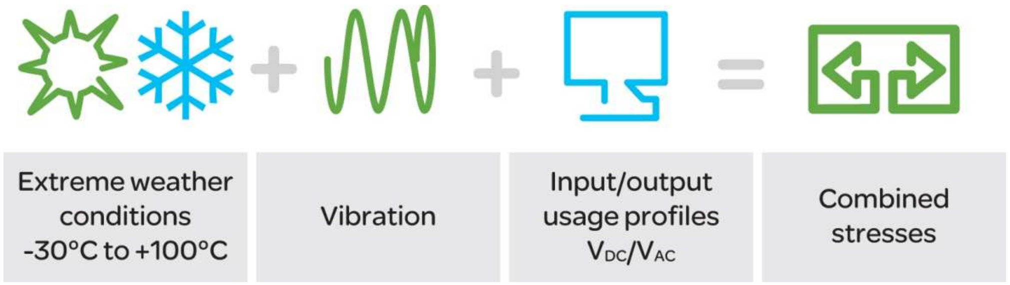
Refer to **Appendix D** to understand how Conext RL helps you harvest 1-5% additional energy than a representative competitor inverter in situations of high ambient temperature.

And the bonus: Reliability

And the bonus: the inverter that lasts longer

With Schneider Electric's high quality standards, Conext RL undergoes rigorous MEOST (Multiple Environmental Over Stress Testing) to ensure a well-engineered and high-quality product that lasts longer with minimum downtime.

Figure 3 - *Multiple Environmental Over Stress Testing*



The inherent reliability of power conversion products from a global and bankable inverter manufacturer like Schneider Electric is an additional factor that assures high energy harvest and optimal return on investment.

Conclusion

In this application note, using simple analysis with conservative assumptions, we have discussed how Conext RL can help harvest higher energy than a representative competitor inverter in typical installation situations. This helps to establish the fact that the flexible, efficient and reliable Conext RL is an ideal choice to maximize your energy harvest over the life time of the installation.

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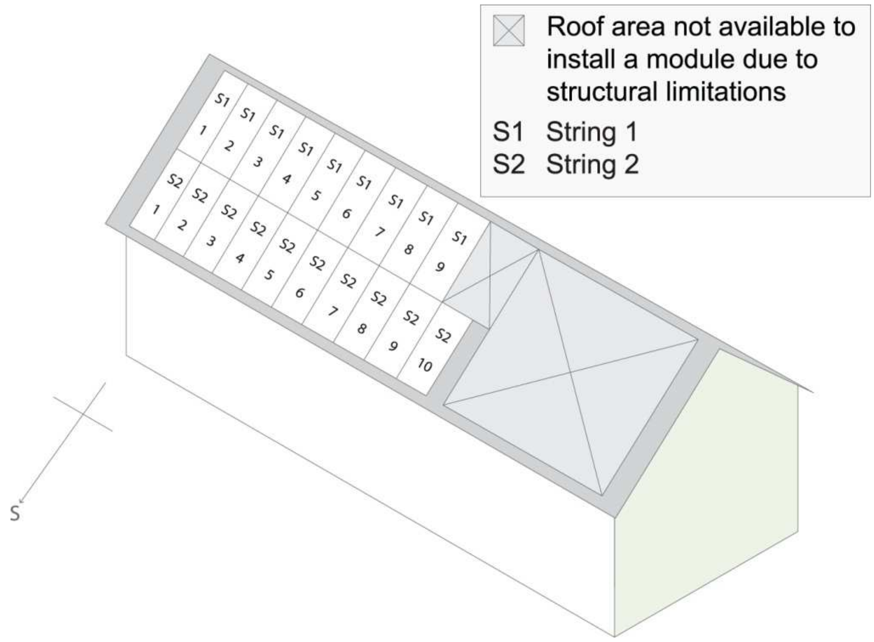
Appendix A1: Maximize roof utilization

A1. Make maximum utilization of the available roof surface area, e.g., unequal strings

Consider a solar PV installation as shown below:

Figure 4 *- Solar PV installation with odd number of modules*



As represented above, the entire roof area is not available for the solar PV installation due to structural limitations. Assuming the plant owner is willing to install a typical 220 W polycrystalline module, the DC power rating of the first string (S1) with 9 modules becomes 1980W and that of the second string (S2) with 10 modules becomes 2200W.

However, the feasibility of the installation of the above configuration of modules depends on the choice of the inverter as shown below:

***Table 2** – Description of installations with odd number of modules*

	Inverter	Inverter power rating	PV I/P connection	PV I/P power
Installation 1	Representative competitor single MPPT inverter	4kW, single MPPT with dual string input	Two PV strings of 9 modules each to single MPPT	3960W
Installation 2	Conext RL	4kW, dual MPPT inverter	One PV string of 9 modules to MPPT1 and the second string of 10 modules to MPPT2	4180W

As seen in the table above, a representative single MPPT competitive inverter (Installation 1) does not have an ability to handle unbalanced array inputs. Hence the designer has no choice but to design two equal strings with total power rating of 3960W to a 4kW inverter.

However, with 4kW Conext RL the user can design two unequal strings with the total power rating of 4180W as an input to the inverter.

Conclusion: Appendix A1

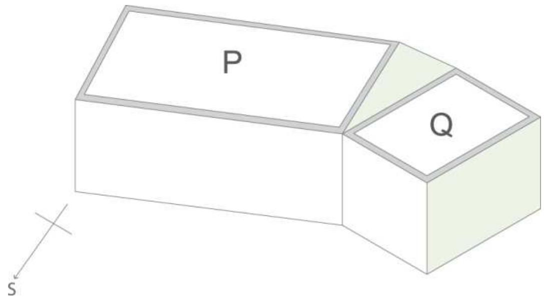
Thus, Conext RL provides the user with an opportunity to harvest more than 5% additional energy with the same roof structure by using an inverter of the same power rating.

Appendix A2: Maximize roof utilization

A2. Make maximum utilization of the available roof surface area, e.g., multiple pitched roofs

The other example of an installation that involves unbalanced arrays input is as shown in Figure 5 below. Here the roof areas ‘P’ and ‘Q’ are not only of different sizes but also have different orientations. Let us say the power rating of the string in roof area ‘P’ is 2kW and that of the string in roof area ‘Q’ is 1kW.

Figure 5 *- Solar PV installation with different orientation roofs*



A typical single MPPT inverter does not have an ability to handle unbalanced array I/Ps and hence it cannot be used to accept both strings from roof areas ‘P’ and ‘Q’ as the inputs. With such an inverter you have two options:

- **Option1:** Design the plant with PV modules installed only in the roof area ‘P’ and no PV module installed in the roof area ‘Q’. Here you use one inverter with power rating corresponding to the string in roof area ‘P’ (i.e., a 2kW inverter)
- **Option2:** Use two inverters, i.e., a 2kW inverter to accept string I/P from the roof area ‘P’ and a 1kW inverter to accept string I/P from the roof area ‘Q’

However, a single Conext RL 3000E can be implemented in this case by connecting 2kW input string ‘P’ to one MPPT and the 1kW I/P string ‘Q’ to the other MPPT.

Conclusion: Appendix A2

The dual MPPT input Conext RL is a better choice as compared to a typical single MPPT competitor inverter in both the options as described above.

- **Option1:** Conext RL enables the user to harvest ~50% more energy with the given roof structure and using a single inverter.
- **Option2:** Conext RL enables the user to reduce the complexity of the installation as the user can use a single Conext RL instead of two single MPPT competitor inverters.

Additional considerations in both the cases A1 and A2 above involve economics calculations, e.g., in the A2 case

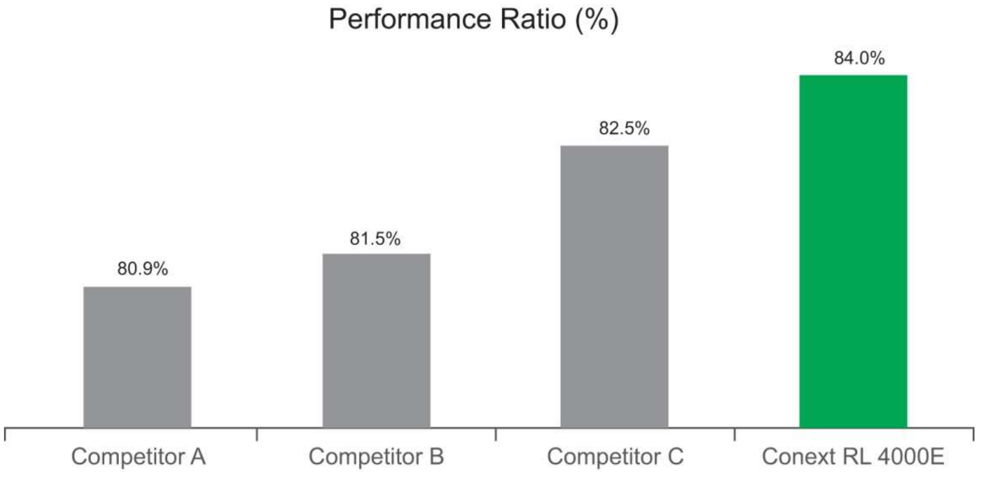
- **Option1:** Trade-off between additional energy harvested by utilizing roof area 'Q' and additional cost of installing a Conext RL 3000E inverter instead of a 2kW competitor unit
- **Option2:** Cost of installing two single MPPT inverters (one 2kW and one 1kW) vs. cost of installing a single Conext RL 3000E

There is little doubt that Conext RL will emerge as a superior choice in both the cases due to its high conversion efficiency, minimum downtime due to robust and reliable design, lower complexity of installation and the competitive pricing.

Appendix B: Ensure higher conversion efficiency

An analysis with simulation software like PVsyst for a typical South facing PV installation with no external influences (e.g., shading or high ambient temperatures) exhibits the following performance ratios (PRs).

Figure 6 *- Comparison of PR of PV installations with different inverters*



Performance ratio (PR) represents the ratio of the effectively produced energy and the energy which would be produced by a "perfect" system continuously operating at STC under same irradiance. The PR calculation includes the array losses (shadings, module quality, mismatch, wiring, etc.) and the system losses (e.g., inverter efficiency).

Conclusion: Appendix B

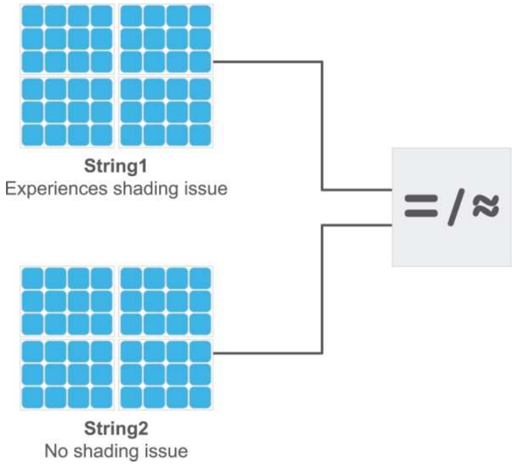
Since the PVsyst simulation models identical PV plant installations but with different PV inverters, the higher PR (upto 3%) of the PV plant with Conext RL 4000E inverter is directly attributed to its higher conversion efficiency.

Appendix C1: Minimize shading effect

C1. Observations in a field experiment

In the representative solar PV installation studied below, one of the PV strings experiences the shading issues in the morning time. Each string comprises of 11 modules of 175W.

Figure 7 *- PV installation with one string experiencing shading issue*



Here we will compare the output of the following two installations.

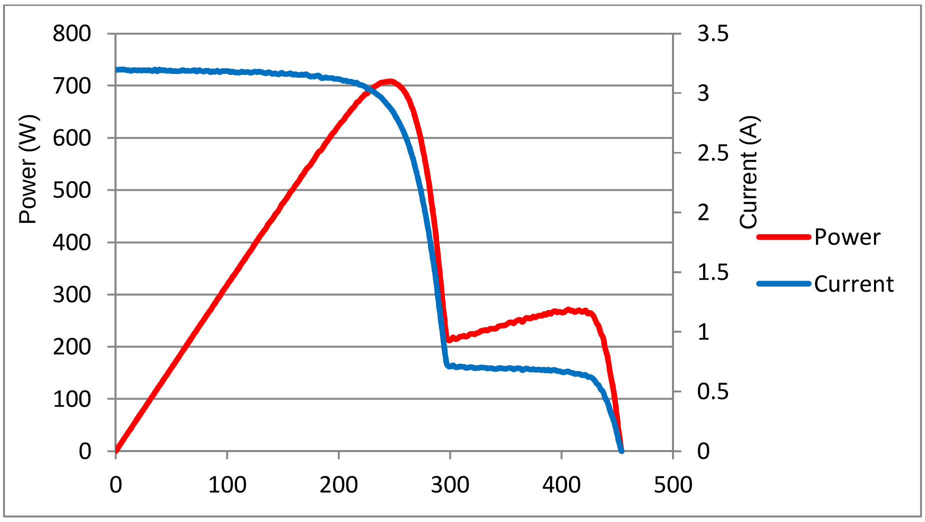
Table 3*- Details of PV installations with one string experiencing shading issue*

	Inverter	PV I/P connection
Installation 1	Representative competitor single MPPT inverter	Two PV strings input to single MPPT
Installation 2	Conext RL	One PV string input to each of the two MPPTs

Both the installations experience a shading issue on one of the strings in the morning time.

The PV and IV curves of the string that experiences the shading issue are as follows:

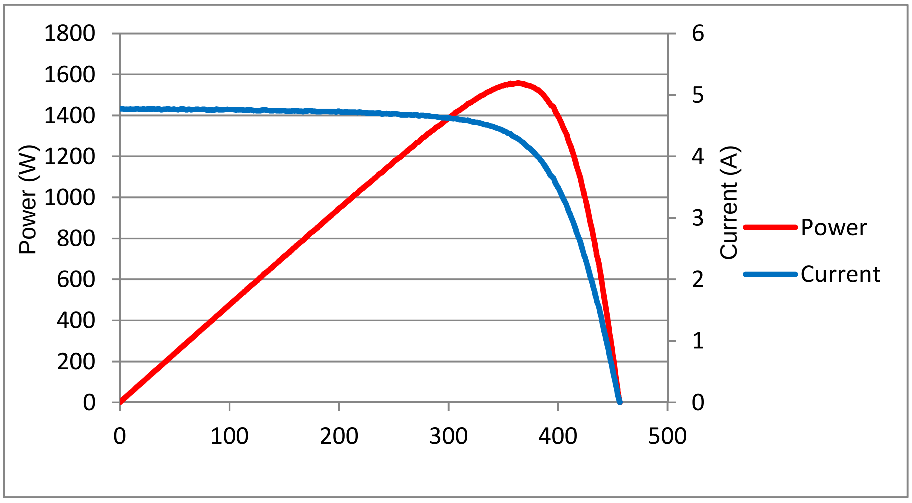
***Figure 8** - PV and IV curves of the string experiencing shading issue*



At the global maximum power point (MPP), the power harvested (P1) is 705W at voltage of 245V.

The PV and IV curves of the string that does not experience any shading issue are as follows:

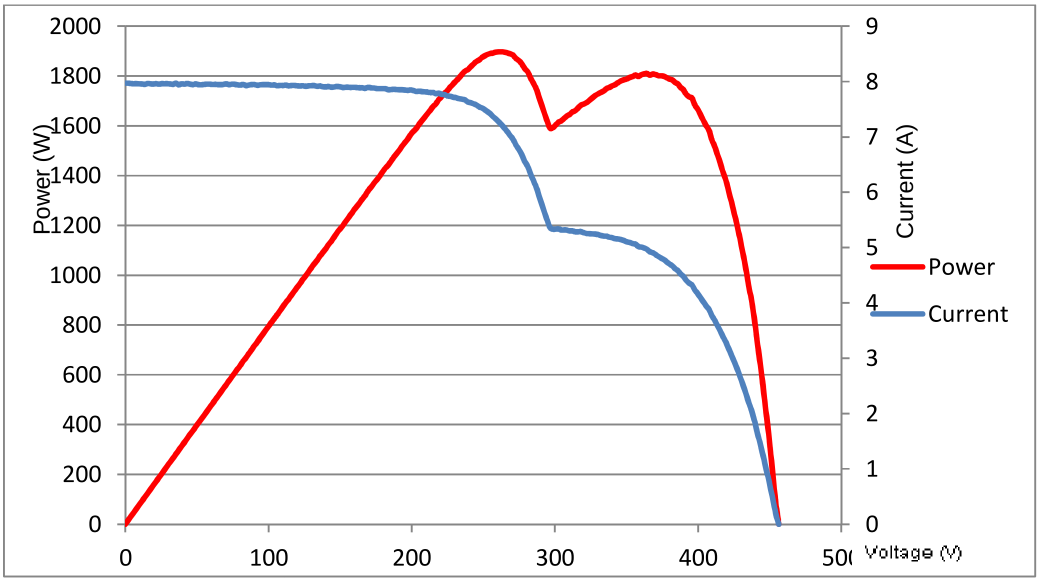
***Figure 9** - PV and IV curves of the string with no shading issue*



At the maximum power point (MPP), the power harvested (P2) is 1550W at voltage of 335V.

Based on the individual string characteristics, the PV curve of the first installation is:

Figure 10 *- PV and IV curves for the PV Installation 1*



Depending on the effectiveness of the shade tolerant algorithm, the power corresponding to either the local or the global maxima will be harvested. The best case power harvested in the installation 1 is 1900W at 263V. If the MPPT algorithm of the inverter is not effective, the power harvested can be even lower, i.e., 1810W at 365V.

Installation2

Thanks to its dual MPPT feature, Conext RL allows to harvest maximum power from each of the individual strings. The power harvested is = P1 + P2 = 705W + 1550W = 2255W

Conclusion: Appendix C1

When comparing the power output of installation1 and installation 2, Conext RL with its dual MPPTs helps harvest 19 to 25% more power in this scenario of the shading issue.

If the shading situation lasts for ~1/5 of the day (full sun hours), Conext RL helps harvest ~4-5% higher energy than a representative competitor unit.

Appendix C2: Minimize shading effect

C2. Analysis using PV simulation software

Figure 11 *- Shading situation simulated*

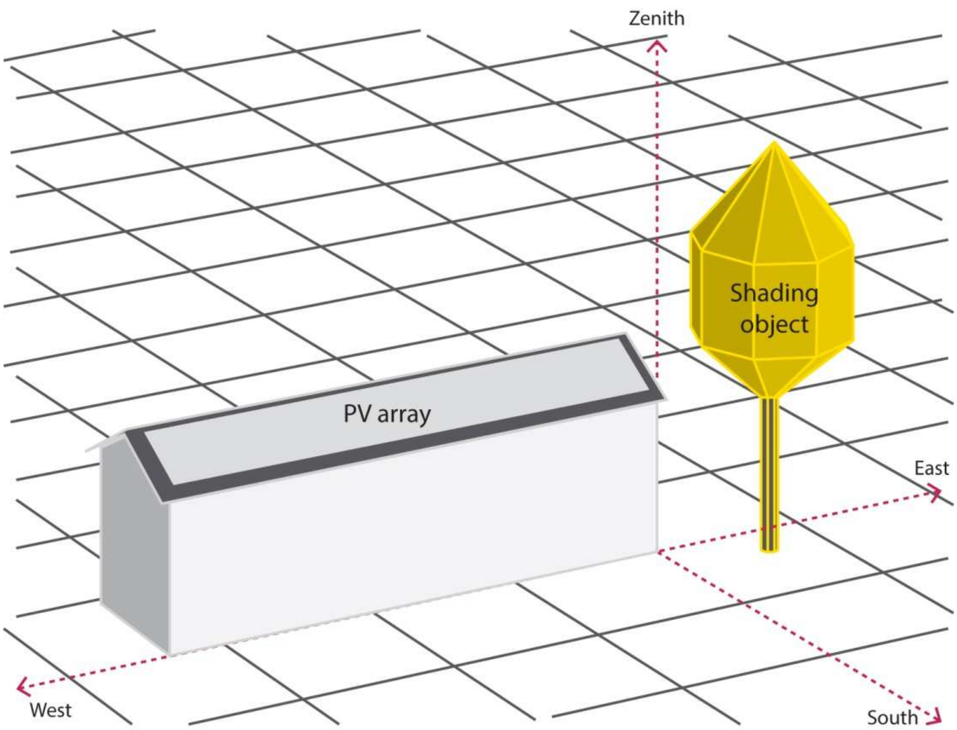
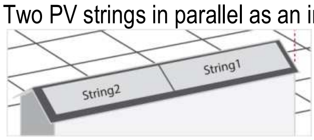
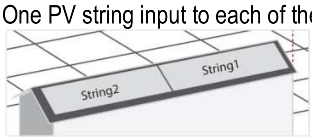


Table 4 *- Installations considered for simulation of shading situation*

	Inverter	PV I/P connection
Installation 1	Representative competitor single MPPT inverter (4kW)	Two PV strings in parallel as an input to single MPPT 
Installation 2	Conext RL (4kW)	One PV string input to each of the two MPPTs 

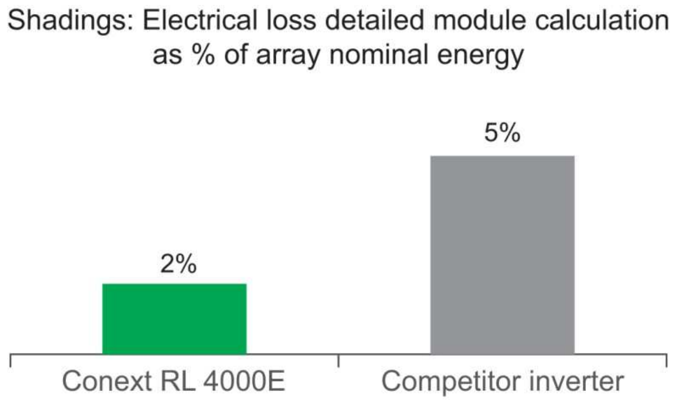
Simulation of the shading effect on the PV plant output is a somewhat complex topic and there are several studies published on this topic. The typical shading situation shown in Figure 11 is analyzed in the PV simulation software PVsyst.

In this installation, the string1 (towards the shading object e.g., tree) is more affected by the shading issue than the string away from the shading object.

Conext RL will track both the strings independently for maximum energy harvest to minimize the impact of shading.

A simulation for the impact of shading on the annual energy harvest shows the following result:

Figure 12 *- Simulated electrical loss dues to shading*



The above simulation does not take into consideration the effectiveness of the proprietary shade tolerant algorithm from Schneider Electric[3] which is implemented in the Conext RL series of inverters. The effectiveness of the algorithm ensures even higher energy harvest for Conext RL in real life situations.

Conclusion: Appendix C2

On a conservative basis, Conext RL helps you harvest >2% higher energy than a representative competitor inverter for a typical shading situation described above.

3 "Photovoltaic String Inverters and Shade-Tolerant Maximum Power Point Tracking: Toward Optimal Harvest Efficiency and Maximum ROI", December 2010, Dr. Andrew Swingler, Schneider Electric

Appendix D: Minimize thermal derating effect

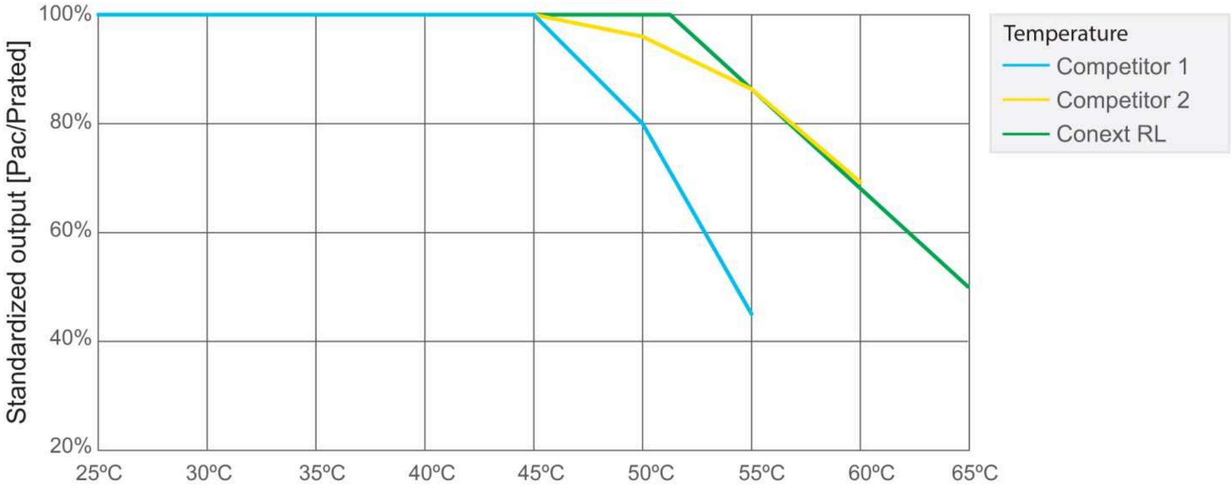
In outdoor installations where inverter might be exposed to direct solar load for some time every day, there is a solar heat built up inside the inverter. Due to this solar heat gain, the equivalent ambient temperature experienced by the inverter could be higher by 10^0C than the actual ambient temperature.

Inverter installations in locations like an attic or a garage are not uncommon. If such locations have poorly insulated walls/roofs and have poor ventilation, the effective ambient temperature of an inverter installed inside such locations can be higher than the outside temperature by 10^0C or even more.

On hot summer days, the outside temperature can be as high as 30^0C to 45^0C based on what part of the world you are in. This implies that the effective ambient temperatures for inverters installed in certain situations as described above can be as high as 40^0C to 55^0C.

In order to harvest maximum energy even in scenarios of high ambient temperatures, an inverter with a higher temperature derating point is required. The following are the thermal derating curves of Conext RL and other competitive inverters with comparable output power rating:

Figure 13 *- Thermal derating curves for Conext RL and other competitor inverters (at nominal voltage)*



At ambient temperature of 50^0C Conext RL harvests 100% of the rated output power. Competitor 1 unit harvests 80% of the rated output power while Competitor 2 unit harvests 95% of the rated power.

Conclusion: Appendix D

Conext RL helps harvest 5- 25% higher energy than representative competitor inverters at the ambient temperature of 50^0C.

If the high ambient temperature situation lasts for ~1/5 of the day (full sun hours), Conext RL helps you harvest 1-5% additional energy than a representative competitor unit for such installations.