

Residential & Commercial On-grid PV Systems in Europe, SolarEdge vs. Competitors

Lior Handelsman, Shalhevet Bar-Asher
SolarEdge Technologies



Background

Residential and commercial photovoltaic installations in today's market suffer from a variety of problems that prevent them from realizing their full potential, and present hurdles for further market acceptance. Many of the problems stem from power losses, system design limitations and constraints and from lack of monitoring and analysis tools. Further, a lack of safety features can pose risks to both workers installing or maintaining the system, and to firefighters handling fires in the vicinity of PV installations¹.

SolarEdge Technologies' distributed power harvesting system is the only architecture that offers a comprehensive, robust and cost-effective solution to these problems.

This paper will highlight advantages of the SolarEdge Technologies system in addressing the various problems described, when compared against competing systems in both residential and commercial configurations.

The Current PV Structure

Current residential and commercial PV systems are typically built from ten to a few hundred PV modules connected in a series-parallel connection. Several modules (typically 10 to 15) are connected in series, forming a string, to achieve a voltage high enough to enable efficient DC/AC inversion. This is usually between 150V to 900V – with 600V being the typical upper limit for string voltage based on currently available equipment. More power can be added to the system by adding multiple strings in parallel. A schematic diagram of such a system can be found in Figure 1.

Since the strings are connected in parallel, each string must have the same operating voltage in order to efficiently produce power. This generally includes matching in module make and model, string length and orientation and shading conditions, to name a few parameters. The entire array is then connected to a solar inverter which is responsible for harvesting the electrical power and inverting it to AC so it can be fed into the grid. If an array consists of two strings with differing operating voltage characteristics (e.g. module model or module orientation), two inverters will be needed.

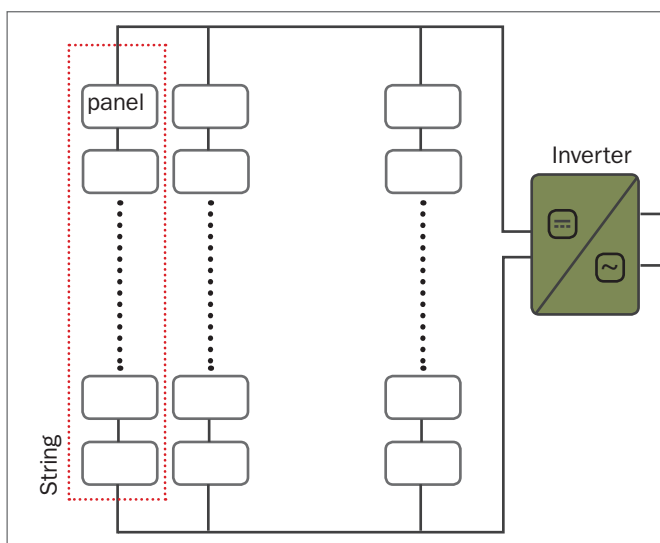


Figure 1 – multiple string photovoltaic system

The series connection in each string also poses problems that reduce the maximum power available for inversion. This stems from the fact that the same amount of current flows through all of the modules of each string, disabling individual module power maximization.

The SolarEdge Difference

By introducing a distributed power harvesting architecture, the SolarEdge system overcomes the limitations present in current PV systems. Instead of using a single power harvesting device – an inverter – for the entire array, SolarEdge divides power harvesting functions between two devices:

- Module-integrated Maximum Power Point Tracking (MPPT) units. These units optimize the energy output from each module.
- Central inverter: The SolarEdge inverter handles only DC to AC inversion - not high power MPPT schemes. Further, because this inversion is handled at a fixed DC voltage, the inverter can be a simpler, more cost-effective device.

Well performing Balance of System components, among them the inverter, are of high importance to the overall performance and longevity of a PV system². The SolarEdge distributed architecture approach contributes to improved system performance. In addition, quality of installation is of critical importance to system performance. As will be evident from this document, SolarEdge systems

allow for simplified installation, therefore posing fewer complications and potential errors. The following sections will illustrate how the SolarEdge solution leads to higher system efficiency and to substantial cost savings compared to competitors' solutions, in both residential (home and farm) and commercial sites.

Residential model case – home in GroßStove, Germany

In this case, we look at a rooftop in Germany that is suitable for the installation of a photovoltaic system. We will analyze how using different design approaches affects the system layout and the site's energy production and wiring requirements.

Site description: the home is pictured in Figure 2. A schematic view of the roof is shown in Figure 3. The roof is 9m high by 31m wide and has several chimneys, pipes and windows that are sources of shading and pose design challenges.



Figure 2 – photo of home in Germany

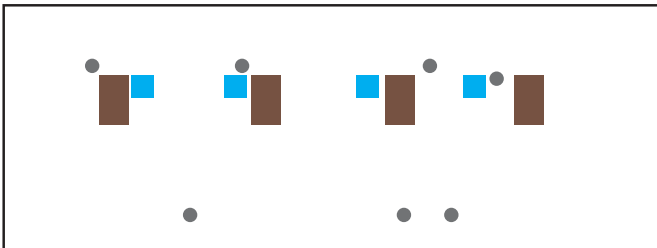


Figure 3 – schematic roof layout of roof in Germany

Using common modules that are 1.6x1m, the roof can physically accommodate a maximum of 128 modules. Of these modules, 26 are subject to partial shading due to the obstructions on the roof. A schematic layout of the roof showing the module positioning can be seen in Figure 4. Partially shaded modules are marked with a red line.

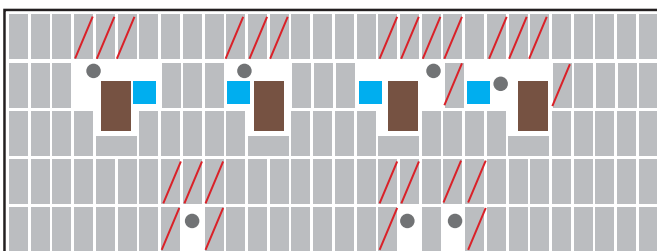


Figure 4 – schematic layout of roof with modules

We will compare three design approaches that may be applied to this roof. The first, using a competitor's traditional inverters and omitting modules subject to shading (Shading Avoidance), the second using the same competitor's inverters but fully covering the roof, and the third using the SolarEdge system. The inverter used in the first two cases is of a leading manufacturer of traditional inverters. This latest model was launched in 2010, and has multiple string MPP trackers. Its parameters are listed in Table 1:

Minimum inverter voltage	150 V
Maximum inverter voltage	1000 V

Table 1 – inverter parameters

The modules used in all three cases are widely used modules with the parameters listed in Table 2. All parameters assume a 240V grid AC voltage.

Physical Dimensions	160*100 cm
Power	230 W
Vmpp (@ STC)	28.8 V
Voc (@ STC)	36.4 V
β = Voltage temperature co-efficient	-0.33 %/°C

Table 2 – module parameters

Based on the parameters in Tables 1 and 2, it is possible to compute the maximum and minimum number of modules per string permissible for the competitor's inverters, according to the following calculations:

1. V_{oc}' (effective V_{oc} with temp de-rating) = $V_{oc} * (1 + \beta * [\text{minimum ambient temp} - \text{STC temp}]) = 40.6 \text{ V}$ (assuming a minimum ambient temperature of -10°C).
2. V_{mpp}' (effective V_{mpp} with temp de-rating) = $V_{mpp} * (1 + \beta * [\text{maximum ambient temp} - \text{STC temp}]) = 24.5 \text{ V}$ (assuming a maximum ambient temperature of 70°C).
3. Maximum number of modules per string = maximum inverter voltage / V_{oc}' .
4. Minimum number of modules per string = minimum inverter voltage / V_{mpp}' . The final string sizes reached are listed in Table 3.

Minimum number of modules per string	7
Maximum number of modules per string	24

Table 3 – string size limits



The SolarEdge technology allows a much wider range of 10 to 42 modules per string for the selected type of modules, when connected to a 3-phase inverter. Using the above string size limitations we have grouped the modules into strings as presented in Figures 5-7. These figures also schematically show the wiring requirements of each layout. Note that the lines represent logical connections, and are not positioned in the actual wiring locations. The red and black lines mark all string-inverter connections, red representing the plus connections and black the minus connections. Module to module wiring is not sketched, but represented by module numbers (for example in string A, module A1 is connected to module A2 that is connected to module A3 and so forth). The grey circle represents the wiring duct entrance to the house. All modules belonging to the same string have the same colour, and all strings connected to the same inverter are coloured in different shades of the same colour (for example, light and dark blue).

The SolarEdge case uses three 10kW inverters. A single 42-module string is connected to each of two inverters, and the third inverter has two 22-module strings connected to it.

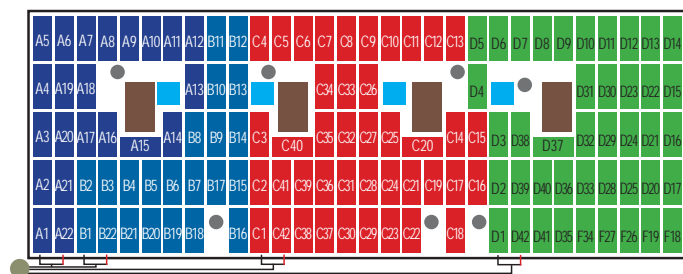


Figure 7 – SolarEdge case system layout

Because the partial shading in this site is significant, we calculated the produced energy in each case, accounting for the changing shading pattern during the day. We also calculated the wiring needs of each case. The results of these calculations are presented in Table 4:

The Shading Avoidance case assumes modules are installed only where they won't suffer from partial shading. The gray modules represent module positions that remain empty. This setup uses two 12kW inverters. Three 17-module strings are connected to each inverter.

Solution	Installed Power	Annual Energy ³	BoS Cost
Traditional design, shading avoidance	23.46 kW 79.7%	28.15 kWh 86.3%	3 inverters Wiring: 100m
Traditional design, full roof	29.44 kW 100%	32.61 kWh 100%	3 inverters Wiring: 76m
SolarEdge design	29.44 kW 100%	34.55 kWh 106.6%	3 inverters Wiring: 62m

Table 4 –energy production and wiring requirements

The design approaches using leading traditional inverters result in two very different amounts of produced energy, depending on the treatment of partially shaded modules and subsequently the affect of their performance on the system's performance. But the SolarEdge system produces more energy than even the best Competitor case, which make use of multiple MPP tracker inverters. The SolarEdge energy gain is of 6-7% more energy. At the same time the SolarEdge system requires 20% less wiring, which also means less labour.

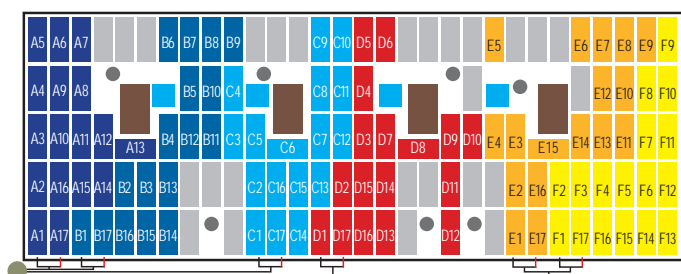


Figure 5 – Shading Avoidance system layout

The Full Roof case uses three 10kW inverters. Two 21/22-module strings are connected to each inverter.

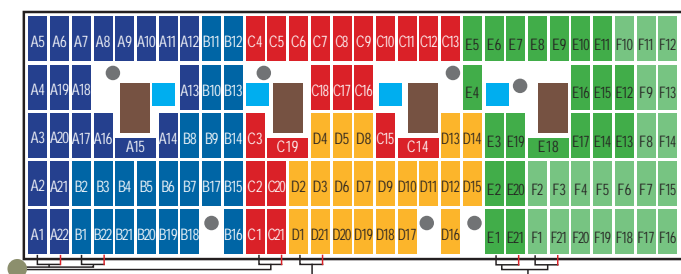


Figure 6 – Full roof system layout

Residential model case – farm in Germany

In this case, we look at a common farm building with an installed system. We will use the module layout of the system shown below, and analyze how using different inverters would affect the system layout and subsequently the costs and requirements for wiring and labour.

Site description: the farm, with its installed system consisting of 40 modules, is pictured in Figure 8. A schematic view of the roof is shown in Figure 9. The roof dimensions are 6.8m high by 8.6m wide.



Figure 8 – photo of farm installation in Germany

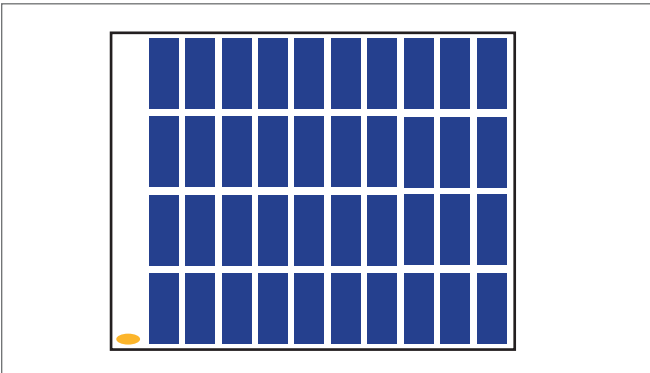


Figure 9 – schematic layout of farm installation in Germany

We will compare three systems with the presented module layout, two using competitors' inverters and one with a SolarEdge system. Like in the previous case, string lengths must be calculated in order to design the system architecture, and these depend on the inverter and module parameters.

Two inverters of leading manufacturers were selected. Their parameters are listed in Table 5:

	Competitor A	Competitor B, inverter type 1	Competitor B, inverter type 2
Minimum inverter voltage	230 V	224 V	125 V
Maximum inverter voltage	600 V	600 V	550 V

Table 5 – inverter parameters

The modules used for the site comparison are widely used modules with the parameters listed in Table 6. All parameters assume a 240V grid AC voltage.

Physical dimensions	160*80 cm
Power	175 W
V _{mpp} (@ STC)	35.9 V
V _{oc} (@ STC)	44.3 V
β = Voltage temperature co-efficient	-0.38%/°C

Table 6 – module parameters

Based on the parameters in Tables 5 and 6, the following values were computed as described in the previous section:

1. V_{oc}' (effective V_{oc} with temp de-rating) = 51.03 V
2. V_{mpp}' (effective V_{mpp} with temp de-rating) = 34.53 V
3. Maximum number of modules per string = maximum inverter voltage / V_{oc}'
4. Minimum number of modules per string = minimum inverter voltage / V_{mpp}'

The final figures reached are listed in Table 7.

	Competitor A	Competitor B, inverter type 1	Competitor B, inverter type 2
Minimum number of modules per string	7	7	4
Maximum number of modules per string	11	11	10

Table 7 – string size limits



The SolarEdge technology allows a much wider range of 6 to 25 modules per string.

Using the above string size limitations, we have grouped the modules into strings as presented in Figures 10-12. All systems have the same number of modules and therefore can produce the same amount of power, but the wiring needs vary from system to system according to its architecture. The schematic wiring is also shown in these figures. Note that the lines represent logical connections, and are not positioned in the actual wiring locations. The red and black lines mark all string-inverter connections, red representing the plus connections and black the minus connections. Module to module wiring is not sketched, but represented by module numbers (for example in string A, module A1 is connected to module A2 that is connected to module A3 and so forth). The yellow circle represents the wiring duct entrance to the house. All modules belonging to the same string have the same colour, and all strings connected to the same inverter are coloured in different shades of the same colour (for example, light and dark blue). Competitor A's setup requires an 8.4kW inverter (all the strings are connected to this inverter, but wiring capacity limitations require two connections to the inverter, each for two strings, and not a single wire connecting all four strings).



Figure 10 - Competitor A system layout

Competitor B's setup requires a 4.3kW inverter (the two blue strings are connected to this inverter) and a 2.7kW inverter (for the two red strings).



Figure 11 - Competitor B system layout

The SolarEdge setup requires a 5kW inverter (for the red string) and a 3.3kW inverter (for the blue string).



Figure 12 - SolarEdge system layout

A calculation of the wiring needed in each of the systems is presented in Table 8.

	Competitor A	Competitor B	SolarEdge
Power (W)	7000	7000	7000
	20.8 m	20.8 m	17.6 m
Total wiring	100%	100%	84.6%
	€ 17.68	€ 17.68	€ 14.96

Table 8 - Germany farm installation wiring requirements

Also in this case, as can be seen in Table 8, the SolarEdge system reduces the amount of wiring needed, using 15% less wiring than the competitors' systems. This simplifies installation, which translates to savings in labour cost, on top of the wiring cost savings. Of course, as systems get larger, the savings become more significant.

Residential model case – farm in Spain

In this case, we look at a farm building with an existing photovoltaic installation. We will compare the current system layout (modules, strings, wiring etc.) with a system using the same module layout, but with SolarEdge inverters.

Site description: the farm, with its installed system consisting of 120 modules, is pictured in Figure 13. A three-dimensional model of the farm is presented in Figure 14 and a schematic view of the roof is shown in Figure 15, where the grey circle is located at the wiring duct entrance. The roof dimensions are 6m high by 40m wide. The roof isn't facing the optimal direction for a solar installation, therefore the panels were placed on a slant and not directly on the roof.



Figure 13- photo of farm installation in Spain

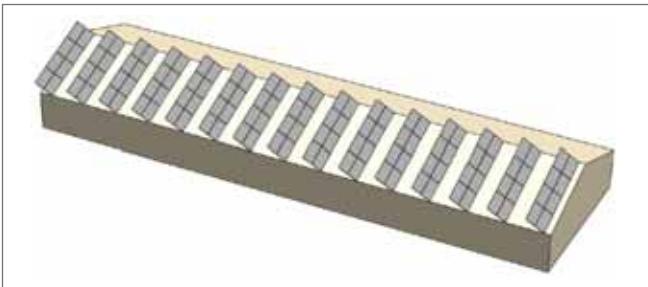


Figure 14 – three dimensional model of farm installation in Spain

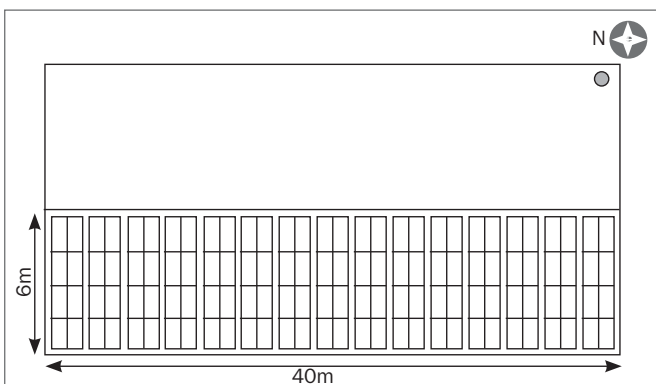


Figure 15 – schematic layout of farm installation in Spain

The modules installed in this site have the parameters listed in Table 9.

Physical dimensions	160*80 cm
Power	150 W
Isc (@ STC)	4.9 A
Voc (@ STC)	43.8 V

Table 9 – module parameters

The current system design is presented in Figure 16. The strings are coloured grey and white alternately. Blue lines represent module to module connections, and the red and black lines mark all string-inverter connections, red representing the plus connections and black the minus connections. The system characteristics are detailed in Table 10:

Number of inverters	6
Number of strings per inverter	2
Number of strings	12
Number of modules per string	10
Power per string	1500 W
Power per inverter	3000 W
Total site power	18000 W

Table 10 – Competitor system characteristics

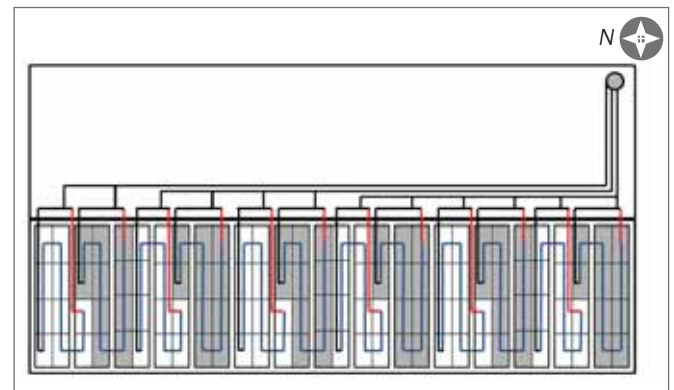


Figure 16 – Competitor system layout



Due to wiring losses that increase with distance, the wiring connecting the farther strings is of greater ampacity than that connecting the closer strings. Table 11 lists the various types of wiring used in this installation:

Strings	Wiring
First six (beginning from the South end)	6 mm ²
Next four	10 mm ²
Last two	16 mm ²

Table 11 – Competitor wiring scheme

When planning a SolarEdge system for this module layout, installers can achieve a much simpler design. This is because SolarEdge technology uniquely allows for strings of differing lengths to be connected to the same inverter. The SolarEdge system layout is presented in Figure 17. The system characteristics are detailed in Table 12:

Number of inverters	3
Number of strings per inverter	2
Number of strings	6
Number of modules per string	16 / 24
Power per string	2400 / 3600 W
Power per inverter	6000 W
Total site power	18000 W

Table 12 – SolarEdge system characteristics

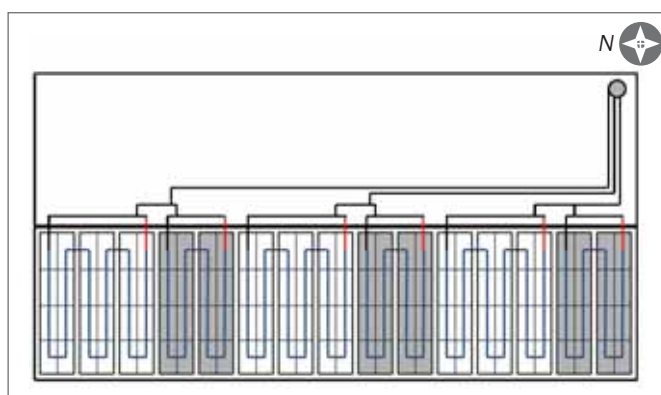


Figure 17 – SolarEdge system layout

Also in the SolarEdge system, wiring with various ampacities is used, as presented in Table 13:

Strings	Wiring
First two (beginning from the South end)	6 mm ²
Middle two	10 mm ²
Last two	16 mm ²

Table 13 – SolarEdge wiring scheme

After determining the wiring needs in both layouts, a comparison can be made. This is presented in Table 14:

	Competitor	SolarEdge
6 mm ²	66.8 m	20.95 m
	100 %	31.36 %
	€ 56.78	€ 17.8
10 mm ²	66.85 m	36.7 m
	100%	54.9%
	€ 86.9	€ 47.7
16 mm ²	59.35 m	50.45 m
	100 %	85 %
	€ 116.33	€ 98.9
Total wiring price (€)	260	164

Table 14 – Spain farm installation wiring requirements

The total wiring price of the SolarEdge system is 60% of the Competitor's price. This difference becomes even more significant when hundreds of farm systems are being installed. Furthermore, the SolarEdge system design is simpler, leading to easier implementation. This translates to savings in labour, on top of the savings in wiring costs.

Commercial model case

A commercial solar installation ranges from hundreds to tens of thousands of solar modules. The modules are organized in strings, which in turn are organized in clusters. In addition to the constraints listed previously, fuses and fuse boxes are of critical importance when designing a commercial site layout because very high currents are present.

The modules used for the commercial site comparison are widely used thin film modules with the parameters listed in Table 15.

Physical dimensions	60*120 cm
Power	70 W
Voc	89 V
Vmpp	67.1 V
Isc	1.19 A
Voltage temperature co-efficient	- 0.25%/°C
Current tolerance	10%
Voltage tolerance	10%
Maximum fuse rating	10 A

Table 15 - module characteristics

The calculations made in order to determine the Competitor's field setup are:

1. Voc' (effective Voc taking temperature changes into account) = Voc * (1 + Voltage temp co-efficient * [minimum ambient temp - STC temp]) = 97.9 V (assuming a minimum ambient temperature of -15°C).
2. Vmpp' (effective Vmpp taking temperature changes into account) = Vmpp * (1 + Voltage temp co-efficient * [minimum ambient temp - STC temp]) = 73.81 V (assuming a minimum ambient temperature of -15°C).
3. I_{max} = I_{sc} * 1.25 (this is the IEC maximum permitted current) = 1.49 A.
4. Number of modules per string = 10, as this is the lower of:
 - a. 1000 / Voc' = 10 (1000 is the string Voc upper limit)
 - b. 820 / Vmpp' = 11 (820 is the string Vmpp upper limit)
5. Number of strings per cluster = 12 (this is the commonly used number)
6. Fuse current = number of strings per cluster * I_{max} = 17.88 A

7. Number of clusters per fuse box = fuse box current * 0.95 / fuse current. A standard fuse box is of 100 A, and operates at no more than 95% of its capacity (the maximum allowed) resulting in 5 clusters per fuse box.

In a SolarEdge system the fuse and fuse box currents are not a factor in determining the field setup because of the electronic design that prevents current from flowing backwards through the modules. Instead, the wiring ampacity plays a part as detailed in the following calculations that determine SolarEdge's field setup:

1. Maximum current through wiring = wiring current capacity * 0.8 (due to the 80% limit on the capacity). Assuming 20A wiring, the standard for photovoltaic systems, produces a maximum current of 16 A.

2. Number of modules per cluster:

- a. Number of strings per cluster * maximum string current (I_{max}) ≤ Maximum current through wiring
- b. I_{max} = number of modules per string * power per module / 800 V (800 V being the optimal input DC voltage for inversion to 240 VAC)

This leads to the constraint: number of modules per string * number of strings per cluster = number of modules per cluster ≤ 182.

The SolarEdge system allows for different string lengths in a cluster; therefore, these 182 modules can be divided into 3 strings with 50 modules in each (the maximum string length in a SolarEdge commercial system) and a fourth string with 32 modules. This yields I_{max} = 4.37 A or 2.8 A, depending on string size.

3. Number of clusters per fuse box = fuse box current * 0.8 / cluster current. The cluster current is given by 3 * 4.37 + 2.8 A and a standard fuse box is of 100A, and operates at no more than 80% of its capacity (the maximum allowed) resulting in 5 clusters per fuse box.

We will show how the results of these calculations affect the possible layouts of a model case, a 250kW commercial installation.

The figures listed in Table 16 were obtained:

	Competitor	SolarEdge
Modules per string	10	50 / 32
Strings per cluster	12	4
Clusters per fuse box	5	5

Table 16 - Field system characteristics



Once these numbers are at hand, the field layout can be designed.

We will begin by describing the layout using the Competitor's inverter. The modules in each string (10 modules) are placed one above the other, in groups of four. These groups of four are lined up next to each other and are installed on a slant (a 50 degree slant is typical for the European climate). The strings are lined up next to each other to form a cluster. A photo of a typical layout can be seen in Figure 18. To avoid any shading problems, we allow for a distance between rows of clusters that is based on the height of the string. In this model case, this amounts to a distance of 2.4m. Schematic top and side views of a cluster, consisting of 12 strings with 10 modules in each string, per the Competitor's figures, can be seen in Figure 19. Each string is outlined in a thick line; dimensions are not to scale.



Figure 18 – photo of typical field installation

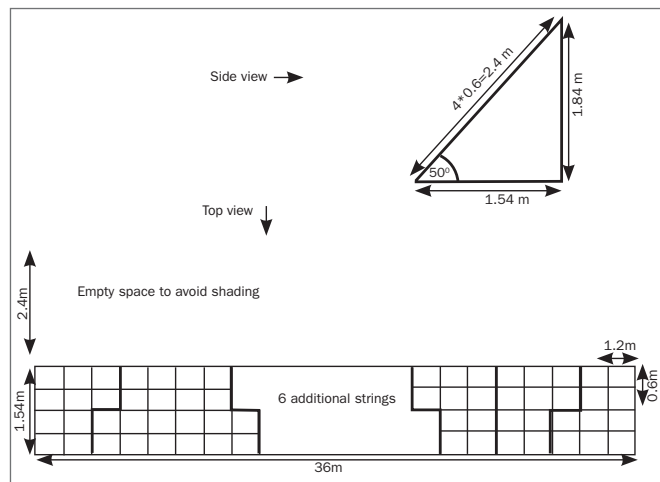


Figure 19 – Competitor cluster layout

On the next level, clusters that are connected to the same fuse box are lined up next to each other (either one behind the other or next to each other, depending on site dimensions). The clusters using a different fuse box are lined up in a row behind the first row of clusters and so on. In an installation of 250kW as in this model site, 8 such rows are needed. To obtain this number we calculate:

1. Power per cluster = modules per cluster * power per module = 8400 W.
2. Power per fuse box = clusters per fuse box * power per cluster = 42 kW.
3. Number of fuse boxes = total site power / power per fuse box = 6.

This leads to a setup as described in Figure 20. The layout is schematic, dimensions are not to scale. Symbols: C – cluster, FB – fuse box.

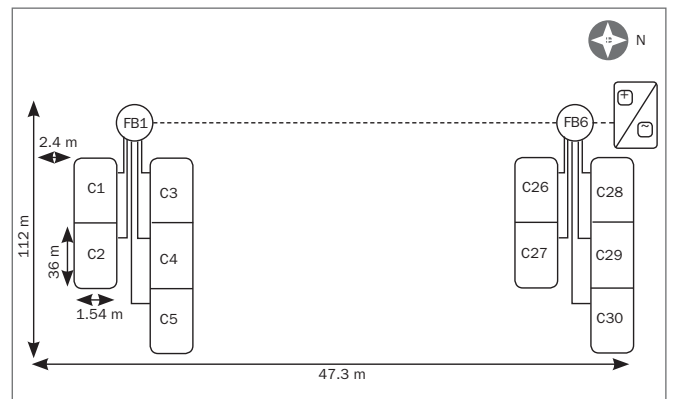


Figure 20 – Competitor field layout

We will now describe the layout using the SolarEdge solution. Clusters are formed in the way described above, where now three strings in each cluster have 50 modules each and one string in each cluster has 32 modules. Schematic top and side views of such a cluster can be seen in Figure 21. Each string is outlined in a thick line.

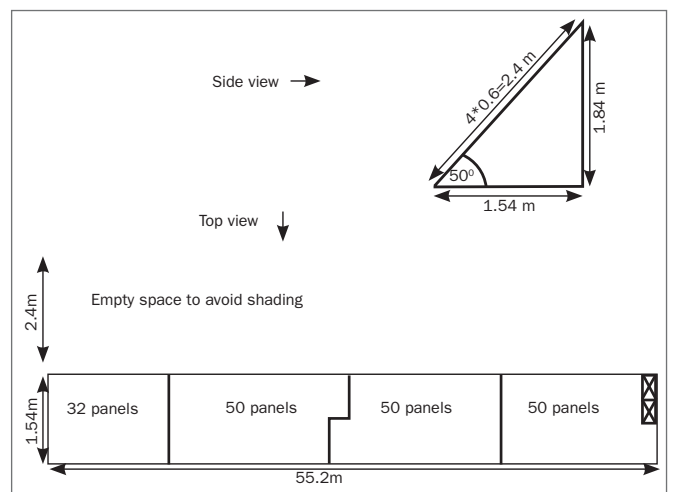


Figure 21 – SolarEdge cluster layout

To determine the number of fuse boxes in the SolarEdge system, we follow the calculations described above which produces the number 4. This leads to a setup as described in Figure 22. Once again the layout is schematic, dimensions are not to scale.

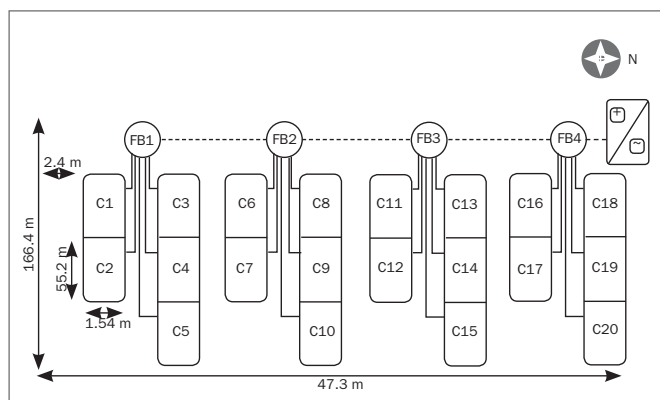


Figure 22 – SolarEdge field layout

It is evident that the SolarEdge setup requires less wiring, since there are fewer fuse boxes which leads to fewer cluster – fuse box connections (these are done with 20A wiring) and less fuse box – inverter wiring (this is done with 100A wiring). Exact calculations, according to the dimensions and wiring schemes in Figures 19-22, produce the numbers in Table 17:

	Competitor	SolarEdge
20A wiring	864 m	883.2 m
	100%	102%
100A wiring	91.44 m	39.04 m
	100%	42.7%
Fuse boxes	6	4

Table 17 – field wiring requirements

The SolarEdge layout requires only 2% more 20A wiring and 60% less 100A wiring than what the Competitor layout requires, and only 4, instead of 6, fuse boxes. The total wiring and fuse box costs of each system, as well as the price per Watt of each system, are presented in Table 18.

	Competitor	SolarEdge
Wiring price (€)	913.62	827.24
Fuse boxes price (€)	1500	1000
System price (wiring and fuse boxes, €)	2413.62	1827.24
price per Watt (€/W)	0.0096	0.0072

Table 18 – Field system cost

Using the competitor's system means spending 30% more than would be spent using a SolarEdge system on wiring and fuse boxes. This translates to a SolarEdge price per Watt that is 25% lower than the Competitor price per Watt. In addition to the SolarEdge savings seen in Table 18, the SolarEdge system allows for significant savings in labour due to less wiring and simplified installation.

Conclusion

We have described and exhibited the advantages of SolarEdge Technologies' system over systems of leading companies. These advantages are present in both residential (home and farm) and commercial systems. These significant advantages include maximum system utilization, flexible system architecture that leads to maximal space utilization and cost savings on both materials and labour. All this is possible due to SolarEdge's distributed power harvesting architecture, which offers a full and robust solution to problems inherent in other systems.

¹ "Problems and Disadvantages in Current Residential & Industrial On-grid PV Systems", SolarEdge Technologies (2008)

² "PV Installations, A Progress Report", John C. Wiles, Bill Brooks, Bob-O Schultze (2002)

³ In all annual energy calculations we assume the competitor's inverters will never mistakenly lock on local maxima.



About SolarEdge

SolarEdge provides next generation power conversion electronics that effectively remove all known system constraints across the photovoltaic energy space. Our Smart DC technology enables increased production of clean, grid-ready energy at a lower cost.

The SolarEdge technology marries traditional photovoltaic workflows and installation methods with a groundbreaking holistic system approach. It is a quiet revolution that is disruptive because of its profound benefits in changing the manner in which energy is harvested, deployed, managed and delivered and at the same time complementary because it fits into the current photovoltaic workflow.

At SolarEdge we believe the PV delivery chain is ultimately only as strong as its weakest link. By adopting a “system first” philosophy that identifies and eliminates the Achilles heel in each step in the process, we enable a constraint-free delivery of sun harvested energy.

USA 2225 East Bayshore Road, Suite 200 Palo Alto, CA 94303, USA

Germany Königstr. 5, 01097 Dresden, Germany

Japan B-9 Ariake Frontier Building, 3-7-26 Ariake, Koto-Ku, Tokyo, 135-0063, Japan

Israel 6 HaHarash St. P.O.Box 7349, Neve Neeman, Hod Hasharon 45240, Israel

www.solaredge.com

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