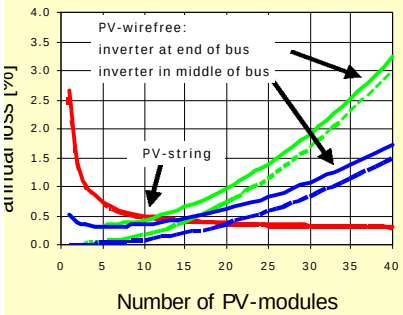
Ultimate reliability and efficiency

Reliability

To compare PV-wirefree with a PV-string system we consider malfunctioning of:

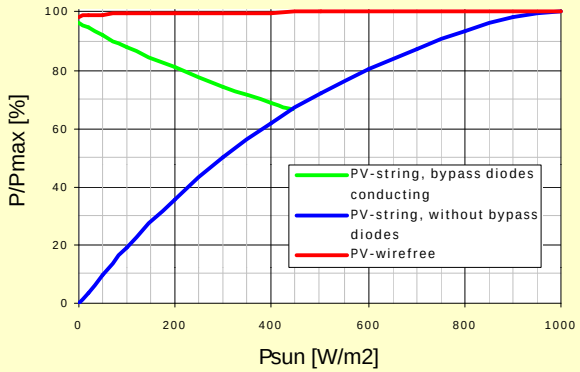
- **Connector.** The high-pressure PV-wirefree connector is very robust and with its large gas-tight contact area, it is as reliable as a commonly used dc-connector.
  But even if one PV-wirefree connector would fail, the reduction in output will remain limited to the potential yield of one PV-module only, since the PV-laminates are connected in parallel.
- **DC-wiring.** In case the relatively thin dc-wiring of a PV-string is damaged, the full PV-system will be out of order. Since the PV-wirefree mounting bus is extremely robust with a cross section of 120mm^2, breaking it has become merely impossible.
- **PV-module**. If one PV-module in a PV-wirefree system is not functioning properly, the output of this PV-module will decrease accordingly, but the other PV-modules will continue delivering power to the grid since these are connected in parallel.
- **Bypass diodes**. Short-circuiting of bypass diodes cannot occur in a PV-wirefree system, since these are omitted. In a PV-string system short-circuiting of the bypass diodes decreases the annual yield of the total PV-string, and even might blow a PV-system fuse.



Graph shows conductor losses in a PV-string and a PV-wirefree system versus the number of PV-modules. The dashed lines show the conduction loss (I^2R), the solid lines represent the conduction losses plus 25% of the energy content of Al and Cu, based on a lifetime of 20 years.
Assumptions: The PV-laminates are 75 Wp@5 A, the PV-string system uses 2.5 mm^2 copper-wire, 2 meter per module for interconnections between the PV-modules. The distance between the modules and the string-inverter is 10 meters. Cross section of PV-wirefree mounting bus is 120 mm^2, width of PV-wirefree laminates 0.7 m. the PV-wirefree inverter is mounted directly on the bus.

Efficiency

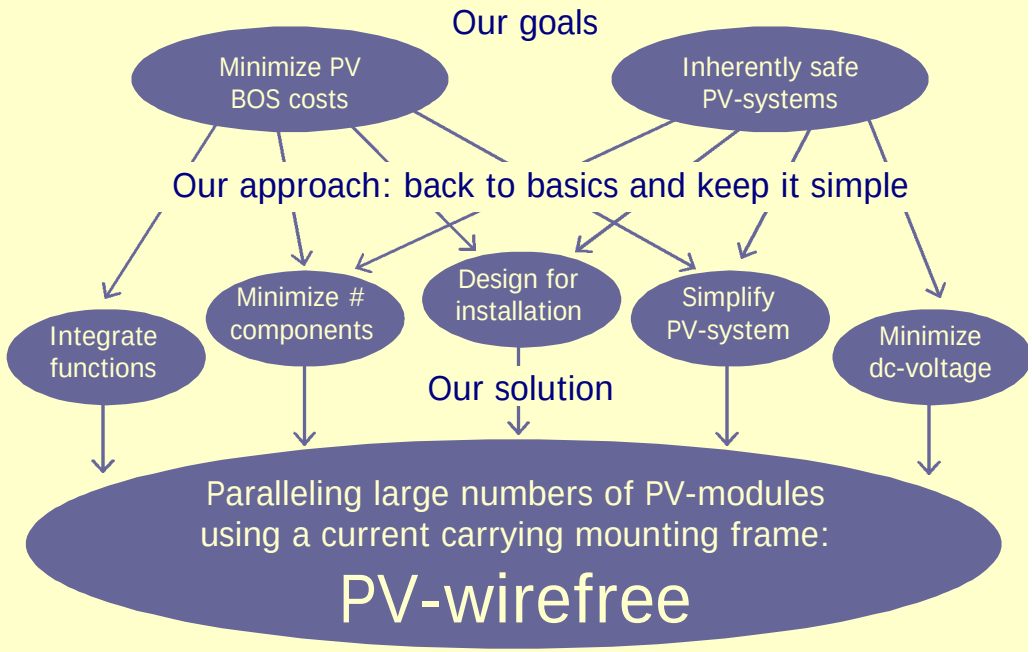
- Since the PV-modules in a PV-wirefree system are connected in parallel **mismatch losses** at system level due to differences in illumination of PV-modules do not occur, resulting in an annual increase of the PV-system efficiency with 5-15% as shown in the graph below.



Effect of difference in illumination of two PV-modules in series compared with two PV-modules in patallel. One PV-module is illuminated with 1000 W/m^2, the illumination of the other PV-module increases from 0 to 1000 W/m^2

- One of the main advantages of **connecting PV-modules in parallel** is that the PV-modules operate independently from each other, whereas in PV-string systems there is a strong interdependency. Malfunctioning of only one component – dc-wiring, a dc-connector or one PV-module or cell - immediately affects the output of the total PV-string. Hence, the annual yield of a PV-wirefree system will always be higher.
- To limit the **conduction losses** of a PV-system in which PV-modules are connected in parallel, thick dc-wiring is required. By using the PV-wirefree mounting bus with a cross section of 120 mm^2, this disadvantage is mainly overcome. As shown in the graphs below the conduction losses in PV-wirefree systems up to 15 PV-laminates remain well below of those in a comparable PV-string system. Conduction losses in PV-wirefree systems of up to 35 PV-laminates become higher but the relative increase is still less than 1%.

Reinventing PV-systems



Ultimate integration of functions and removal of abundant components

- No dc-wiring anymore: mounting frame is used to carry the current
- PV-module frame and junction box are replaced by one component: the module connector
- By paralleling the PV modules many components can be omitted and are removed: bypass diodes, internal wiring for bypass diodes, blocking diodes, dc-fuses, dc-overvoltage protection and more

Ultimate reliability and efficiency

- Increase of annual yield of 5-15% since mismatch losses are avoided, and reliability is increased
- Increase of reliability, by avoiding series connections and minimizing the number of dc-components

Ultimate safety

- Fully touch-safe as the maximum voltage is 21 volts, even when a large number of PV-modules are connected in parallel.
- Fire hazard is strongly reduced compared with PV-strings as the 21 volts maximum system voltage is too small to maintain an arc.

Ultimate ease of installation

- No special tools or devices required to install the PV-modules
- Simple click the module connector onto the mounting bus, and mechanical and electrical installation is complete
- Inherent safe installation by limiting the dc-system voltage to 21 volts

PV-wirefree is an invention of Henk Oldenkamp, OKE-Services. Other PV-wirefree partners are ECN, NKF Electronics and Oskomera.
A study into the feasibility of PV-wirefree was financially supported by Novem, Netherlands Agency for Energy and the Environment.

For more information visit http://www.pv-wirefree.com

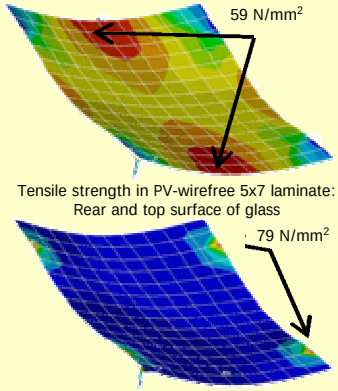
Ultimate integration

The numerous PV-string components are replaced by only three PV-wirefree components

- PV-cells
- Cell-to-cell connection
- Glass
- EVA
- Tedlar
- ~~Class II isolation~~
- ~~Bypass diodes~~
- ~~Wiring bypass diodes~~
- ~~Aluminium frame~~
- ~~Junction box~~
- ~~High voltage dc-connectors~~
- ~~High voltage dc-cables~~
- ~~Blocking diodes~~
- ~~DC fuses~~
- ~~Overvoltage protection~~
- ~~DC-isolation monitoring~~
- ~~System grounding~~
- Support structure

PV-wirefree laminate

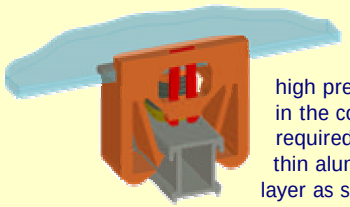
To enable the use of a 4-points connection instead of a frame without using thicker glass, the cells are arranged in 5 columns of 7 cells, resulting in a significant lower tensile stress on the glass. The distance between the connection points is 0.7 m (in both directions). The electrical contacts are positioned on the diagonal angles of the laminates. Except for the cell to cell connections no internal wiring is required. The electrical outputs are located directly under the first and last cell of the PV-laminate, which eliminates the risk of an internal or external short circuit.

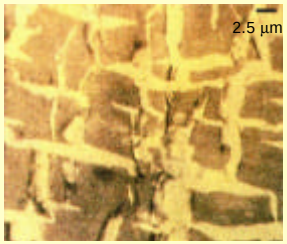


Tensile strength in PV-wirefree 5x7 laminate: Rear and top surface of glass

PV-wirefree module connector

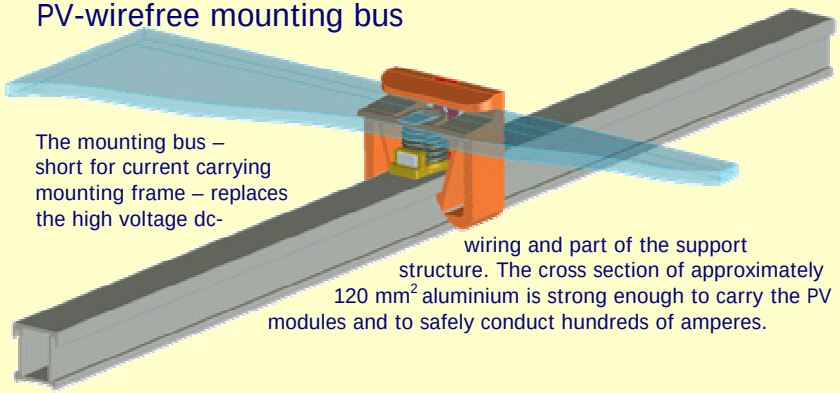
The junction box and the aluminium frame are replaced by four low-cost click and fit module connectors. They secure the module in place. Two of these take care of the electrical connection, a gas-tight aluminium-to-aluminium connection. To ensure a reliable performance of over at least 20 years, the stabilized normal contact force is 100 N, tenfold from what is usual for copper. The high pressure employed in the connection is required to crush the thin aluminium-oxide layer as shown in the picture on the right.





Aluminium-oxide layer crushed under the high pressure of a contact force. The darker areas are oxide, the lighter metallic aluminium

PV-wirefree mounting bus

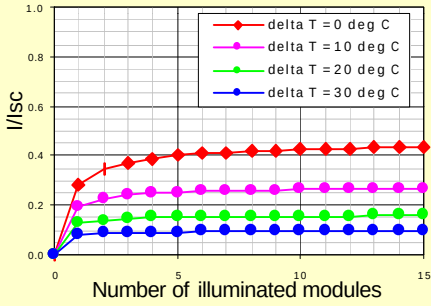


The mounting bus – short for current carrying mounting frame – replaces the high voltage dc-wiring and part of the support structure. The cross section of approximately 120 mm² aluminium is strong enough to carry the PV modules and to safely conduct hundreds of amperes.

Inherent safety

The following basic assumptions regarding unsafe and hazardous situations do **NOT** apply to PV-wirefree:

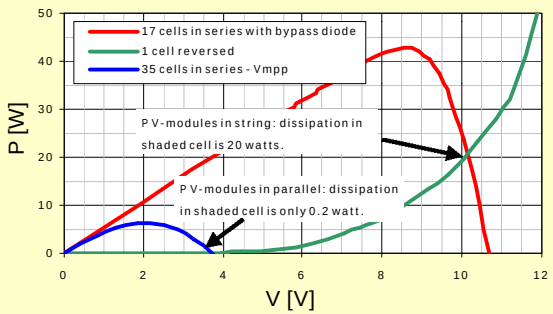
1. **Interruption of high dc-currents is dangerous since it can cause continuous arcing.**
   Arcing requires a minimum voltage of approximately 30 volts. Since the dc-system voltage will never exceed 21 volts continuous arcing will not occur in a PV-wirefree system. Also laboratory and field measurements have shown that during the transient of interrupting a short circuit-current of about 200 amperes in a PV-wirefree system, no voltages above 21 volts occurred.
2. **More than three PV-modules connected in parallel represent a fire hazard due to unlimited back-feeding current**
   With an increasing number of PV-modules in parallel the worst-case back-feeding current will stabilize at less than 0.2 I_{sc}. Provided that the internal wiring can never cause short-circuits within the laminate and blocking diodes are omitted the current is limited to the physics of the cells. Even up to six cells in one PV-laminate may be in full short-circuit without causing the current to increase to values above 2 x I_{sc}, a generally accepted safe value.
3. **Bypass diodes are required to avoid hot spots in case of partial shading.**
   This assumption only applies to PV-string systems. Because of the low difference between de V_{OC} and V_{MPP} the voltage across one shaded cell in a PV-wirefree system will not exceed 4 volts. So, significant reverse current in this cell cannot occur, avoiding hot spots.



Normalized back-feeding current in one shaded PV-module versus the number of parallel connected normally illuminated PV-modules at several differences in temperature of illuminated and not illuminated PV-modules

Fully touch safe

- **During installation** all parts can be touched safely since the dc-system voltage will never exceed 21 volts.
- **During operation** the dc-voltage drops to an even safer value of approximately 16 volts. Moreover, the mounting bus, which carries the current, is covered by the PV-laminates and is therefore hardly accessible.
- **Accidental short-circuits** will not lead to unsafe situations, since interrupting the current in a PV-wirefree system will not cause voltages above 21 volts.



Dissipation caused by partial shading of one cell in a fully illuminated PV-wirefree system will only be 0.2 watt, in a PV-string it will be 20 watts

Elimination of fire hazard

- **No local overheating or continuous arcing in malfunctioning electronic connections.** In a PV-string system malfunctioning of connectors, damaged wiring or a failure in one of the PV-modules causes a fire hazard since a substantial part of power of the total string might be dissipated locally. In a PV-wirefree system this phenomena is limited to the power of one PV-laminate only, which is not enough to cause a fire hazard. Moreover, the voltage is too low to cause continuous arcing and the rugged mounting bus is unlikely to break.
- **No over-current due to back-feeding.** Proper design of the PV-wirefree laminate has eliminated the risk of over-current caused by back-feeding.
- **No hot spots due to partial shading** As explained above partial shading cannot cause hot spots in PV-wirefree systems.