Highly Reliable Redundant Solar Topology

Introduction

The conventional serially connected solar topology is prone to system failure impacting energy production and prompting costly repairs.

A highly reliable solar topology can be achieved by uncoupling the individual photovoltaic elements down to the most basic level, and providing alternate current paths through the system (from cell-to-grid).

1. Problem Statement

In conventional photovoltaic (PV) solar arrays, serially interconnected solar modules are strung together to increase the voltage from module-to-module, limited to 600VDC in North America and 1000VDC in Europe (480 VDC and 800 VDC with required safety margin).

Scaled down inverters termed "micro-inverters" have been introduced for smaller systems where the inverter is attached to each module, but retain many of the topological features of the large central inverters. DC optimizers have also been introduced for attachment at the module, for allowing an improvement in string balancing between panels to reduce the inherent mismatch losses between panels.

One of the most notable issues facing each of these solar topology is the single-point-of-failure nature of these entire systems. Failure of any component in a string, including cells, cell connectors, module wiring, combiner boxes, inverters, etc., results in an immediate failure and requires field service to repair and restart the lost array portion or in many cases the entire array. While micro-inverters and DC optimizers help to minimize the interdependencies of the string components, they are often limited in their operating range and introduce additional electrical components with their own single-point-of-failure dependencies and field service requirements.

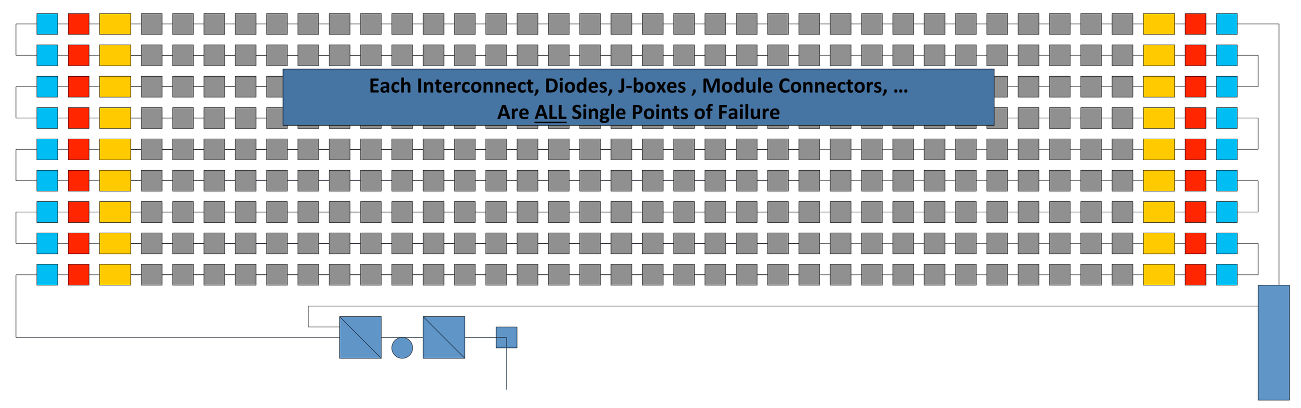

Figure 1. Conventional Solar Serial Topology

2. Highly Reliable Solar Topology

An alternate topology, where there are no single-point-of-failure dependencies within the entire system results in increased efficiency and reliability. This highly fault-tolerant topology is much more consistent with other highly distributed commercial applications, such as in information storage, telecommunications, and the power distribution grid, where failures are tolerated without significant performance impacts, and repairs are managed on extended and planned maintenance schedules. Solar modules used in a redundant topology do not have cells wired serially, but rather use a combination of serial and parallel connections within the module and a proprietary interconnection method to a DC bus. It should be noted that all the components in the system are standard "off-the-shelf" components, they are just configured in a unique package.

Due to the lower voltage at each cell interconnected panel, in order to generate a current and voltage sufficient for conversion to AC energy, a solar charge controller is integrated into each redundant and interconnected module to produce a regulated 48V nominal voltage. In the charge controller is a set of redundant DC converters where the number of available DC converters exceeds the number required to produce full power from the module.

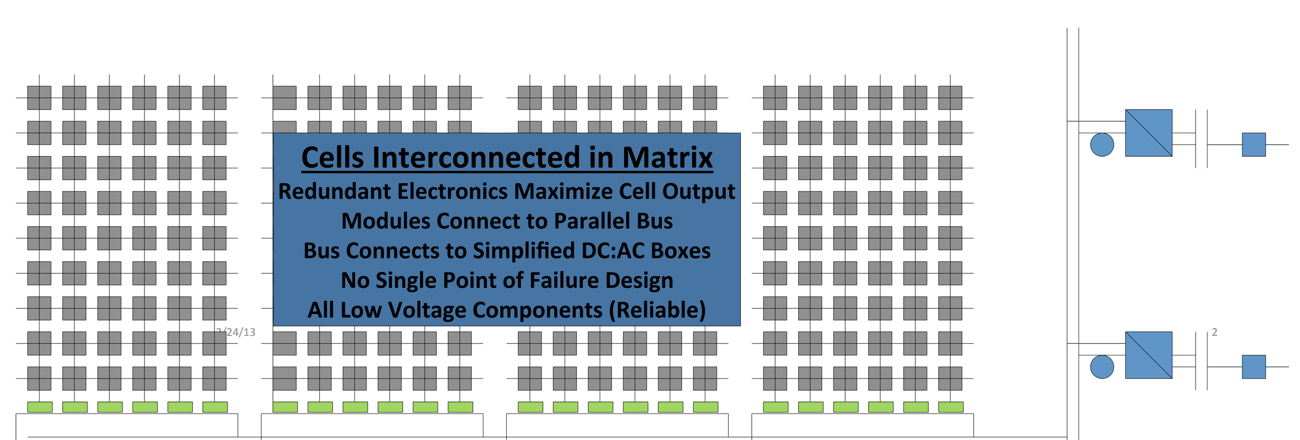

Figure 2. Redundant array of solar modules with interconnected cells.

The deep electronics integration level and the cell wiring method, means any failure in a cell, interconnection, or electronic component does not result in a superordinate decrease in the power production capability of the module as current can flow from any cell to any DC converter (the DC converters are not dedicated to specific groups of cells). No bypass diodes are required in the module to achieve this. The module DC bus interconnects the modules in parallel across the system, and is fed into groups of parallel, 5KW inverters to convert the DC bus voltage into three-phase AC voltage.

The inverters are also connected in a redundant manner. In the event of an inverter failure, the power from a group of modules that would normally be lost with a conventional inverter can flow to adjacent inverters in the redundant system of Fig. 2. Some peak shaving may occur in the remaining operational inverters; however, because of the solar daily power profile the impact of this limit on the total annual energy production is minimal. Any required repairs to the inverters can be on a greatly extended and fixed schedule.

3. Economic Model

Taking the known reliabilities of each system component and levels of redundancy and modeling the resulting system Annualized Failure Rate (AFR) and applying service costs and times to repair, it is possible to project the relative financial impact of common implementation of solar topologies. As is demonstrated the redundant topology greatly reduces the impact of losses due to individual component failure.

In the example given, 1 MW DC nominal solar array is modeled.

Micro-Inverter with 270W PV modules	Base Reliability	Units / String	Redundancy	AFR
Silicon Cells	0.999999	60	1	99.9940%
Module Components	0.999900	1	1	99.9900%
Bypass Diodes	0.999990	3	1	99.9970%
Module-Inverter Connections	0.999990	4	1	99.9960%
Inverter	0.997000	1	1	99.7000%
AC Interconnections	0.999990	2	1	99.9980%
AFR / String Unit				0.3249%
# of "Strings"		3704		
Yearly Repairs		12		$12,035
Impact of Failures (Assume Fixed in One Year)				$455
Total Annual Cost				$12,490

4 kW String Inverters	Base Reliability	Units / String	Redundancy	AFR
Silicon Cells	0.999999	900	1	98.8000%
Module Components	0.999900	15	1	98.0000%
Bypass Diodes	0.999990	45	1	99.4000%
Module Interconnections	0.999990	32	1	99.5800%
Inverter	0.980000	1	1	98.0000%
AC Interconnections	0.999990	2	1	99.9980%
AFR / String Unit				6.0798%
# of "Strings"		267		
Yearly Repairs		6.17		$6,174
Impact of Failures (Assume Fixed in One Year)				$2,800
Total Annual Cost				$8,974

Redundant Topology	Base Reliability	Units / String	Redundancy	AFR
Silicon Cells	0.999999	1000	3	100.0000%
Module Components	0.999900	20	3	100.0000%
Module Electronics	0.999000	10	2	99.9990%
Module-Inverter Connections	0.999990	4	1	99.9960%
Low Voltage 5KW Inverter	0.980000	1	2	99.9600%
AC Interconnections	0.999990	2	1	99.9980%
AFR / String Unit				0.0470%
# of "Strings"		200		
Yearly Repairs (One Repair / Five Years)		0.1		$93.99
Impact of Failures (Repair Required / Five Years)				$399.48
Total Annual Cost				$493.47

Conclusion

Utilizing off the shelf proven conventional solar and power electronics materials, but connected in a novel redundant topology reduces the financial impact to solar arrays of component failures.

Contact

Tim Johnson
tenKsolar
tjohnson@tenKsolar.com
612-845-0776