Relex® Meets Complex Reliability Needs of Enphase Energy

Enphase Energy Uses Relex Reliability Prediction and Relex OpSim Availability Analysis for Solar Power System

Enphase Energy, Petaluma, CA

Enphase Energy has designed a revolutionary new microinverter unit to create a scalable, distributed solar power generation system. In traditional solar energy installations, a single centralized inverter converts direct current (DC) energy to grid-compliant alternating current (AC) energy. One inverter may be linked to many solar panels, meaning that the failure of a traditional inverter results in a loss of the power generated by all of the panels connected to it. In contrast, Enphase Energy's microinverters are smaller, more compact units directly attached to each solar panel in an array to convert power independently at the panel. The new system consists of multiple branches of microinverter units and AC interconnects that function in parallel, similar to a bank of batteries. This configuration introduces complex redundant and dependent relationships into the system that influence its reliability. Enphase Energy contracted Relex Consulting Services to assist in determining the reliability of this system.

The Goals: Analyze a System with and without Maintenance

- Predict behavior of a unit for which failure data does not yet exist
- Estimate availability and capacity over 20 years for two scenarios
- Create a scalable solution applicable to systems of various sizes

The Challenge: System Exhibits Several Design Complexities

- Redundancy, where a single part failure will not cause system failure
- Dependency, where part failure degrades system output capacity
- A defined threshold below which the system is considered failed

The Result: Advanced System Analysis with Relex OpSim

- Relex Consulting Services was contracted to model the system
- Relex OpSim's reliability block diagrams accounted for complexity
- Calculated availability, capacity, number failed, and MTBF

Enphase Energy has designed a revolutionary new microinverter system to improve the reliability, maintainability, and energy output of solar arrays while offering scalability to meet the diverse solar energy needs of homes and businesses.

"The overriding philosophy at Enphase Energy is that quality and reliability cannot be tested into any product – they must be part of every aspect of the business."

– Paul Nahi, CEO of Enphase Energy, in Enphase Energy White Paper, Reliability of Enphase Microinverters (available at www.enphaseenergy.com)

The Case

Enphase Energy's microinverter units are linked to each solar panel in an array. The solar panel, which is not included in this analysis, works by converting solar power to DC power. A microinverter takes the DC power generated by the panel and converts it to grid-compliant AC power. Microinverters are arranged in multiple parallel branches. Each microinverter works like an AC bus, passing the power generated by the microinverter before it through to the next microinverter downstream in the sequence while adding its own power to it. This continues for all units in a branch. The input from all branches is then combined by a Load Center onto one AC bus that supplies full system power (see Figure 1). All units share the load equally: therefore, all units will be running at 25% power when the load on the system is 25%.

System Complexity

With microinverter units and AC interconnects arranged sequentially, the system would appear to be arranged in a series; however, the units actually function in parallel, similar to a bank of batteries. The loss of any one unit will not change the system output voltage, although the output power capacity will be reduced. The failure of either the microinverters or the interconnects each has a different effect on the output capacity of the system, as follows:

- The loss of a microinverter unit results in the degradation of the system output, but only by that unit's capacity
- The loss of a connector results in the degradation of the system output by the collective capacity of all microinverter units upstream from the connector
- The system is considered failed or unavailable when total system output capacity falls below an operator-assigned threshold: typically between 95-99% of design capacity

Goals of the Analysis

Relex Consulting Services was contracted to analyze the availability, capacity, expected number of failures, and MTBF (Mean Time Between Failures) of systems employing various numbers of microinverter units. Using Relex Reliability Prediction and Relex OpSim, the team analyzed the following:

- Performance metrics based on a model that is scalable to the number of microinverters in the system: to test its scalability, the team considered systems with 23, 58, 176, 678, and 5,719 units
- System performance after 20 years under two scenarios: system is repaired and system is not repaired
- System performance considering three possible "failed" states: 99.5, 99, and 98 percent required capacity

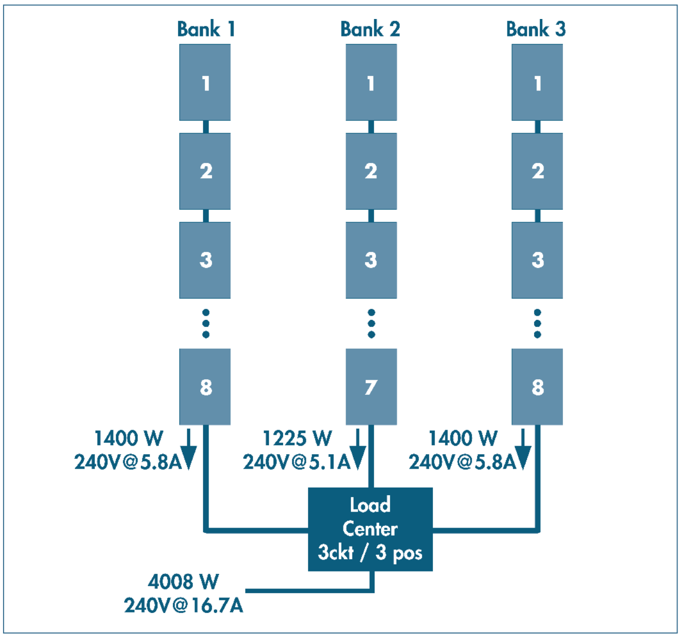

Figure 1: Model of a solar power generation system with 23 microinverters.

The Methodology

To model the anticipated performance of complex system configurations utilizing dependency and redundancy, analysts use a method known as a reliability block diagram or RBD, which is an integrated part of the Relex OpSim module. Relex Consulting Services modeled the system in Relex OpSim using a unique approach to standard reliability block diagrams that supports capacity. Using the model, which was easily scalable for systems consisting of additional branches and additional microinverters per branch, the team was able to calculate system performance measures including point availability, mean availability, capacity, state probabilities, and losses associated with performance degradation. This methodology may be summarized as follows:

1. Because failure data did not exist for the newly-designed microinverter unit, Relex Reliability Prediction was used in accordance with Telcordia SR332 Issue 2 to calculate a base failure rate given the operating parameters of the system
2. A reliability block diagram was constructed in Relex OpSim to account for the configuration of components in the system, the mechanisms of failure, and the effects of failure on system capacity
3. Both functions of the microinverter – AC power generation and AC interconnection – were considered separately because the effects of failure on the system are different for each
4. Capacity was represented as a function of the total number of units in a system, taking into consideration that the failure of the AC interconnect between units n and $n+1$ results in the loss of capacity supplied by microinverters 1 through n of the failed unit's capacity

5. Because the loss of a connector is modeled differently from the loss of capacity, the failure rate may be modeled as a summation of the failure rates of the upstream and downstream connectors

The Results

The system was modeled in Relex OpSim using the powerful features of reliability block diagrams to capture system complexities as follows:

- Diagram linking enabled the microinverter unit to be modeled individually with the correct failure rate and capacity parameters
- All figures in a branch diagram can be linked to the microinverter unit diagram to capture changes in the contributing capacity of one unit as it would be applied to all of the units in the system
- Branch diagrams can be configured with any number of microinverters, with the microinverter figure used multiple times, so that the model can be scaled to accurately represent any size system

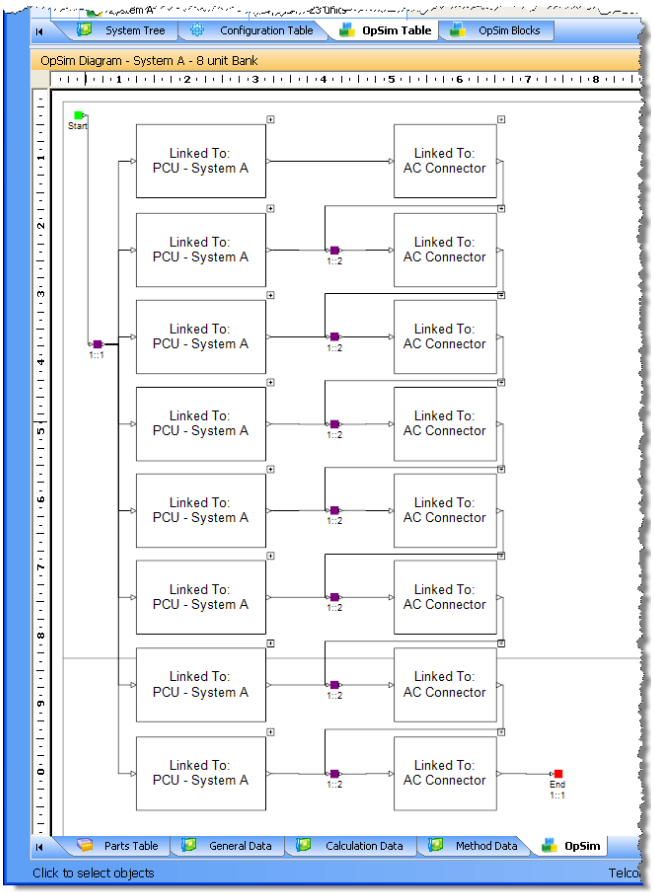

Figure 2: Screen shot of branch block diagram of system modeled using Relex OpSim.

With the system modeled in an accurate, scalable fashion (see Figure 2), calculations can be performed to return availability, capacity, expected number of failures (ENF), and mean time between failures (MTBF) in hours. Calculations accounted for systems of various sizes (Systems A - E, with 23, 58, 176, 678, and 5,719 units, respectively), both with and without repair, and with consideration given to the 99.5, 99, and 98 percent required capacities. In summary, the expected number of failures will increase and the mean time between failures will decrease as the total number of units in a system increases.

- Non-repairable results:

System	MTTF	Capacity
A	3,110,098	81.606522
B	3,760,720	80.915517
C	4,719,274	80.3818352
D	4,498,184	73.014511
E	5,512,335	74.289689

- Repairable results, 99.5% capacity:

System	Avail.	MTBF	ENF
A	1.0000	43,964	3.97
B	1.0000	17,582	9.97
C	0.9998	5,802	30.23
D	0.9999	5,685	30.47
E	0.9999	5,346	32.35

- Repairable results, 99% capacity:

System	Avail.	MTBF	ENF
A	1.0000	43,964	3.97
B	1.0000	17,582	9.97
C	0.9998	11,492	14.99
D	1.0000	9,826	17.43
E	1.0000	8,645	19.82

- Repairable results, 98% capacity:

System	Avail.	MTBF	ENF
A	1.0000	43,964	3.97
B	1.0000	35,104	4.75
C	1.0000	22,670	7.37
D	1.0000	18,171	9.23
E	1.0000	15,244	11.05

Bibliography

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3. Enphase Energy White Paper: "Reliability of Enphase Microinverters." http://www.enphaseenergy.com/downloads/Enphase_WhitePaper_Reliability_of_Enphase_Micro-inverters.pdf

About the Authors

Duane Huffman, a Senior Application Engineer with Relex Consulting Services, and France Antelme, Director of Product Verification with Enphase Energy, authored the 2009 RAMS Conference paper on which this case study was based. Mr. Huffman is an ASQ Certified Reliability Engineer and Six Sigma Green Belt who partners with Relex customers to provide reliability engineering consulting services across the product lifecycle. Mr. Antelme has twenty years of experience in the design and testing of High Reliability Military and Telecommunications Carrier-Class Quality Systems.

For More Information

To learn more about Relex OpSim, or to try a free product demo, visit **www.relex.com/products/OpSim.asp**. To learn more about Relex Consulting Services, visit **www.relex.com/services/index.asp**.

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