# The Systems Driven Approach to Inverter R&D

SAND2005-3089C

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## ABSTRACT

The U.S. DOE Solar Technologies Program includes a broad-perspective inverter research and development plan. Sandia National Laboratories supports and emphasizes the Systems-driven Approach (SDA) in dealing with challenges facing the solar inverter industry today. The approach focuses on identifying the most important research needed to construct reliable hardware to assure effective power transfer from photovoltaic modules to the loads. Selection of R&D priorities weighs how changes in an inverter design affect the market and conversely how changes in the market affect requirements such as inverter cost and performance. For instance, the levelized energy costs (LEC) of a system can be similar with an inexpensive, short-lived inverter or with a more expensive, long-lived inverter. Consumer requirements can exert dominant influences on the inverter design. The importance of materials, processes, components, products, applications and markets for the inverter technology and how they are related to each other are weighed and prioritized for R&D. The "High-reliability Inverter Initiative" along with supporting activities is one activity following the approach and is presented in this paper. Further, a follow-on "High Tech Inverter Research & Development - A Five-year Strategy" that will seek to leapfrog inverter technology with higher reliability, better performance, lower costs and application synergisms is introduced.

## 1. Objectives

Teams at Sandia National Laboratories are focusing today's resources on "Inverter Reliability" that was identified as the most critical inverter challenge in the first "DOE Systems-driven Approach to Inverter Research and Development [1]." Various inverter approaches exhibit unique attributes and specific technical challenges. Accordingly the SDA activities are complemented by inverter modeling and system analysis tools capable of identifying full systems issues. The Solar Program Multi-Year Technical Plan (MYTP) is being used to help determine topics needing the most attention, to explore all of the implications of the research goals, and for linking the objectives of the R&D in a PV systems context.

The overall inverter R&D program being directed by Sandia applies to section 4.1 (Photovoltaic Systems) of the MYTP and in particular to the Technology Development Task, Parts 9 (PV Systems Performance and Standards), 11 (Inverter Testing and Industry Support), 12 (High-reliability Inverter Initiative) and 13 (Inverter R&D –5-year Strategies).

## 2. Technical Approach

The technical approach to inverter R&D is comprised of several fronts. The first and "in-progress" activity is the "High-reliability Inverter Initiative" that was initiated in 2002. The approach for this initiative was to conduct work in three phases. A second "upcoming" front is the "High-tech Inverter Research and Development – A Five-year Strategy". The 5-year strategy is being organized to incorporate new component technologies such as wide band-gap semiconductor devices, high temperature components, thorough thermal management, highly integrated controls and drivers, advanced surge protection, innovative packaging, full systems integration, intelligence, communications and consumer friendly products.

Both the R&D initiative and the 5-year strategies are based on the results of well attended workshops where the inverter industry, the photovoltaic industry, systems designers, utilities, universities and laboratory experts assembled to provide valuable inputs and prioritization for needed R&D.

## 3. Results and Accomplishments

### *3.1 The High-reliability Inverter Initiative.*

The "High-reliability Inverter Initiative" was initiated in 2001 with the first contracts being issued in 2002. The initiative was begun as a response to reports of unacceptable high percentages of inverter malfunctions and outright failures in photovoltaic installations. The schedule included three different phases. The initiative focused on developing designs that could be mass-produced while improving reliability to at least 10 years mean-time-to-failure. Costs were to be improved or at least held in line. The work was coupled to market analysis and prospects for systems integration resulting in high (>10,000 units per year) production rates.

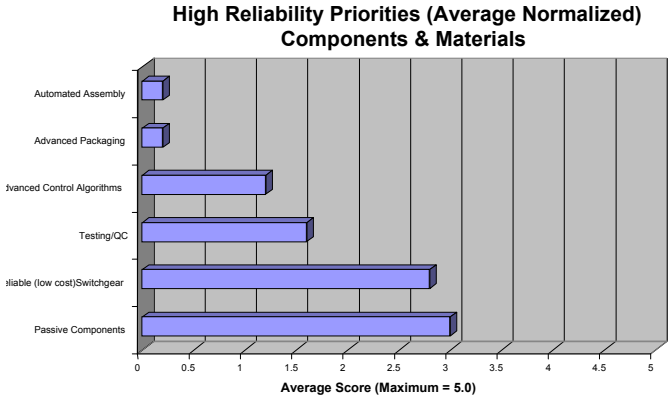


Figure 1. Components and materials prioritization for high reliability inverter development

One theme of the first workshop and the initiative was to examine inverter improvement issues with respect to cost and reliability and to provide perspectives from each. Figure 1 shows the results of one components and materials session of the first workshop and from a high reliability perspective. It shows the passive components (capacitors, transformers, connectors) as a topic needing the most attention from a high reliability perspective.

Figure 2 shows another set of priorities base upon low-cost considerations for inverters. Capacitors were identified as the

highest priority. Thermal management that can be tied to components and packaging followed. All of the high-reliability initiative contractors carefully considered the results of the inverter workshop while designing their next generation high-reliability inverters.

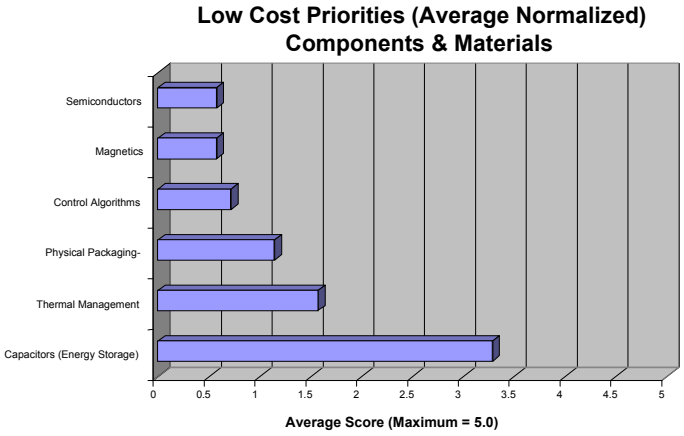


Figure 2. Components and materials prioritization for low-cost inverter development

The Phase I final reports were reviewed by inverter-cognizant personnel at Oak Ridge National Laboratory, NREL and Sandia National Laboratories. This resulted in the three Phase II contracts. The three high-reliability inverter contractors are now in the final stages of Phase II. Deliverables consist of prototype development, follow-on market analysis, product layout, drawings and working prototypes. The Underwriters Laboratories' (UL) required safety and listing testing has been initiated by all contractors. Some HALT tests have been conducted but are required of all. The three contractors will be submitting prototype inverter hardware to Sandia for characterization and evaluations in December 2004. Phase II reports will be used in combination with hardware evaluation results to determine which contractors can be funded for Phase III work. Phase III will take products to commercialization.

***Phase I activities were***

1. Solicit inverter industry proposals requiring high reliability goals and mass production plans for 10,000 units per year. (Three proposals were selected from 12 submissions for Phase I work.)
2. Provide product configurations and architectures that maximize reliability while minimizing costs and manufacturing difficulty.
3. Provide a technical and market plan indicating how the new inverter will be developed.
4. Demonstrate adherence to UL, IEEE, and performance and safety requirements.
5. Report on the Phase 1 where the results were used to determine further development with original contractors.

***Phase 2 is in progress. The Activities are***

1. Conduct Phase II with at least two contractors. It was determined that results of the Phase I work warranted Phase II prototype development with all three. The three contractors are General Electric, SatCon and Xantrex.
2. Finalize development of new inverter designs, with emphasis on efficient switching; manufacturing processes, packaging, thermal management, surge suppression, and overall enhanced performance.
3. Assess, test, and validate new designs, including full characterization; component-level tests, system performance analysis, packaging validation technology and cooling effectiveness.
4. Validate compliance to utility-interconnection standards such as IEEE 1547 and UL1741**.**

***Phase 3 is intended to***

1. Conduct Phase III with at least two contractors.
2. Refine prototypes into commercial products, maintaining conformity to pertinent standards, performance, cost, and manufacturing objectives.
3. Conduct testing of final products through laboratory evaluations, UL, highly accelerated life tests (HALT), environmental testing, and long-term evaluations.

### *3.2 The "High-tech Inverter Research and Development – A 5-year Strategy"*

The high-tech strategy to inverter R&D is currently in the planning stages A with a first draft of the strategy document nearly complete. A final draft is scheduled for final draft stage in January 2005. This strategy will also be based on the outcome of DOE Solar Technologies Program inverter workshops. It will be designed to partner with key stakeholders to determine needs and to set priorities before proceeding. The structure of the proposed "High-tech Inverter R&D Strategy" is to conduct work in phases with interim sanity checks with opportunities to introduce new contractors and ideas for evolving technology on an annual basis.

## 4. Conclusions

The SDA to inverter R&D is now matching products with system- and market-driven needs. The SDA workshops have been extremely successful in identifying industry needs and program directions. The initial reliability and cost estimates of the new high-reliability inverter designs exceed the goals of the initiative. The participating contractors are planning to include the new high reliability inverter designs into primary product lines. Impacts for the photovoltaic industry include lower LEC and a general improvement in the reliability and public perceptions of grid-tied photovoltaic systems.

## ACKNOWLEDGEMENTS

The author acknowledges Dan Ton for his supporting efforts in organizing key DOE workshops used to prioritize inverter R&D and to provide input for the needs of the high reliability initiative and the 5-year strategies. Additional acknowledgements go to Sigifredo Gonzalez and Jerry Ginn for the many technical reviews and support with the high-reliability inverter initiative. This work is supported by the U.S. DOE under contract to Sandia National Laboratories, a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

## REFERENCES

[1] D. Ton; A. Bulawka, W. Bower, *Summary Report on the DOE Workshop On a Systems-driven Approach to Inverter Research and Development*, published by the US Department of Energy, September 2003.