

Progress on a 100-kw, Low-cost Energy Storage Inverter¹

Larry Rinehart (Rinehart Motion Systems, LLC; Lake Oswego, Oregon, USA); larry@rinehartmotion.com
Memo Romero (Rinehart Motion Systems; Lake Oswego, Oregon, USA)

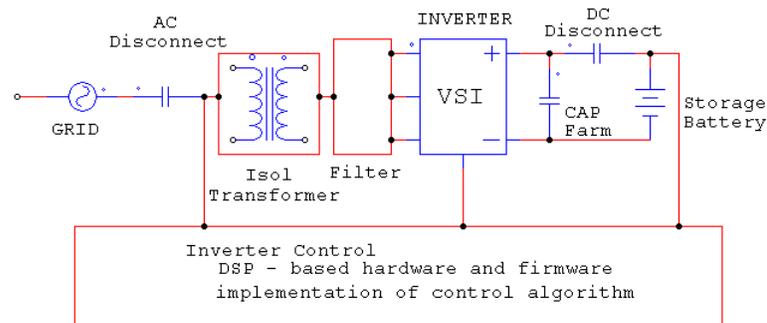
Introduction

Based on the technology developed under a grant from the United States Department of Energy, Rinehart Motion has completed a full-scale, 100-kVA utility-interactive storage inverter prototype. The prototype (shown in the photo, right) measures 28 × 28 × 36 inches (0.71 meters square × 0.91 m tall, or 462 L)—about the size of a residential dishwasher. The system-level specific volume is 0.216 kVA/L and, at approximately 760 pounds, the specific density is 0.29 kVA/kg. This prototype offers significant size and cost reductions compared with currently available inverters in this power range. The custom-designed cabinet and cooling system replace a 7-foot-tall industrial switchgear enclosure (an approximately 3:1 volume reduction) and allow for stand-alone outdoor or indoor use.



The prototype is actually a complete power conversion system (PCS) not simply an inverter. The complete system, shown in the line-diagram below, includes the following components:

- A new water-cooled inverter assembly;
- A standard switchgear;
- System-level circuit protection devices (including AC and DC disconnects, fast fault-limiting fuses, circuit breakers, etc.);
- A line-frequency isolation transformer;
- A system-level, closed-fluid cooling loop (including power module heat exchanger, flow and temperature monitoring, and cooling radiators);
- A graphical user interface for system operation and monitoring (including local PC-based and internet WAN-based communications); and
- Control power and housekeeping functions.



¹ Funded by the Energy Storage Systems Program of the U.S. Department Of Energy (DOE/ESS) through the Small Business Innovation Research (SBIR) program, and managed by Sandia National Laboratories (SNL).

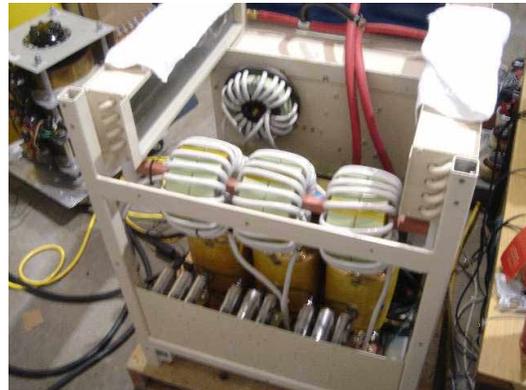
The Issues

The electric utility industry's requirement for galvanic isolation between the DC battery storage system and the AC distribution line is a major issue that dominates the size, weight, and cost of the system. *In our prototype, the line-frequency transformer used for galvanic isolation accounts for 660 pounds of the system's 760-pound total weight (and 30% of the system by volume) and is the single largest cost item in the system (see the photo at right).* Using a high-frequency, bi-directional isolated DC-DC converter for galvanic isolation is technically feasible and would reduce the component weight from 660 to approximately 100 pounds, but would increase the component cost from \$.20/kVA to an estimated \$50/kVA for a 100-kVA unit. Obviously, such a large cost increase is unacceptable when one is developing a 'low-cost' inverter.



A more practical approach for cost reduction would be to eliminate the requirement for galvanic isolation between the DC storage system and the AC distribution line. Currently, the photovoltaic inverter industry allows a non-isolated inverter system design for isolating DC photovoltaic generation from AC distribution. For battery storage applications this isolation could be accomplished by appropriately packaging the storage battery(ies). *Following the lead of the photovoltaic industry with respect to the isolation issue is the single most significant system cost reduction opportunity available for inverters in this power range.*

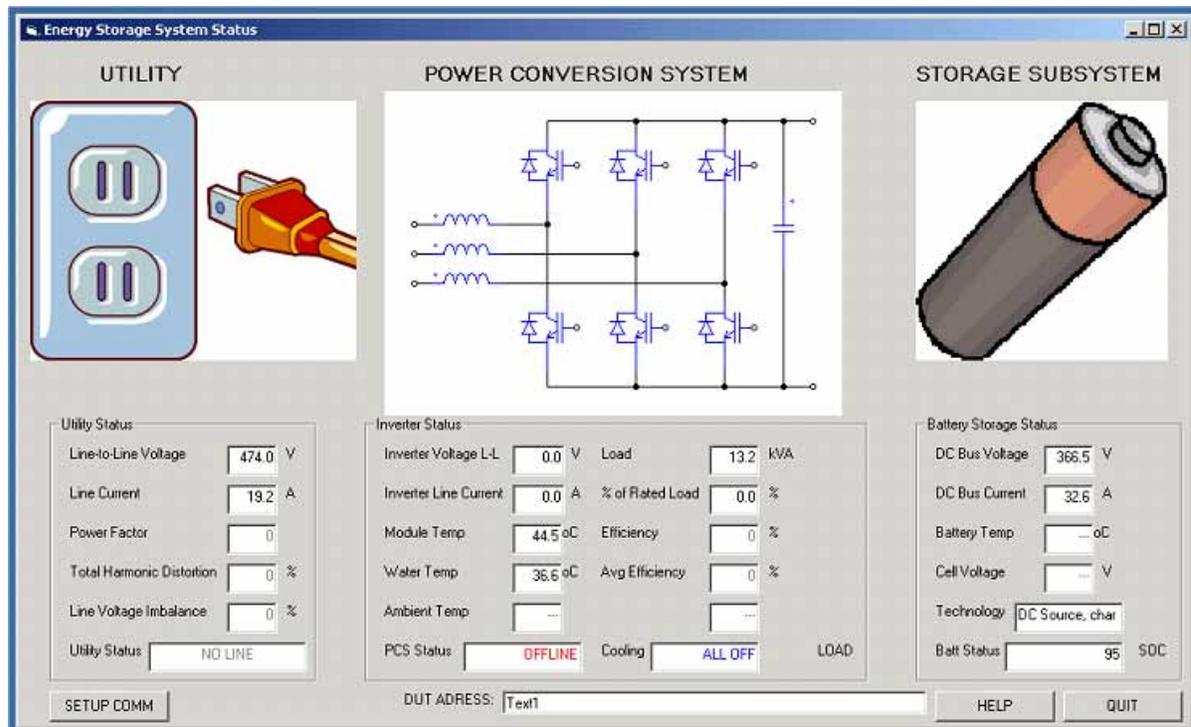
Other factors affecting the total cost of these inverter systems are electromagnetic interference (EMI) suppression, system cooling, and providing adequate software for operations and communications among all system components (the utility, the PCS, and the battery storage device). Providing adequate EMI filtering is required for compliance with International Electrotechnical Commission (IEC) and Federal Communications Commission (FCC) regulations. The necessary filtering equipment (shown at right) adds significantly to the cost and volume of the system and reduces the overall efficiency of the inverter system (or PCS). Presently, an easy, economical solution for providing the necessary filtering simply does not exist.



Although the inverter for the system contains a large IGBT power module that generates significant heat, the inverter itself does not represent the major cooling challenge for the system. The new, closed-loop, liquid cooling system is a highly efficient solution for cooling these components—the real challenge is cooling the balance of the system. The major issue is air handling. The system must be designed to allow sufficient air flow through the transformer and EMI filtering magnetics in order to avoid heat conduction into the sealed cabinet that houses the system's computer control hardware and prevent premature aging or damage to these passive components.

Software development is also a significant factor in the cost (if not the size) of the system. Software is used to allow communication between the battery storage system and the inverter and between the inverter and the utility and to provide operation and/or monitoring functions for one or more of these systems (see the sample system operation and monitoring screen, below). Once the inverter hardware has been integrated with the utility and the battery, establishing communications between these systems is necessary, but rarely straightforward. While

the inverter system itself is well understood, once integrated, the inverter system's software must be refined to accommodate differences in utility transmission and distribution systems as well as differences in battery storage devices. Additionally, users have come to expect an easy-to-use, graphical interface and remote system monitoring and operation that can be accomplished in real-time. These expectations, while not unreasonable, add to the complexity of any system software.



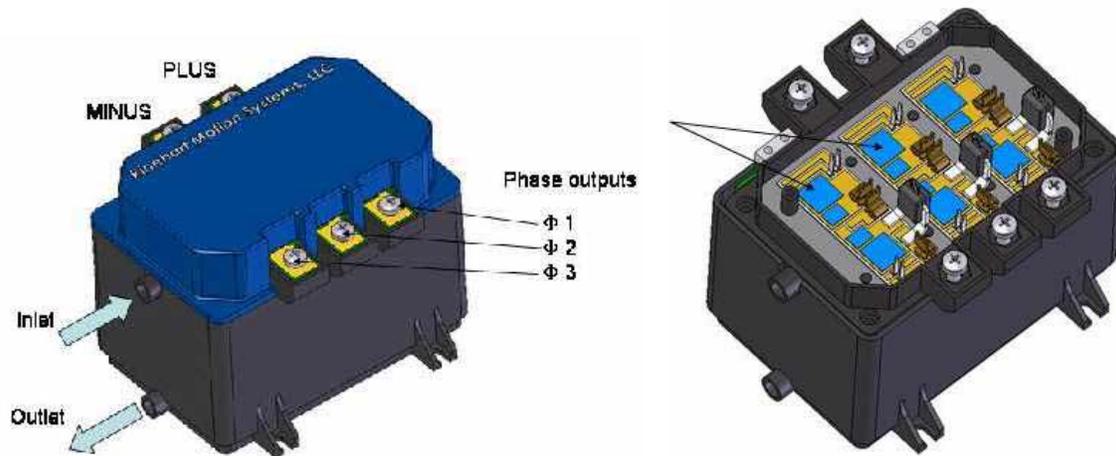
The Next Steps

Currently, production prices for the 100-kVA unit are estimated at \$120/kVA or 60% of today's market price. This is still too high to create the widespread market acceptance that will generate a large demand for such systems. Our examination of the opportunity indicates that the cost should be reduced to around \$70/kVA (or around 35% of today's market price) to stimulate significant adoption and market growth. Developing a non-isolated integration strategy (as discussed above) would be one practical and extremely effective way of accomplishing this cost reduction as well as reducing overall system volume, weight, and air-handling requirements. Additionally, the system's control software needs to be expanded to add storage technologies other than lead-acid batteries, specifically advanced battery technologies (*e.g.*, lithium-ion and sodium/sulfur) and electrochemical capacitors.

Finally, to initiate industry's acceptance of the technology, it will be necessary to target a specific niche market to adopt the technology. Once the technology has been proved in the niche market, it will be positioned to gain acceptance across a broader market spectrum. At this point, it will be necessary to fabricate improved small and large inverter systems based on new inverter hardware.

The New Inverter Hardware

RMS is currently developing the concept for a 30-kW, non-isolated inverter (shown in the diagram below, left). The dimensions of this inverter are 85 mm × 100 mm × 126.5 mm (1.07 L) for a power density of 30 kW/L. This design incorporates the bus capacitors into the inverter module itself and takes advantage of fluid cooling to decrease the size and prolong the life of the device. The gate drivers and digital signal processor (DSP-) based controls will fit on two printed circuit boards arranged in tiers above the sealed power electronics envelope. The power electronics envelope will contain IGBTs and diodes that mount internally on small substrates that are cooled by the fluid flow (as shown in the diagram below, right). This inverter represents the low end of a technology that can, theoretically, be scaled up to 1 MW.



Conclusion

Developing a new, low-cost 'inverter' is relatively easy. Developing a complete PCS for energy storage applications that will be viable in the marketplace is considerably more complex. Nevertheless, many opportunities exist for reducing costs for both the inverter hardware and the PCS, but doing so will require some significant changes to regulatory guidelines and standard industry practices.

Acknowledgements

Rinehart Motion Systems would like to thank Dr. Imre Gyuk and the DOE Energy Storage Systems Program for continued financial support and Stan Atcitty and Sandia National Laboratories for the technical support that has allowed this program to succeed.