Selective Source AC/DC Power Supply

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In an effort to improve efficiency, the Missouri S&T Solar House Team is exploring the idea of using a household DC electrical circuit which uses power directly from the solar panels. This would bypass conversion losses both at the inverter and in household components that rectify AC to DC current internally, therefore saving energy and money. The approach taken was to develop a power converter that will allow power to flow bidirectionally, either from the solar array when available, or from the grid otherwise, and simultaneously power both DC and AC loads in the house. A prototype converter system design has been implemented in hardware in a scaled-down (200W) version and is being optimized for maximum efficiency. When completed, the system can be scaled up and modularized to best match efficiency vs. system size vs. cost. This will also enable homeowners and businesses to improve the efficiencies of photovoltaic products that they already own.

The project team began by developing a block diagram of a system to allow both an AC and a DC bus to be used simultaneously in a house utilizing photovoltaics. The converter incorporates a SEPIC type converter for maximum power point tracking (MPPT) on the solar side, a power factor correction (PFC) circuit to minimize power consumption from the grid and achieve unity power factor, and an inverter to supply the AC loads. The heart of the system is a highly efficient, high frequency dual active bridge (DAB) converter. The DAB is used both to isolate the two different sources of voltage from each other, and to allow the power from these sources to be transferred in either direction, depending on source availability and household load requirements.

The project was technically intensive and it took time to find and recruit team members who were capable of the complex circuit design. A good mix of electrical engineering undergraduate and graduate level students was finally recruited from the Solar House Team. The team then had to determine input, output and bus voltage levels for each module, and the sensors required to monitor the circuits to enable control. Taking an overall view of the system function made clear these requirements. Each module was designed and tested separately to cater to specific needs, and each had their own troubleshooting challenges. Finally, after individual modules were constructed and operated as specified, DSP programming was required to integrate them into a properly-operating combined system. This required the assistance of an upper level graduate student with the expertise necessary to accomplish this task. The combined efforts of the team members eventually yielded a working prototype converter, and test results were positive and promising.

The SEPIC converter performs as designed and effectively accepts input voltages between 12V and 35V to accommodate a range of operating conditions for the PV module, a Kyocera KD215GX-LPU (215 W @ 26.6 V, 8.09 A, with open-circuit voltage of 33.2 V). An outer control loop achieves MPPT using the conventional perturb-and-observe (P&O) algorithm. Fig. 1 shows the input voltage of the SEPIC converter when the MPPT algorithm is reaching the maximum power point. In this case the top trace is the input voltage of the SEPIC and the bottom trace is the input current to the SEPIC. The MPPT algorithm regulates the input voltage from 30 V initial to 16.5 V and the input power to the system from the PV module is increased to 110 W from the initial value.

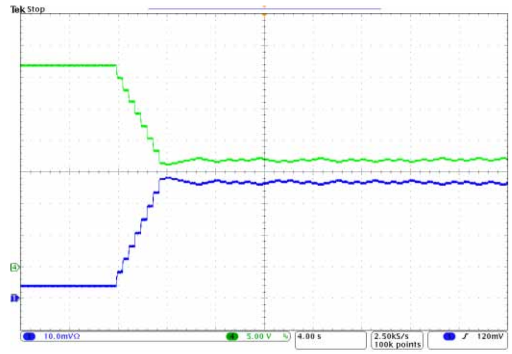
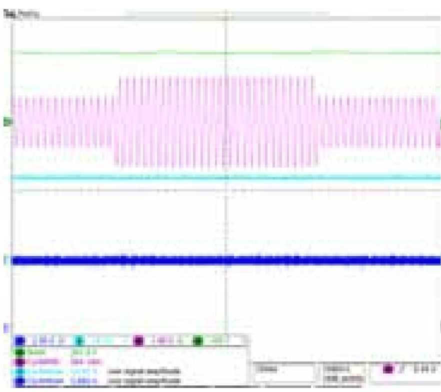
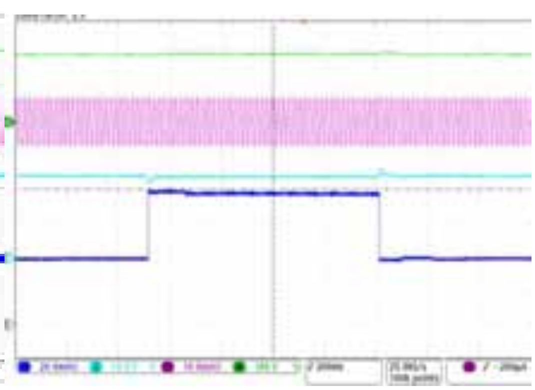


Figure 1 - MPPT in Action

DC loads are connected to the 24 V bus, and the DAB converter regulates the low voltage dc bus under a wide range of operating conditions and supports bidirectional power flow. Fig. 2 shows the performance of the system when the dc load equals to 100 W and the ac load is stepped-up from 60 W to 120 W and then stepped back down to 60 W. Fig. 3 shows the performance of the system when the ac load equals 60 W and the dc load is stepped up from 100 W to 200 W and then is stepped back down to 100 W.





200 VDC Bus

AC Current Load

24 VDC Bus

DC Current Load

Figure 2 – AC Load Step Change

Figure 3 – DC Load Step Change

In both experiments, the PV module is supplying constant power to the low voltage dc bus and the high and low voltage buses are robust against the changes. The PFC converter is a rectifier cascaded with a boost converter and effectively provides power factor correction and 200 V bus regulation. The various power converters are all controlled via a central digital signal processor (DSP), a Texas Instruments TMS320F28335.

To pursue this research, a grant was obtained from the US Environmental Protection Agency via their People, Prosperity and Planet (P3) program. The P3 program is a student competition involving pilot studies in support of sustainability. After presentation of the converter at the P3 Expo in Washington, D.C., the team was awarded an honorable mention for its potential long-term impact in the area of energy efficiency.

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Biographical Information

Charles Wright (cmwwv8@mail.mst.edu) is a senior at Missouri S&T majoring in Electrical Engineering and Economics. He holds an A.A.S. in Aviation Maintenance from Spartan College of Aeronautics and Technology - Tulsa, OK, and has worked in the aviation electronics engineering industry since 1990. He is the electrical lead for the Missouri S&T Solar House Team and a member of Tau Beta Pi, Phi Kappa Phi, and I.E.E.E.

Reza Ahmadi received the B.S. degree in Electrical Engineering from Iran University of Science and Technology, Tehran, Iran in 2009. He is currently a Ph.D. candidate and graduate research assistant at the Missouri University of Science and Technology, Rolla. His research interests include modeling, design and control of power electronic converters, electric-drive vehicles and multi-input power converters.

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Anagha Rayachoti is a graduate student at Missouri S&T, pursuing her Masters degree in Electrical Engineering. She is also associated with the Solar House Team at Missouri S&T.

Alberto Berrueta Irigoyen is a senior in Electrical and Mechanical Engineering at Universidad Pública de Navarra, in Spain. He was a member of the mechanical group for the Missouri S&T Solar House Team. He is currently taking part in a research project about ultracapacitors and fuel cells at his university. He volunteers in an acquired brain injury association and is a national badminton referee.

Jonathan W. Kimball (kimballjw@mst.edu) received a BS from Carnegie Mellon University in 1994 and MS and PhD degrees from the University of Illinois at Urbana-Champaign in 1996 and 2007, respectively. He has ten years industry experience at Motorola, Baldor, and SmartSpark Energy Systems. Since 2008, he has been an assistant professor of electrical and computer engineering at Missouri University of Science and Technology in Rolla, MO.

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Power Converter to Improve Solar House Efficiency

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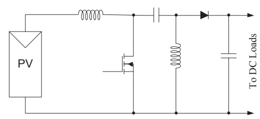
Abstract

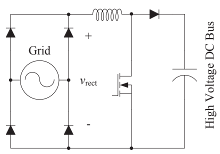
In an effort to improve efficiency, the Missouri S&T Solar House Team is exploring the idea of using a household DC electrical circuit which uses power directly from the solar panels. This would bypass conversion losses both at the inverter and in household components that rectify AC to DC current internally, therefore saving energy and money. The approach taken was to develop a power converter that will allow power to flow bidirectionally, either from the solar array when available, or from the grid otherwise, and simultaneously power both DC and AC loads in the house. A prototype converter system design has been implemented in hardware in a scaled-down (200W) version and is being optimized for maximum efficiency. When completed, the system can be scaled up and modularized to best match efficiency vs. system size vs. cost. This will also enable homeowners and businesses to improve the efficiencies of photovoltaic products that they already own.

Technical Accomplishments

The converter incorporates the following modules:

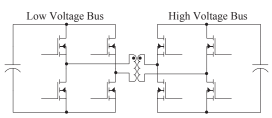
MPPT - a SEPIC type converter for maximum power point tracking on the solar side

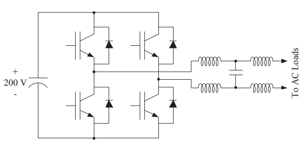




PFC - a power factor correction circuit to minimize consumption from the grid, achieve unity power factor, and maintain a constant grid-side dc bus voltage

DAB - the heart of the system is a highly efficient, high frequency dual active bridge. The DAB is used to both isolate the two different sources of voltage from each other, and to allow the power from these sources to be transferred in either direction depending on source availability and household load requirements.





Inverter - to supply the AC loads

DSP - The various power converters are all controlled via a central digital signal processor (TMS320F28335, Schematic Not Shown)

Lessons Learned

- <u>Recruiting students with correct skills:</u> project was very technically intensive and it took time to find team members who were capable of complex circuit design. A good variety of electrical engineering undergraduate and graduate level students was finally recruited from the Solar House Team.
- <u>Defining port specifications for each module:</u> had to determine input, output and bus voltage levels for each module, and the sensors required to monitor the circuits to enable control. Taking an overall view of the system function made clear these requirements.
- <u>Design of individual modules:</u> each module was designed and tested separately to cater to specific needs, and each had their own troubleshooting challenges.
- <u>Coordinating the functionality of different modules:</u> after individual modules were constructed and operated as specified, DSP programming was required to integrate them into a operating overall system. This required the assistance of an upper level graduate student with the expertise necessary to accomplish this task.

The combined efforts of the team members eventually yielded the working prototype converter shown in the photo to the right. The scope shots below show: Figure A, the performance of the system when the dc load equals to 100 W and the ac load is stepped-up from 60 W to 120 W and then is stepped down to 60 W. Figure B, the performance of the system when ac load equals to 60 W and the dc load is stepped up from 100 W to 200 W and then is stepped down to 100 W. In both experiments, the PV module is supplying constant power to the low voltage dc bus. In both cases the high and low voltage buses are robust against the changes.

Figure A

Figure B

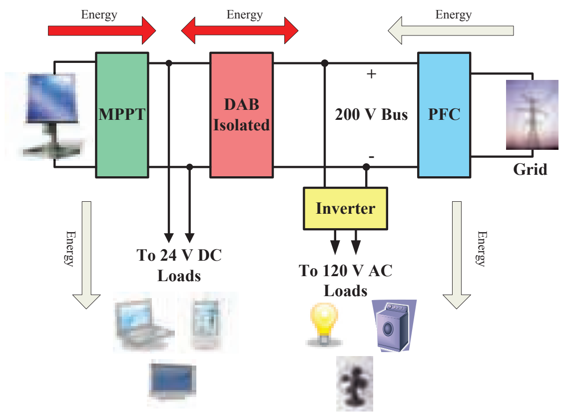
200 VDC Bus (green)

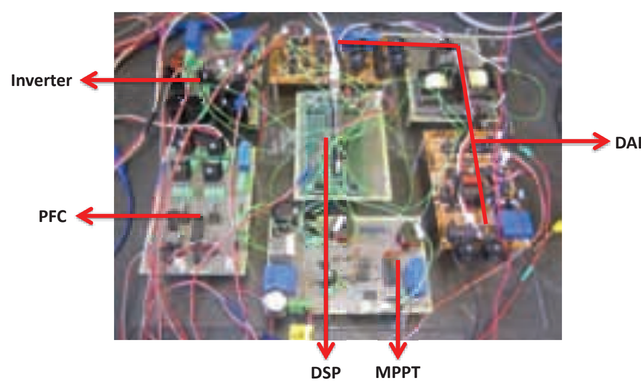
AC Current Load (magenta)

24 VDC Bus (cyan)

DC Current Load (blue)

Block Diagram Implemented in Operational Hardware





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