HYBRID AC/DC POWER CONTROLLER FOR DC HOUSE

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Executive Summary

At Cal Poly State University, we are currently developing a Hybrid AC/DC house as a proof of concept in implementing a mixed of DC electrical system and AC electrical system in residential distribution system. The implementation of the dedicated DC electrical system is motivated by the promise of increased efficiency through a direct path for DC sources and DC loads. In particular, the avoidance of DC-to-AC and AC-to-DC conversions used in typical residential systems especially those with DC sources such as solar panels could experience higher efficiencies through only DC-to-DC conversions between the sources and the loads. Another feature of the proposed Hybrid AC/DC House is the existence of the crisscrossing paths between AC source to DC loads, and DC source to AC loads. Using this architecture allows for improved reliability in power delivery to the house in case one of two sources is not functioning or out of service. This report summarizes the design and development efforts to establish an AC/DC Hybrid house at Cal Poly State University. Results of the development along with further work needed for the complete construction of the Hybrid House will be presented in this report.

Introduction and Background

Electrical power passes through transformers during distribution introducing power losses. The U.S. Energy Information Administration (EIA) shows that this distribution process averages losses of 5%. These losses translate to billions of kWhs are lost due to the size of the operation. AC power distribution has its benefits, but the increase of direct current (DC) loads in consumer products decreases its effectiveness. Residents with photovoltaic systems experience losses from DC to AC conversion. AC power commonly converts back to DC either for energy storage or for DC loads such as LED lights and rechargeable USB devices. AC to DC conversion experiences losses between 23% and 28%, resulting in substantial amounts of wasted power.

The use of hybrid AC/DC systems in urban neighborhoods promotes the use of renewable energies and increases the sustainability of the community. Neighboring houses utilizing hybrid systems can form a local DC grid allowing sharable power. The connection of multiple DC systems allows a system producing excess power to provide electricity to a system producing less power than required by the loads. Neighborhoods utilizing connected DC systems can also benefit from a more robust power grid that can mitigate blackouts. When AC service lines experience a disruption, all the homes downstream are affected, while a broken connection in DC does not result in the same effect since homes on either side of the break provide power to one another. Use of DC electricity in rural communities lends another application to the DC system. Rural communities lacking AC infrastructure benefit from an efficient DC power system. Furthermore, the use of DC systems and infrastructure provides a more practical approach to powering these communities [3]. The system includes energy storage which provides power to the system when the sources have low or no production. The use of energy storage increases the robustness of the system and is ideal not only for users who lack access to AC power but also to reduce power consumed from the grid for those with a grid connection. The increased focus on renewable energy requires efficient residential systems. Our society requires electricity to function, and because of this, innovations must be made to our current power systems. Finding new ways to increase efficiencies and make power available to all is crucial to our future. A hybrid AC/DC house aims to fulfill this.

Design Requirements

The Hybrid AC/DC House project will serve as a basis for further senior project work in the future. Designing a 48VDC bus to implement direct DC power within preexisting residential power systems generation is the primary design goal of this project. The project will be implemented into a 7 foot by 12 foot shed outside the Electrical Engineering building at Cal Poly. The system is designed to meet NFPA 70A: Requirements for one- to two- family dwellings. Shown in in Figure 1, the preliminary system consists of two inputs, the typical 120V, 60Hz AC already available in residential homes and a 12VDC input which comes from a solar panel. The system can implement more inputs if desired. Energy storage is important when solar power is being used, so excess power produced from the panels will be stored in batteries and can be utilized when the solar panel is not producing sufficient power for the system. This project implements three different outputs, a preexisting AC output, a 12VDC output, and a 24VDC output.

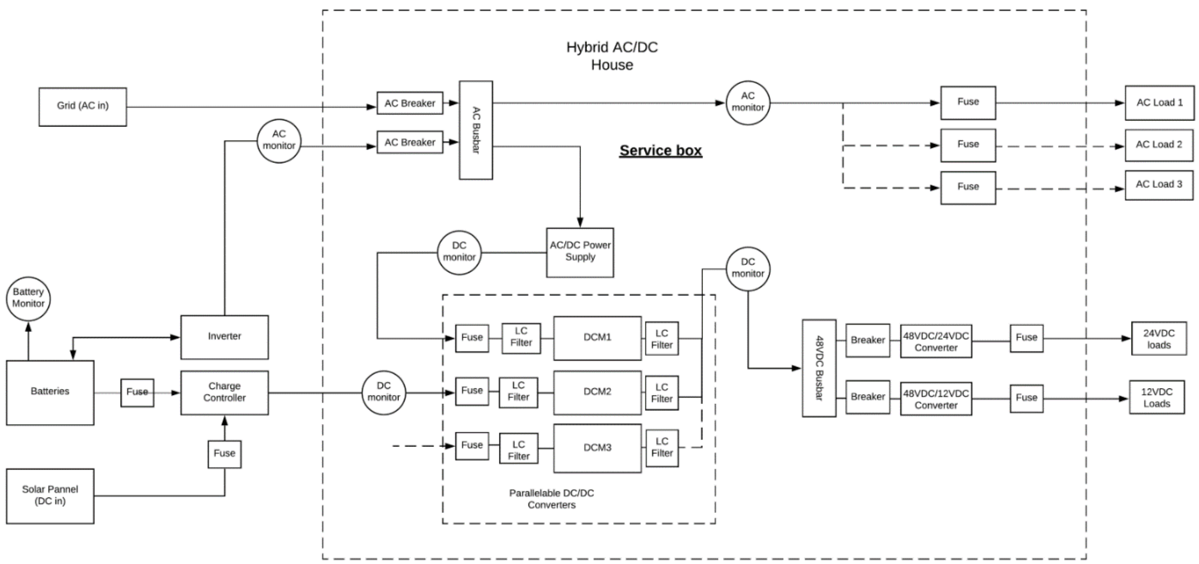

Figure 1. Block Diagram of the Hybrid AC/DC House

These are several major components selected for the Hybrid AC/DC house:

1. Solar panel capabilities: a preinstalled 18V, 210W solar panel will be the primary source of DC power
2. Charge controller: a Renogy Rover 30A MPPT charge controller that allows for DC loads up 20A
3. Energy storage: Li-ion battery since it a higher energy density, more charge cycles, and less maintenance then lead acid
4. Parallelable converters: Vicor DCM3623T50T53A6T00 converters for a wide range of input voltages which enables us to add more converters with input sources that may have different voltage levels
5. Power supply: the PSC-15124 by Altech. The PSC-15124 provides 150W at 24V from 115VAC source

Table 1 summarizes the specific design requirements for the house.

Table 1. AC/DC hybrid home specifications

Engineering Specifications	Justification
A 48V, 6.66A max DC Bus connecting sources and loads.	Research found 48V as the most efficient. DC bus eliminates need for AC/DC conversion. The DC bus is created by Vicor DCMs.

One DC output of 12V, 3A with a ripple factor of 0.02 or less	In our proof of concept, the television and LED light operate at 12VDC. Many LED lighting systems also operate at 12VDC.
One DC output of 24V able to support multiple loads totaling 100W	Our system should be able to support multiple DC loads of varying voltages.
Project requires one AC 120Vrms 60Hz output.	This represents pre-existing AC in home.
System power efficiency from source to load of 90% or more.	AC systems have a typical efficiency of 82%-87%
13VDC input 210Wpk panel	We already have this panel, 210W provides sufficient power for this system.
12V storage capacity of 80Wh for 8 hours	12V is a common battery size and cheaper than its higher voltage counterparts. 12V also matches the solar panel. Devices powered: 65W television, LED light 7W.
Follow NFPA 70A: Requirements for one- to two- family dwellings.	This is the national electrical standard for one and two person dwellings from the National Fire Protection Agency
10 AWG wire to carry DC Bus voltage	This wire size can handle our DC bus voltage with minimum losses.
System will be implemented in a 7 foot by 12 foot shed.	This shed is utilized for DC house in the Electrical Engineering patio at Cal Poly.
5A DC load protection	DC loads take about 5A, anymore would harm the loads. So, 5A limiters are needed. The DC side of the system is a little more unstable since what is being implemented is still relatively new.
Standard AC protection	AC system should be relatively stable since AC is common in most homes today. So, no special power protection is needed.
Ability to monitor voltage, current, and power the system in real time and data log.	Real time measurements will be needed in cases of failure and logged data will be important to find trends with this system.
12V, grid tied, and 500W minimum inverter.	12V is the voltage of the battery. Grid-tied allows for synchronization with the grid. 500W minimum allows for headroom over the load usage.
Ability to safely convert generated power to stored power.	A charge controller will be able to store the generated power safely and efficiently from the solar panel. Efficiency can increase with the usage of an MPPT charge controller.

Hybrid House Design and Construction

Figure 2. Parallel DCMs

The hybrid AC/DC house was constructed in four separate blocks. These blocks are input solar system, bus, output converters, and monitoring. The input stage consists of the solar panel, charge controller, and battery. The DC bus block contains the paralleled DCMs, power supply, and breakers, all of which are contained in the main enclosure. The monitors have a separate enclosure with a clear lid, within these monitors are the AC and DC monitors along with their accompanying shunt bars. Finally, the output stage includes the output converters which are within the main enclosure and wall outlets that are external of the enclosures.

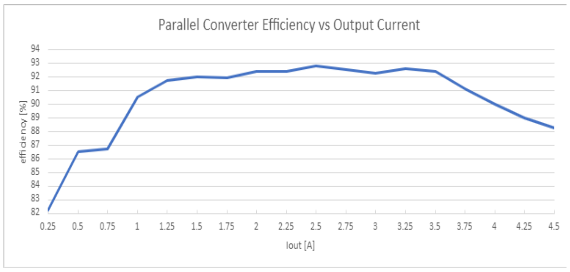

Figure 3. Efficiency of Parallel DCMs

To connect the battery to the charge controller, terminals were required to attach the 12 AWG cables to the battery securely. Size 5/16 nut, bolt, and washer were used to secure the fuse to the terminated cables. To connect the charge controller load output to the converter input, a wire nut was used. The inverter was connected to the Bussman 05171262702 100A fuse and then to the battery using the provided wires. Grounding of the inverter was required so 3/8” x 48” steel rebar and 12 AWG wire were used. The parallel converter design consists of two DC/DC converters in parallel with diodes on the output connected in a common cathode configuration shown in Figure 2. The efficiency curves of both converters running in parallel is shown in Figure 3. Due to power supply restrictions, efficiency vs. output current measurements were taken up to 4.5A, 216W.

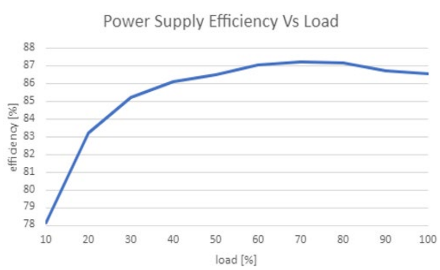

Figure 4. Efficiency of Power Supply

The AC power supply was tested, and the maximum measured efficiency is 87.42% at a 70% load of 105.7W. Figure 4 shows the power supply efficiency vs percent load graph.

The two DC outputs were 24V at 100W and 12V at 120V provided by 48VDC/12VDC 120W converter as seen in Figure 5. For data collection, the electronic load was set in constant current mode, and was adjusted for percent load in 10% increments. As shown in Figure 5, the efficiency for the 48/24VDC 100W is highest around 60% load with a value at 90.1% efficiency. The average efficiency is 88.2%.

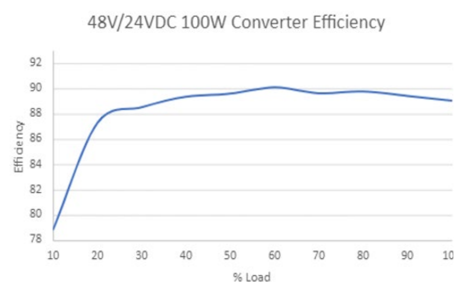

Figure 5. 48V/24VDC 100W Converter Efficiency vs. Percent Load

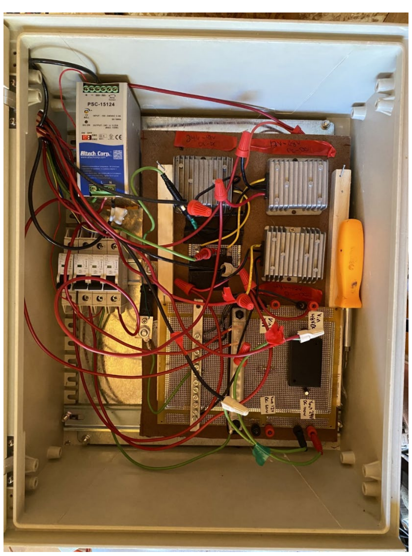

Figure 6: Completed Enclosure

The main enclosure contains the power supply, parallel DC-DC converters, and the output converters. The enclosure used is a NEMA enclosure Vevor B08ZYJ2QC4. A backboard was fitted with DIN clips and attached to the rails to allow for the parallel converters and the output converters to be hung by nails. The inside of the enclosure can be seen in Figure 6. The monitors will be placed in the BUD NBF-32218 NEMA enclosure. This enclosure has a clear lid to allow viewing of the monitor. To install the basswood backplate, DIN rails were cut to size and installed using machine screws. The system was tested and works successfully for these five cases: DC only power, both AC grid and inverter power, only inverter power, only AC grid power, and both AC and DC. All cases were powered using the 24VDC lights and the 12VDC fan. Currently there is no way to control which source gets priority over the other. The only way to do so is by closing and opening breakers. This system also requires roughly 2 to 4 minutes in order to startup when all main power cables are unplugged: solar, battery, inverter, and AC grid. The final hybrid system setup is shown in Figure 7.

Figure 7: Final Hybrid AC/DC House System Installation

Conclusion

The project successfully constructed the first version a Hybrid AC/DC house that allows the use of mixed AC and DC sources to power AC and DC loads. The hybrid electrical system has also been successfully installed that connects the AC source from the grid to deliver power to AC and DC loads, and the DC source to also deliver power to AC and DC loads. The parallel converter configuration using the OR diodes that enables the crisscrossing of the AC and DC sources/loads operates as expected. However, avoiding the use of the diodes will further improve the performance and efficiency of the system and therefore will be one improvement project that we plan in the future. To further improve the efficiency of the hybrid house, an improvement to automate the system making it a smart house is desirable. Designing the program for and implementing a microcontroller or similar device would be practical for a real-world setting. The battery monitoring system should also be improved upon so the battery status can be seen on the charge controller. Additional monitoring should be added for the 12V and 24V lines to check load current and power draw. Another function that would be very useful is to add remote monitoring and control. Remote monitoring would allow for the user to see all the values of the system without having to be physically present. Then from those values the user should be able to turn on and off certain sources. Further research could be done regarding this. With these recommendations in mind, we hope that the Hybrid AC/DC House will continue to improve and become a product to be used in residential settings.

References

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