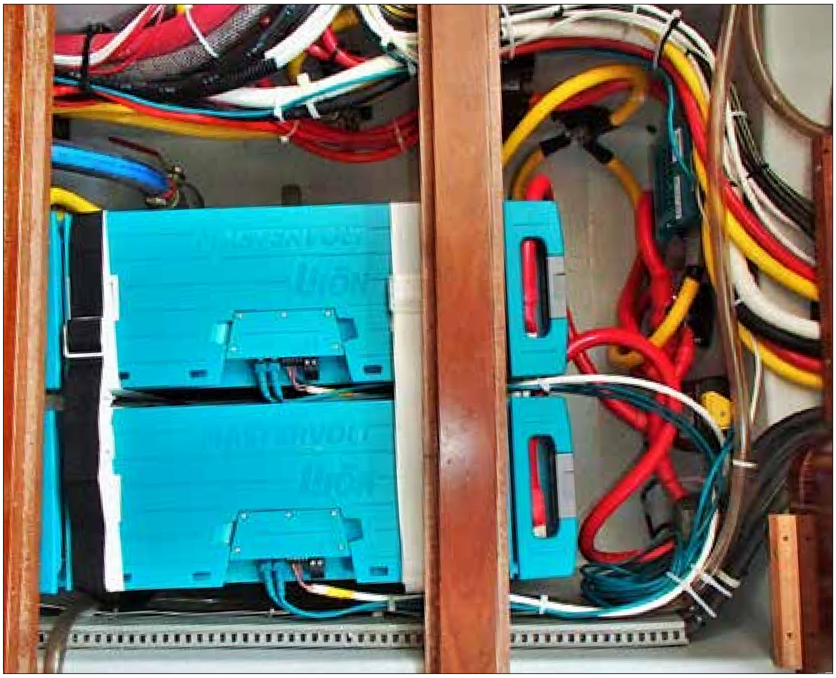


Chemical Conversion

The owner makes the switch from lead-acid to lithium batteries aboard his cruising sailboat.

Text and graphics by Mark Lenci
(except where noted)

When the house battery bank on our sailboat was due for replacement, we converted from AGM (absorbed glass mat) to lithium batteries, primarily to take advantage of their high charging rate. Our goal was to reduce the amount of time we ran the generator while cruising. After cruising for three-and-a-half months with the new batteries, we are extremely pleased with their performance, which reduced genset run time approximately 75%.

Here I'll detail our experiences making critical modifications to the onboard electrical system and then cruising the first season with lithium batteries.

Background

Sunflower is a 2004 Bénéteau Oceanis 523 (53.3'/16.3m) sailboat extensively modified for long-range "luxury" cruising in northern latitudes. She typically carries four to six people, including me, my wife Beverly, and guests. We use a significant amount of AC and DC electrical power. *Sunflower*'s typical battery discharge rate when sailing is 15 amps to 40 amps DC, depending on the draw from equipment and cyclic loads. Discharge rates at anchor at night typically average around 10 amps DC. When cruising we expect to run the genset for a short period in the morning and for a somewhat longer period at night, for a total of about four hours per day. We do not supplement the battery-charging capabilities with solar power or a wind generator due to the relatively large amount of electrical power consumed.

For the house bank on board the author's 53.3' (16.3m) Bénéteau sloop, Sunflower ***(right),*** *these two 12V/360-Ah lithium-ion batteries from Mastervolt* ***(above)*** *replaced six AGM 12V/160-Ah batteries from the same company. The change in battery chemistry allowed for a 30% reduction in weight, cut the physical size of the battery bank, resulted in a 20% increase in usable capacity per cycle, and promises a threefold increase in overall battery life span.*

Prior to the conversion to lithium technology, *Sunflower*'s house battery bank of six Mastervolt AGM 12V/160-Ah (amp hour) batteries provided a total usable capacity of 480 Ah (maximum allowable discharge is 50%). We could charge the house bank with the 80-amp alternator on the Yanmar diesel engine and through a Mastervolt Mass Combi inverter/charger capable of up to 100 amps charging current.

Our primary objective in switching to lithium batteries was to charge the bank significantly faster, reducing run time for the genset at sea and at anchor. The secondary goal was to improve the operational and maintenance efficiency of the generator by putting a higher load on it while running. Running at low loads for prolonged periods is detrimental to the longevity and performance of a diesel generator (for more on generator efficiency, see "Genset Shootout," *Professional BoatBuilder* No. 113).

In practice, the charging current for lead-acid batteries (including AGM, gel, and flooded cells) starts high and quickly drops off, decreasing to near zero as the battery approaches full charge. This results in long periods of genset run time at low current.

The charging current for lithium batteries in practice is limited by the capacity of the battery-charging devices, and the charging current remains high until the batteries are essentially fully charged (99%). The charging efficiency of lithium batteries is 90%–94% (compared with 70%–83% for lead-acid batteries). This means that for 100 Ah discharged, you charge approximately 111 Ah into a lithium battery or 142 Ah into a lead-acid battery. I estimated that a lithium battery bank would charge in about half the time of the AGM battery bank, due to the lithium battery's higher sustained charging current and its better efficiency.

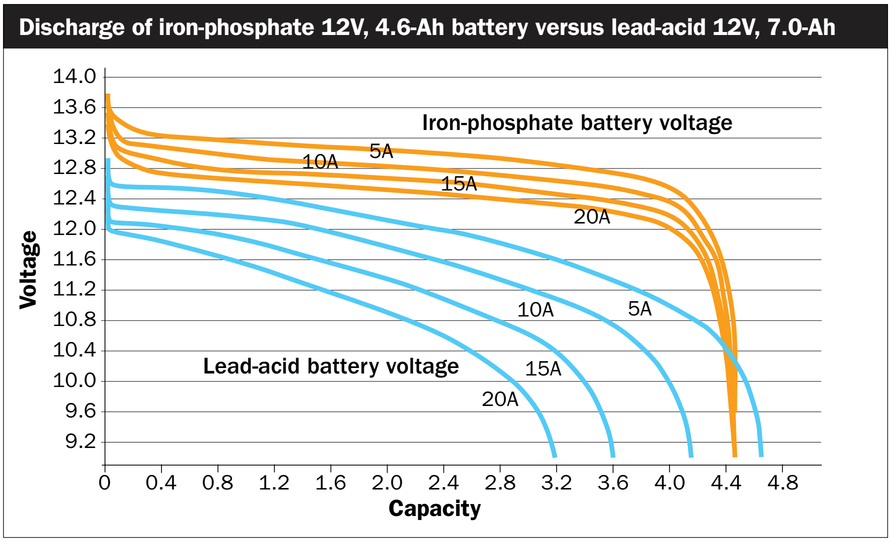
In addition to faster charging, lithium batteries promised these additional compelling advantages over lead-acid chemistry:

No voltage drop during discharge. The voltage of lithium batteries doesn't drop as they discharge, unlike lead acid batteries. This was important to us, as some of our electronics—the radar dome with a long cable partway up the mast and a satellite receiver—do not function properly with reduced DC voltage.

Battery lifetime and bank capacity. The new lithium house bank should offer more than three-and-a-half times longer life than the AGM house bank. Based on our historical battery use on *Sunflower*, we could expect a lifetime of 20 or more seasons. The two 360-Ah lithium batteries have 20% more usable capacity per cycle than six 160-Ah AGM batteries.

Weight and size. Lithium batteries weigh about 30% of comparable lead-acid batteries. Additionally, the footprint of our two lithium batteries measures somewhat less than half the footprint of the six AGM batteries they replaced.

Maturity and safety of the technology. In spite of some concerns that we early adopters might be vulnerable to battery-development glitches, professional experience and preliminary research left me confident that lithium batteries were a safe and practical alternative to our AGM bank. I have an electrical engineering background and spent a career as an officer in U.S. Navy nuclear submarines. I have been following lithium battery technology for years. In my opinion, the technology of the batteries, control systems, and other major electrical system components has matured sufficiently to justify their broad marine application. The three vendors I would recommend—Mastervolt, Genasun, and Arc3—offer lithium-phosphate batteries that have extensive field time and have been proven safe. Their



Lithium–AGM battery bank comparison

Battery type	Number of batteries	Total Ah house bank capacity	% discharge per cycle	Lifetime cycles	Lifetime in Ah	Usable bank capacity
Lithium – 360 Ah	2	720	80%	2,000	1,152,000	576 Ah
AGM – 160 Ah	6	960	50%	660	316,800	480 Ah

Top—*Typical discharge rates of lithium and lead-acid batteries illustrate that the former chemistry holds its working voltage to a lower level of discharge than the latter. Many modern electronics are sensitive to voltage drops and are not reliable when bank voltage is nominal.* ***Bottom***—*Despite its smaller physical size and lower total amp hours, the lithium bank delivers higher usable amp hours and longer service life than the AGM bank.*

Left*—*Building a new base with brackets for the new lithium house bank, left, and for the smaller standard AGM starting battery. Considerations for housing the new system included adequate ventilation for temperature control around the new chargers but not the batteries themselves.* ***Right*—*The author's brother Greg Lenci unpacks one of the new lithium batteries dockside as the new system is installed.

sophisticated control systems should provide worry-free operation. As you will see, this doesn't mean I believe that consumers, boatbuilders, or service yards should embrace any and all lithium batteries on the market. You have to do your homework.

Cost. Lithium batteries cost five to eight times more than equivalent-capacity AGM batteries in initial purchase price. The lithium batteries from the three companies I cited above are in the 360-Ah to 400-Ah range and priced somewhat over $6,000 each. However, lithium batteries' expected service life is at least three times that of AGM batteries. When I calculated the cost of replacing a bank of six AGM batteries three times and compared it to the cost of a single bank of two lithium batteries, the lithium batteries cost significantly less. But, as we discovered, there are additional costs associated with conversion. New electrical-system components are likely required when switching to lithium batteries, as well as labor for the upgrade. However, savings will also be realized if the genset run time is cut by more than half, with resulting reductions in fuel, maintenance, and frequency of generator replacement.

With all these promising qualities in mind, we resolved to make the change.

Choosing a Vendor

An Internet search will produce a dozen or more vendors of lithium batteries advertised for marine applications. I ruled out most products as engine starting batteries, batteries designed for small-boat trolling motors, and any vendor that suggested lithium-ion batteries are a "drop-in" replacement for a house bank of lead-acid batteries. While drop-in replacement might be the case for a start battery, that is *not* the case for a house bank. Mastervolt, Genasun, and Arc3 stood out as understanding the complexity of applying lithium batteries to larger house banks and having meaningful practical experience.

I chose Mastervolt because of the large investment I had already made over the years in its equipment on *Sunflower*. After speaking with the other vendors, I believe all three are good choices, and I'll discuss their different technical approaches on page **xx**.

Designing the New System

On any boat, an upgrade to lithium batteries requires a thorough design review and most likely reengineering of the charging portion of the DC electrical system. Let's consider the characteristics of the lithium batteries that drive the design of the DC system and the practical implications based on our experience.

To start with the battery itself, a battery management system is essential to any lithium battery. That's because during charging, one or more cells in the battery pack will reach maximum charging voltage before the others; during discharge, the cells that are not fully charged will be depleted before the other cells in the pack. Both situations are detrimental to the

The open top of a Mastervolt lithium battery reveals wiring that runs through the unit's internal active management system, which balances the eight different cells, transferring current of as much as 20 amps from the stronger to the weaker during charging and discharging.

battery. To avoid this, each Mastervolt lithium battery has a cell management system. (Other vendors have their own management systems.)

According to Mastervolt's lithium battery user's guide, the management system in our batteries does the following:

• balances between the eight different cells within a single battery. Mastervolt's "active" system transfers current up to 20 amps from the stronger cells to the weaker cells during charging and discharging;

• protects each separate cell from overcharging or discharging, by monitoring the voltage of each cell;

• prevents overdischarge of each battery with an external cutoff relay;

• monitors temperature of the eight cells, the external temperature of each battery pack, and the printed circuit board;

• communicates with charging devices via the MasterBus network and controls charging devices (stop-charge, reduce-charge, etc.).

Two primary characteristics drive the design of a lithium-battery-powered DC electrical system to differ from that of a conventional lead-acid-battery system. First, the charging requirements of lithium batteries are different from those of lead-acid batteries. Second, the operating voltage of lithium batteries differs from that of lead-acid batteries. That means the lithium battery does not use the three-step charging algorithm of lead-acid batteries. Basically, a lithium battery is either charging or it's not. To accommodate these characteristics with a battery-charging device designed for lead-acid batteries, the charging algorithm must be modified, which requires a battery charger with the capability to accommodate such adjustment.

For example, the manual for our new lithium batteries specified the following modifications:

• Bulk and absorption voltage setting: 14.6V, as opposed to 14.4V bulk phase charging voltage and 14.25V for the absorption phase for AGM/lead-acid batteries.

• Float voltage setting: 13.5V, as opposed to 13.25V for the float voltage phase for AGM/lead acid batteries.

• All charging devices can receive a stop-charge command from the lithium battery, allowing cell balancing. Each lithium battery sends out a stop-charge command to the AC-powered battery chargers and to the regulator for the engine alternator; this switches the charging devices to the float stage.

Lithium batteries require three significant considerations in designing the charging portion of a boat's DC electrical system:

1. Charging devices for the lithium batteries must enable adjustment to deliver the batteries' charging requirements, and must be able to respond to the stop-charge command from the batteries, in our case, via Mastervolt's MasterBus control network.

When we started this project, *Sunflower* was equipped with a Mastervolt 12V, 2,000W inverter/100-amp DC charger ("Mass Combi"). This

To meet the altered charging demands of the new battery bank, this 160-amp ElectroMaax alternator replaced the original the 80-amp alternator fitted to Sunflower's *100-hp (75-kW) Yanmar diesel engine.*

COURTESY ELECTROMAAX

Since the existing alternator needed to be removed and its control system modified to permit the use of an external regulator, we opted to purchase a new, higher-capacity alternator, which we thought would provide a higher charging current to the lithium batteries.

I initially planned to use a Mastervolt alternator, but it became apparent that significant custom work would be required to devise mounting brackets for the Mastervolt alternator and to upgrade the two pulleys on the Yanmar engine to a double-V belt or serpentine belt. To control costs, I looked for a solution that would provide both the alternator and the belt/pulley kit.

I found that ElectroMaax (Beamsville, Ontario, Canada) provided high-capacity small-case alternators and an engine pulley kit specifically for Yanmar engines. ElectroMaax was willing to remove its built-in regulator system and configure the alternator per the guidance provided from Mastervolt's technical support team. This was more complicated than I anticipated,

device was monitored and controlled by an older Mastervolt control system (MasterLink MICC or Mass Inverter Charger Control), which could not support the newer MasterBus interface of the lithium batteries. We removed the old system and its associated DC shunt, and installed a new Mastervolt MasterShunt. A Mastervolt MasterView Easy Mk II monitoring-and-control panel replaced the older inverter-control panel, and since the Mass Combi inverter/charger has only a serial interface for control, we purchased a Mastervolt MasterBus serial-interface to connect it to the new MasterBus control network.

Sunflower was equipped with the original 80-amp alternator for her 100-hp (75-kW) Yanmar diesel engine. To respond to a stop-charge event and to be able to adjust the charging algorithm for lithium batteries, we would need to install a Mastervolt Alpha II Pro external regulator, which connects to the control network.

because Mastervolt's external regulator uses a negative (N) field control, and most U.S.-manufactured alternators use a positive (P) field control. ElectroMaax could accommodate both, so I purchased a custom-configured ElectroMaax 160-amp alternator and serpentine belt/pulley kit.

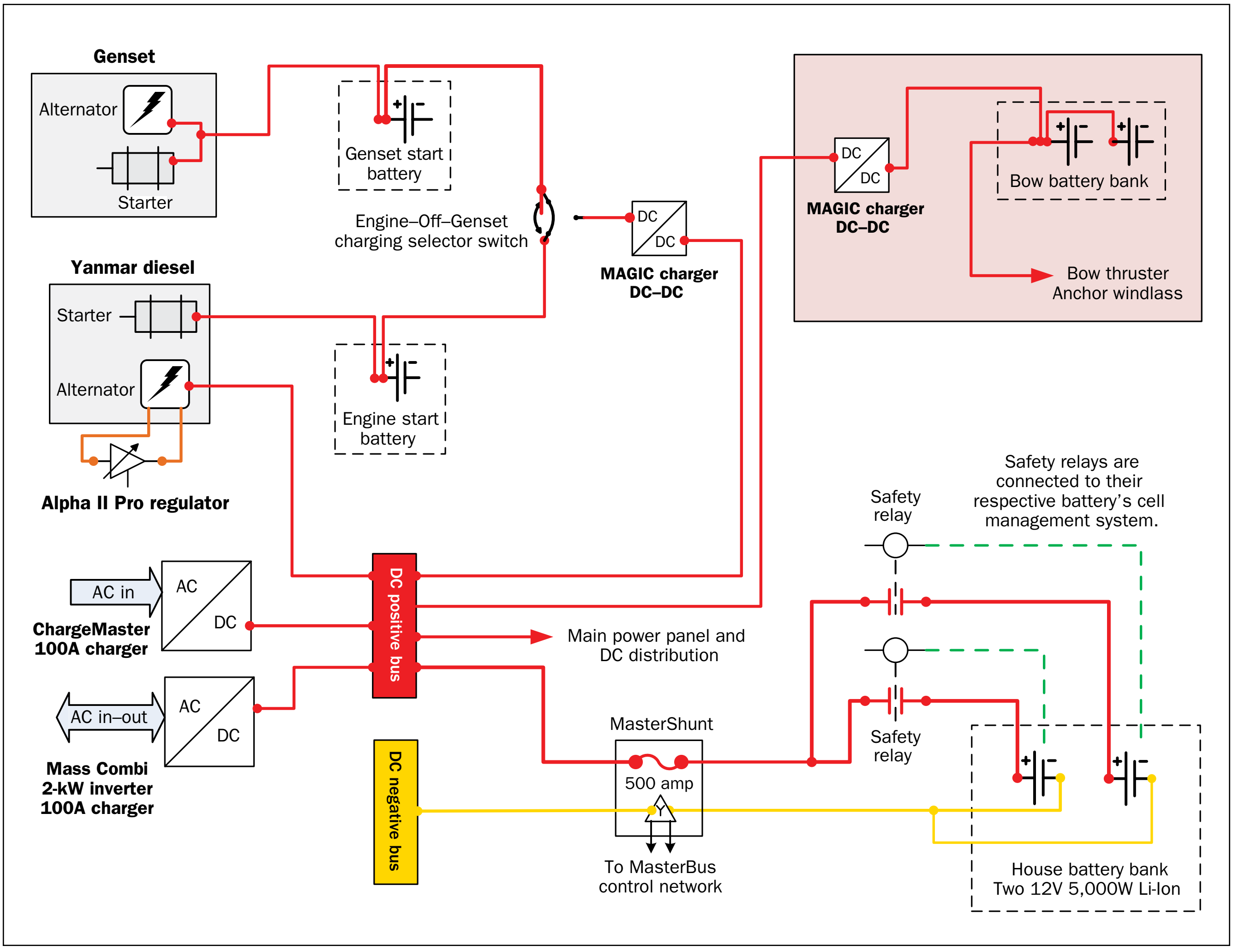
With the aid of the company's installation video and basic mechanical tools, I finished the installation easily in 45 minutes.

COURTESY ELECTROMAAX

The new alternator was equipped with a serpentine belt/pulley kit, which the author installed himself. Note that even this higher-capacity model was not designed for the draw from lithium batteries; the unit's sole defense against overheating during extended periods of high-capacity charging is its temperature sensor and external regulator.

ElectroMaax cautioned that alternator design had not yet advanced to handle lithium batteries drawing full capacity while charging from the alternator for extended periods. They also cautioned that the alternator temperature sensor of the external regulator (attached on the outside of the alternator casing) is critical to prevent alternator overheating. Temperature control of the alternator would turn out to be one of the most significant lessons learned.

Control and monitoring of the charging system is through Mastervolt's MasterBus data network, a CAN-bus with a proprietary overlay that connects different Mastervolt devices via Ethernet cables. It also enables central monitoring and control of connected devices. The network enables connected devices to be programmed to send commands to initiate various actions in connected devices. We do routine monitoring with the MasterView Easy MKII monitoring-and-control panel mounted into the boat's custom electrical and control panels; however, more extensive capability than is provided by the MasterView Easy is required to program devices and analyze their performance. MasterView provides free downloadable MasterAdjust software for this purpose. The monitoring and configuration capabilities of MasterAdjust were essential for the initial setup of our system and periodic detailed monitoring. It requires a USB interface device to connect the boat's laptop to the MasterBus.



A simplified diagram of Sunflower*'s new DC power system. Note that important fuses, disconnect switches, loads, and most of the DC negative cabling is omitted for clarity.*

2. Charging AGM/lead-acid batteries in the boat's DC system will require a separate device to deliver the proper three-step charging profile.

Sunflower's DC system still has four AGM batteries—one diesel-engine start battery, one generator-set start battery, and a bank of two batteries in the bow for the thruster and anchor windlass. Her new design automatically charges these batteries through two Mastervolt 12V-to-12V, 20-amp MAGIC (multipurpose adjustable galvanic isolated converter) devices configured as three-step battery chargers. One charger normally charges the diesel-engine start battery and if needed, the generator start battery via an "A–Off–B" switch. The other charger charges the thruster/windlass battery bank. Both chargers draw 12V power from the main DC bus.

The two fully automatic MAGIC chargers charge the AGM batteries with a standard three-step charging profile. In the default configuration as a charger (set by dip switches), the MAGIC charger will charge the AGM batteries automatically whenever they are discharged. This means that if there is no other charging source (i.e., the engine alternator or the 120V chargers) operating, the lithium batteries will supply MAGIC chargers. I found that load on the lithium batteries from the MAGIC chargers was insignificant after normal operations using the anchor/windlass battery bank or the engine-start battery.

The MAGIC chargers can optionally be connected to the MasterBus network for advanced configuration, monitoring, and control. This connection requires a MasterBus serial interface unit for each charger. I purchased and installed a unit on one MAGIC charger to obtain more detailed monitoring of the charger's operation and to explore custom configurations. My most significant observation was that if the load on the lithium batteries from the MAGIC chargers was of concern when no other power source was available, the configuration options using this interface would allow the operator to configure the MAGIC charger so that it charged only the AGM batteries if the lithium batteries were also being charged. This is accomplished by adjusting the "low input on" setting to 13.4V, which is higher than the nominal lithium voltage (13.2V) and below the float charge voltage (13.5V) of the lithium batteries. Thus the MAGIC charger should operate only when a charging source for the lithium batteries is present. As we found the load from the MAGIC chargers was insignificant, we did not use this alternate configuration.

The chargers have the optional capability to be switched off remotely by a push button. I did not test this capability, and we do not use it.

3. Sufficient charging capacity is required to take advantage of the lithium battery's higher charging rate.

We purchased a Mastervolt ChargeMaster 12V/100-amp battery charger to double the charging capacity of the boat's Mass Combi 2,000W/100-amp inverter/charger. Because the ChargeMaster connects directly to the MasterBus, no network interface device is required.

I considered replacing the installed 2,000W/100-amp inverter/charger with a Mastervolt 4,000W/200-amp model. After analyzing AC loads on *Sunflower*'s inverter bus and reviewing operational experience, I determined there was already excess inverter capacity, so the additional expense of a larger inverter/charger, versus simply adding the second charger, was not merited.

As we gained experience with the new system, we found we needed the ability to limit the battery chargers' output in port so we did not exceed shore-power capacity. The inverter/charger had this feature, and the ChargeMaster charger did not (see Lessons and Recommendations, below).

Figure 1 is a simplified view of *Sunflower*'s DC power system. Please note that important fuses, disconnect switches, loads, and most of the DC negative cabling are omitted for clarity.

Lessons and Recommendations

• We concluded that lithium batteries are ready for prime time. The Mastervolt lithium batteries, their battery management, monitoring-and-control system, and the other required major components are mature and ready for production use. The battery-monitoring system appears to work very well in practice. Extensive monitoring capability is provided through the network and monitoring software.

Each battery has a safety relay that can automatically disconnect the battery for "safety events" triggered when the battery management system of either battery detects a parameter that reaches the safety limit. Examples are low voltage, high voltage, and high cell or battery temperature. If everything is working properly, these limits will never be reached because the control system will correct the situation before either battery reaches a safety limit. The operator can also open these relays remotely or manually. (We leave them open when the boat is in winter storage.) The batteries and components are built for the marine environment. Indeed, the battery-monitoring system is in a waterproof enclosure. All necessary system components are readily available, and the manufacturer's technical support is very good.

To be cost effective, lithium batteries should be incorporated when a boat is built. If done as an upgrade, the project should be viewed as a reengineering of the DC power system, in which all charging sources (chargers, inverter/chargers, alternators, etc.) must be adjusted, modified, or replaced, and a good monitoring-and-control system added. The decision to upgrade to lithium batteries and reengineer the DC power system

Wiring for the new battery bank showing the safety relays and shunt. The original 2-kW inverter/100-amp charger remained, but the relays and shunt were upgraded to meet the demands of the new system. The author also added a Mastervolt ChargeMaster 12v/100-amp battery charger, doubling the charging capacity when paired with the original equipment.

should be based on whether the benefits are worth the significant cost of the project. In our case, where the generator run time was reduced 75% or more and the existing bank needed replacement, the upgrade was worth the cost.

• Our upgrade was successful largely because we chose a single vendor for most of our system. Our Mastervolt components, which have smooth plug-and-play integration, connect through the Mastervolt network control system, and all have excellent and extensive technical support. There are innumerable details in the integration and the design of a new DC system. I think this project would be significantly more difficult to accomplish and would likely have run afoul of integration problems if more than one vendor supplied the major components. However, the other two lithium battery vendors I looked at have some differences in their technical approaches that appear to me to make it easier to use chargers, alternators, etc., from multiple vendors.

• Vendor technical support from Mastervolt and ElectroMaax (alternator) were essential to the success of this project.

• Carefully consider whether to do the work yourself or hire it out. This

Variation Among Vendors

Among the three lithium battery vendors I recommend for house bank batteries—Mastervolt, Genasun, and Arc3—there are more similarities than differences. All use lithium-iron-phosphate batteries, although the cells are constructed differently. All provide battery management systems that balance between cells and prevent overcharge, undercharge, and overheating. All designs have either external or internal relays to disconnect and protect the lithium batteries in response to the battery management system. All offer lithium batteries of similar capacity (360 Ah to 400 Ah) suitable for house banks and at similar prices. All say they have many customers, although few detailed case studies are available.

Here are the primary differences I found:

Overheating of small-case alternators. Mastervolt offers its own alternators but was reluctant to comment on their ability to handle sustained high currents while charging lithium batteries. I am skeptical that these alternators will do anything other than cycle off high temperature sensed by the casing temperature sensor. The Mastervolt external alternator regulator has a temperature sensor, and the set point can be adjusted using downloadable software. The regulator does not have the ability to limit field current, so the only method of limiting alternator output is by sensing the alternator-casing temperature and reducing the field when the set point is reached. In my opinion, this is a significant drawback. This regulator can regulate only an N-type field, so you will need an alternator that can accommodate, or is modified for, an N-type field control. Mastervolt provides instructions on modifying a "standard" Bosch alternator for use with the Mastervolt regulator. Mastervolt does not offer any belt/pulley kits for its alternators, so you are on your own to fit up the alternator and find belts/pulleys that work for your engine.

Genasun's representative reports that they typically use an American Power Systems 42 series (180-amp) alternator limited to 80% capacity by an external regulator. It has the ability to set a limit on field current as well as having an external casing-temperature sensor for safety. The manufacturer's representative can provide the belt-and-pulley kits required (procured separately on a custom basis). The manufacturer's representative reports good results with this setup.

Arc3 acknowledges that the overheating of small-case alternators is an issue and does not provide a specific solution. It reports that its customers have used newer Balmar alternators successfully.

Preventing overcharging. Mastervolt prevents overcharging by requiring that all charging devices are capable of properly reacting to a "stop-charge event" sent to the charging device from the lithium batteries via the MasterBus network. This works well on our boat, but I think it means you are likely limited to Mastervolt chargers and alternator regulators.

Genasun has an interesting approach to the design of the DC electrical system. It uses two positive DC buses, one for loads and one for charging devices. In an overcharge situation, the relay on the charging bus opens, disconnecting all the charging sources from the battery. The battery-monitoring system opens the alternator field before opening the charging relay, to prevent damaging the alternator. Loads are still connected via the load bus. This approach appears to me to make it project was really a reengineering of the charging portion of the DC electrical system. Developing the system design requires in-depth knowledge of lead-acid and lithium batteries as well as charging components such as chargers and alternators. The execution of the work requires specialized tools, experience, potential modification of structural components, and more. Note that Mastervolt's technical support commented that they had not previously worked with an owner/do-it-yourself installation of lithium batteries.

• Alternators were designed for lead-acid batteries, where the charging current builds relatively quickly and then tapers off to a float over the period of the charge. Lithium batteries, on the other hand, will take the full charging current capacity of charging devices for the entire charging period. Conventional small-case alternators simply cannot handle this high current for an extended period, and they overheat. The temperature sensor of the external regulator senses the alternator-casing temperature and reduces the charging current by reducing the alternator field voltage. In my opinion, the alternator temperature monitor was never intended to be a primary method of controlling the alternator output. It was intended as a safety function, so relying on the alternator to continuously cycle to its maximum temperature is not a satisfactory way to operate long term.

ElectroMaax now has multiple solutions to this issue. In 2014 it launched the Voyager "hairpin" 165 advanced-technology alternator along with an E-MAAX Pro external smart regulator/battery monitor. The new alternator design has significantly increased heat-dissipation capacity, and meets the needs of the majority of cruising boats employing small to medium lead-acid, AGM, and/or gel batteries. The brushless version of this alternator is specifically targeted for the lithium battery market. It will generate 195 amps in a small case and significantly less heat than its conventional counterpart. For cruisers or racers with larger banks, it is specifically targeted for the lithium battery market.

• Additional cooling may be needed around battery chargers due to the heat they generate when running at full capacity for extended periods. Note that the batteries do not need additional cooling. *Sunflower* already had a thermostat-controlled cooling fan for the cabinet housing the two battery chargers. The fan seldom ran when the AGM batteries were charging. Now, using the full capacity of both battery chargers for the lithium batteries, this fan kicks on during every charging cycle. During the design phase it was challenging to determine how large the battery charger(s) should be to greatly reduce the genset run time. Based on our experience, 100-amp DC charging capacity for each 12V/5,000W lithium battery seems about right.

• We had modified Sunflower some time ago to connect to 50-amp/220V, 30-amp/120V, and 15-amp/120V shore power in our North American cruising areas. We found that if both the inverter/charger and battery charger operated at full charging capacity (for example when arriving in port with the batteries not at full charge), the load from the battery chargers plus house loads could exceed 30 amps AC on shore power until the lithium batteries were charged. To handle this when we were connected to 30-amp shore power, the load on shore power from the battery chargers can be limited by shutting off the ChargeMaster charger and using only the Mass Combi inverter/charger. If the load needed to be further reduced for 15-amp shore power, the Mass Combi inverter/charger has a setting called "shore power fuse" that can reduce the current drawn by the inverter/charger to match the capacity of the shore power. We recommend that, if possible, at least one charging device should be able to reduce the charge to limit the load on shore power if required.

On the Water

During the summer of 2014 we cruised *Sunflower* for 90 days in remote areas and covered more than 3,500 nm with the new two-lithium-battery

The modified battery well, seen here just before battery installation, had plenty of space to accommodate the new lithium models, as they occupied just half the footprint of the original AGM bank.

easier to use other manufacturers' charging devices, but it still requires adjustment of the lead-acid three-step charging process on all charging devices for the lithium batteries, and would require an external regulator for the alternator.

Arc3 takes an equally interesting approach. It simply uses the same charging voltage on all charging devices as is used for lead acid batteries. This voltage is slightly lower than the full charging voltage of a lithium battery. Arc3 reports this prevents the lithium battery from overcharging.

I was specifically looking for a "complete" alternator solution that included the alternator, a serpentine or double-pulley/belt kit for my engine, and if possible a regulator capable of interfacing with Mastervolt's control network. The only company I could find was ElectroMaax, and it hit the mark with the alternator, the serpentine belt/pulley kit, and technical support. It also offers an excellent external alternator regulator capable of limiting field current. Unfortunately, that regulator cannot interface out of the box with the proprietary Mastervolt control network.

—*Mark Lenci*

house bank. These are our key observations:

• We overachieved the primary objective of reducing generator run time by at least 50%. We actually achieved a 70%–75% reduction of genset run time for charging batteries.

We sized the new house bank correctly. The two 12V/5,000W lithium batteries provide sufficient capacity for 24 hours of sailing and still have at least 35% capacity remaining. The two lithium batteries have 20% more usable capacity, charge in a third or less time, weigh less than half, and have half the footprint of our former six-battery AGM house bank. And I expect the lithium batteries to last 20+ years.

• The reengineered DC system performed flawlessly.

• DC charging is more automated. Less of our time is required to monitor and charge the batteries.

• Lithium battery voltage is a constant 13.2V for all practical purposes through the normal range of battery discharge.

• Our crew was able to do all aspects of the upgrade project, including modifying the engine pulley system, installing the new alternator, installing and configuring all Mastervolt components, and the extensively modifying the DC cables. Excellent technical support from Mastervolt and ElectroMaax was essential…and we are probably unusually well skilled in these areas.

• After three-and-a-half months of cruising, the charge efficiency has been 94%. This is what the manufacturer's literature states, and that compares with 73% we measured on the previous AGM batteries.

About the Author: *Mark Lenci was a U.S. Navy officer for 26 years, serving aboard several attack submarines and as Assistant Chief of Staff for Command, Control, Communications and Computers for the U.S. 7th Fleet. More recently, he developed cloud services at Microsoft.*

Resources

Mastervolt
Contact a dealer for technical support. I was quickly put in direct contact with Mastervolt's U.S. technical support, which was excellent. www.mastervolt.com/marine/products/li-ion.

Genasun
www.genasun.com/products-store/lithium-battery-systems, for Genasun, or www.bruceschwab.com, for distributor (Bruce Schwab Energy Systems, 207–370–9112) technical support.

Arc3
www.arc3energy.com. Technical support 1–503–267–4455. Chris Bakken, founder of Arc3 Energy, chris@arc3energy.com.

Electro-Maax
Technical support 1–866–945–8800, www.electromaax.com.

American Power Systems
www.americanpowerinc.com/42i%20for%20Sailboats.htm.