How can I best use my alternator to charge my camper battery?

If your goal is to get all the electrical power you want to enjoy the freedom of your RV, then I hope this summary, associated links, and 'details' will provide you with the information to help you be successful.

Deep Waters Ahead….

- The summary article published in TCAmag was extracted from this full-length analysis.
- A 170A-rated alternator and a '50A' DC/DC charger are used in examples because their capacities are typical and work well together. Substitute your own equipment capacities and follow the same calculations.
- See the playlist; Truck Alternator Charging for the Auxiliary Lithium Battery
- E-mail me with questions: WorkingOnExploring@gmail.com

. I wish I could say that there is lots of reliable information on this topic. Most of the information available on alternator performance is incorrect. Often, it is intentionally distorted by the equipment industry to favor the sale of their equipment rather than provide you with the objective truth.

Most RVs don't include a robust method of using your vehicle's alternator to allow it to be part of your total generation system. It's typically only a minor player. Expecting to get much power available through a trailer connector is unlikely. The potential for getting a lot of power from your alternator is certainly possible, but if you want it to be safe and reliable, assume it involves some education about alternator generation and developing knowledge of the equipment connecting the vehicle to the RV. (Here comes the obligatory 'scare' phrase)….Making hasty, superficial decisions may lead to a system that underperforms expectations, overloads the vehicle's alternator, and may leave you with an expensive tow and repair bill.

My intent is to explain how you can identify and quantify the electrical power available in your alternator and point you to methods that can move that electrical power into your camper's batteries safely, consistently, and reliably. 'Easier' installations will usually develop around DC/DC chargers, as they are most often the necessary solution. Several alternatives to DC/DC chargers are also available.

Estimate Vehicle Generation

The most profound realization for most is that the alternator's 'rated' output is not what they think it is. 'Rated' capacity is a relative measure for comparison of different alternators' potential capacities (assuming alternators operate at the same voltage). It is NOT what they can be expected to produce in any situation other than its standardized factory test and certainly not continuously in your vehicle. A good plan starts with true and accurate information.

An alternator's output 'rating' is the result of a momentary factory test specified by SAE J56/ISO 8854 j56_199906.PDF under which a cold alternator is mounted on a test stand and operated from 0 to at least 6,000RPM, delivering maximum output into a load bank resistor, while being 'cooled' by the presence of stagnant, 75F ambient air. The test is completed in tens of seconds, before significant heating caused by inefficiency can impact the test. Its sole objective is to determine output at 6,000RPM at a minimum of 13.5V. There is no attempt to achieve or measure sustained capacity at a stable temperature.

These test conditions are designed to make testing easy in the factory, not to be similar to operation in a vehicle. The following real-world example provides a better understanding of loads and temperature as well as the root basis of general derating factors proposed for systems using alternators.

A fundamental problem with understanding alternator capacity stems from automotive manufacturers' wanting you to believe common misconceptions about alternator generation. All while they are outright lying to you about the actual capacity of Variable Voltage Alternators (smart = VVA) by allowing you to believe the 'rated' amperage output produces the same power as a Fixed Voltage Alternators (FVA).

Both alternators use the same generation hardware and undergo the same rating test at the same minimum voltage (13.5V). The only mechanical difference between them is the internal regulator. The FVA uses its standard internal regulator, while the VVA's 'smart' regulator is simply 'forced' to a constant high voltage, which won't dip below 13.5V during the test. The 'rating' they both carry correctly indicates they have the same capacity, but it is only true on the test stand.

In a vehicle, a VVA rarely produces voltage above 13.5V. The output voltage is 'managed' by the BCU/ECU at typically between 12.4V and 13.2V. This lower voltage INTENTIONALLY produces less power to conserve fuel (the reason they were created is that it improves CAFE numbers). 'Ratings' in amps, used to compare alternators, are only comparable if the output voltage of both alternator types is the same. Since FVAs and VVAs have different average output voltages, to get an accurate comparison of their true capacity, compute the output power (in Watts) using each alternator's rated amperage and average output voltage.

- Calculating output power for an FVA with a 14V average voltage, and using the example 170A rated alternator, its rated power is (170A x 14V =) 2.38kW
- Calculating output power for a VVA with a 12.8V average voltage, and using the same 170A rated alternator, its rated power is (170A x 12.8V =) 2.176kW
- The VVA produces 9% less power when controlled by the automobile BCU/ECU, even though it is BENCH-rated as having the same ampacity as the FVA.
- In operation, a 700W output DC/DC charger with a minimum efficiency of 93% requires a maximum input of 749W. It will draw the same 749W from a vehicle, regardless of the voltage at which the power is delivered or the alternator type producing it.
  - The FVA needs to produce (749W/14V =) 53.5A
  - The VVA needs to produce (749A/12.8V =) 58.5A (9% more amps).

To determine the usable reserve capacity, at cruising speed, of a 'standard' wire-wound alternator;

1) Calculate the alternator's continuous capacity by converting 'rated' amps to power in kilo-Watts by multiplying the rated ampacity by the average output voltage.
   - For FVA, a 170A-rated alternator has a maximum output power of 170A x 14V ÷ 1,000W/kW = 2.38kW.
   - For VVA, a 170A-rated alternator has a maximum output power of 170A x 12.8V ÷ 1000W/kW = 2.176kW.
2) Calculate the alternator's continuous capacity at cruise speed by multiplying rated power by a derating factor of 60% for wire-wound alternators or 75% for hairpin alternators.
   - For the above 170A rated FVA, 2.38kW x .6 = 1.43kW continuous capacity.
   - For the above 170A rated VVA, 2.176kW x .6 = 1.31kW continuous capacity.
3) Calculate continuous reserve capacity (the alternator's untapped additional capacity, in excess of power demanded by engine and vehicle systems) by subtracting the vehicle operating load (in watts) from the continuous capacity. Assume the vehicle will draw a maximum operating load of 630W.
   - For the above FVA, (1.43kW ÷ $1000\mathrm{W}/\mathrm{kW}$) – 630W = 813W.
   - For the above VVA, (1.31kW ÷ $1000\mathrm{W}/\mathrm{kW}$) – 630 W = 701W.
   - This is the maximum current your alternator can provide long-term while OPERATING AT CRUISE SPEED to charge an auxiliary battery.

Notes :

- If you use an DC inductive ammeter (a 'clamp meter') and wish to determine your specific vehicle's operating power consumption, you will almost certainly perform testing, while stationary, at idle. A stationary test will not be as accurate as moving at cruise speed. Specifically, air needs to be flowing through the engine compartment. The electric radiator fan needs to be operating, which requires loading the engine. The convenience accessories of a vehicle must also be included, such as headlights, windshield wipers, heater, air conditioning, entertainment system, off-road flood lights, seat heaters, resistive defogging glass heaters, etc. They all need to be factored in using a rationale for the maximum number that may operate simultaneously. Seat heaters and electric defoggers (neither of which I have) are large and variable loads. If you don't want to do all of this, use 630W.

▪ Continuous alternator capacity at idle is about half of continuous capacity at cruise, meaning there is likely only enough electrical generation to operate the vehicle systems, so either don't idle for long or plan to have a means to prevent the charger from operating when idling. This also includes 'stop and go' traffic, which involves a lot of idling. Have a manual override switch and use it unless on the highway.

▪ These are 'soft' numbers because they are based on estimates derived from technical study and limited experiments. Equipment and conditions vary so there is some wiggle room, but the purpose in establishing these rules and this process is to operate under control at a level that is sustainable in all conditions. I recommend not giving in to the desire to call overages 'close enough'.

Assumptions/guidelines that apply to alternator capacity estimates;

- Operating at cruise speed requires ~2,000 engine RPM, equating to ~6,000 alternator RPM, which is the speed at which alternator capacity is 'rated'.
- 'Rated' capacity of an alternator is not its continuous, maximum, average or any other classification of output in your vehicle. It arises from a standard factory test, designed to facilitate alternator comparison. It's important to determine the practical continuous capacity, which can be estimated from the 'rated' capacity.
- Efficiency at 6,000 alternator RPM and high load (~50% of rated) for 'standard' wire-wound alternators is about 60% (1kW mechanical input produces 600W_e of electricity and 400W_t of heat). Efficiency decreases further with increased RPM or electrical load.
- Fixed Voltage Alternators (FVA's) and Variable Voltage Alternators (VVA's, aka 'Smart' alternators) use the same voltages in the rating test but different voltages when operating in a vehicle. VVAs operate at an average of 12.8V while FFAs operate at ~14V, resulting in VVAs, delivering 9% less capacity.
- Because of differences in operating voltage between FVAs and VVAs, only alternator capacity measured in units of power can be compared. Compute 'rated power' from rated amps x average operating voltage.
- Assume the maximum continuous alternator capacity, at cruise, for a wire-wound alternator is 60% of rated capacity (in Watts). (75% for a hairpin alternator).
- Maximum continuous capacity (at cruise, in Watts) minus the vehicle maximum operating load (at cruise, is estimated to be 45A@14V/ 630W for trucks) equals the maximum continuous reserve capacity (in Watts) available for auxiliary battery charging.
- The input power to the charging system cannot exceed the alternator's continuous reserve capacity or the alternator will overheat.
- The maximum continuous capacity, at idle, for a wire-wound alternator is half the maximum continuous at cruise or 30% of rated capacity. (37.5% for a hairpin alternator) which is typically only adequate to operate vehicle systems. Charging should only be operated at cruise speed.

In any design, it is essential to know, plan for, and not exceed a realistic capacity. Don't just assume because some experiment 'worked' once in 'friendly conditions' or in someone else's RV, it will work in yours, especially in all conditions. ‘Hope’ is not a valid plan. Those who use it, hold their breath the first time it operates and the next dozen times after that. They never know what conditions could cause an overload, or how to handle one if it occurs. However, they are somehow supremely confident that ‘it's fine’.

The bottom line: ‘Standard’ alternators are inefficient and get hot. With large additional loads, they get very hot. Total generation capacity must be limited because too much heat breaks down enamel insulation on the windings and can damage diodes. Failure occurs, maybe not all at once, but certainly over time. A 200°F engine conducts heat into the alternator, and a 160°F under-hood air temperature raises the alternator to 165°F, then the generation load takes the temperature even higher. Waste heat doesn’t have to be that great for the alternator to exceed its 248°F maximum operating temperature.

Understanding the Load Vs Temperature Relationship of an Alternator

My adventure truck, ‘Maximus’, a 2004 F350 with a 6.0L diesel, has two alternators. Both alternators are attached through a thick aluminum bracket to the engine block that is operating at a minimum of 180°F, and more typically, 200-220°F. Under-hood air comes in through the front grill and successively passes through the A/C condenser, charge air cooler, and radiator, each successively heating the air to ~160°F. This is what is available under the hood for the alternators to ‘cool’ themselves with. Just like yours…

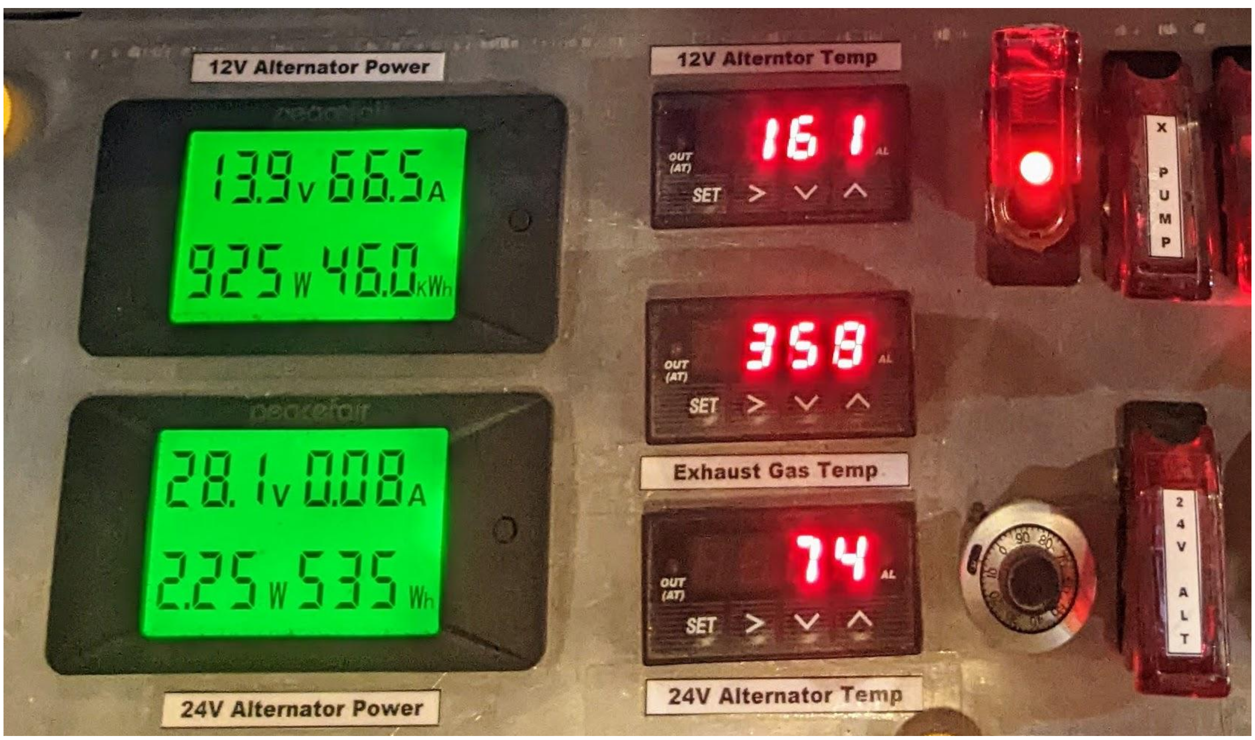


Figure 1: ‘Maximus' Console with Alternator Monitoring Instruments (just after startup, 24V alternator off)

I have instrumented both my alternators with industrial thermal controllers and power meters to study and safeguard them because I intend to operate the secondary at near its maximum capacity/temperature.

- The primary alternator is a fixed voltage alternator (FVA) ‘rated’ at 135A/14V. It has demonstrated continuous capacity of ~80A (59%) measured by its ability to produce this power and remain below 120C/248F. It delivers ~30-45A (420-630W) just to operate the vehicle systems (not including charging after starting). In 'temperate weather,' it typically operates at ~180°F at this output.

- The secondary alternator is an FVA 'rated' at 220A/14V but reconfigured with an adjustable external regulator to operate at ~28V (up to 29.2V). Because it charges a large lithium battery, it can produce over 180A/5.3kW momentarily. It is typically 'off' (it only charges the house battery when I need to) but 'free-spins' at about 165°F just from conducted engine heat and under-hood air circulation (this is as 'cool' as any alternator can get).
- I can assure you that whatever heavy truck you use to move your RV, the engine and alternator will have a similar base operating temperature under load, your vehicle operation will require a similar amount of energy and your alternator will respond similarly to electrical loads.

How much load does it take to overheat an alternator? I know because I have tested it extensively. When I switch the secondary alternator on, I can dial the modified external regulator to produce any amperage I want at any time. Based on SOC, ambient conditions and my driving time, I typically set it to produce as much electricity as possible that keeps the alternator just below the 120C/248°F safe maximum operating temperature.

- When it's hot out (>90F ambient), its generation limit is ~90A (operating at 41% of rated capacity, produces 2.5kW_e of electricity and 1.7kW_t of waste heat).
- When it's cool out (<60°F), its limit is ~120A (operating at 55% of rated capacity, produces 3.4kW_e of electricity and 2.2kW_t of heat).
- Because it operates at ~28V, waste heat generation per amp of output is expected to be double what it would be if operating at 14V. I improved cooling capacity by removing the rectifier bridge to reduce overall heat generation and improve airflow. The conservative 1.3kW_t heat dissipation capacity limit for a 14V wire-wound alternator on which all my 'rules of thumb' are based, is supported by this data.

Additional notes:

1) The thermal controller not only displays the current temperature but also operates as a thermal safety. If the alternator temperature exceeds 120C/248°F, a relay opens, cutting power to the external regulator, shutting the alternator down until it cools to 110C/230°F. Shutting down the alternator is a very safe way to terminate charging and does not produce a 'load dump'. Alternator shutdown does not affect the vehicle because it only charges the camper battery.
https://youtu.be/rBS8cHnhILE?si=pm1edBgNdAfzyFXT

2) Removing the rectifier assembly and relocating it to the fan shroud reduces the heat load inside the alternator, allowing me to generate more electricity. I estimate that doing this has increased my output ~20%. Video of it is here: https://youtu.be/UBnKhqqsNNA?si=pmaa_nNOvsVn47Cy

Rules for a reliable charging system.

- KNOW the limits of the equipment. Calculate a realistic alternator capacity, then plan the addition of equipment that will provide auxiliary battery charging that lives within those limits.
- Maximum continuous capacity is only available at cruise RPM. At a lower RPM, capacity decreases. If the added charging system is designed to use most of the continuous reserve capacity at cruise, operating it below cruise RPM will likely result in overheating the alternator.
- The capacity at idle is only sufficient for vehicle operation. Do not operate any auxiliary battery charging at idle.
- If you want to charge while stationary;
  - Add a 'high idle' switch to force the engine to ~1200RPM. Drawing cooling air through the engine bay normally only occurs when the vehicle is in motion; even then, it's a problematic choice. Many heavy-duty trucks have a high-idle option available in the wire harness.
  - DO NOT, under ANY circumstances, replace the alternator pulley with an 'overdrive pulley'. It increases alternator heating and decreases capacity at cruise RPM.
  - Install a hairpin stator alternator. Even if the alternator is the same size, it provides double the continuous output due to reduced waste-heat generation
  - Use two smaller DC/DC chargers and only operate one at low engine speed.
- Keep the alternator temperature below 248°F and the waste heat generation below 1.3kW_t.
- Add a thermal load-shedding system. It is relatively cheap and easy to do. It will save your alternator if the auxiliary charger overloads it.

Learn about simple load shedding in Detail 6: DIY Thermal Unloader for Load Shedding or more advanced methods on my blog here: alternatorthermal-protectionv216apr26.pdf

Is this enough charging capacity?

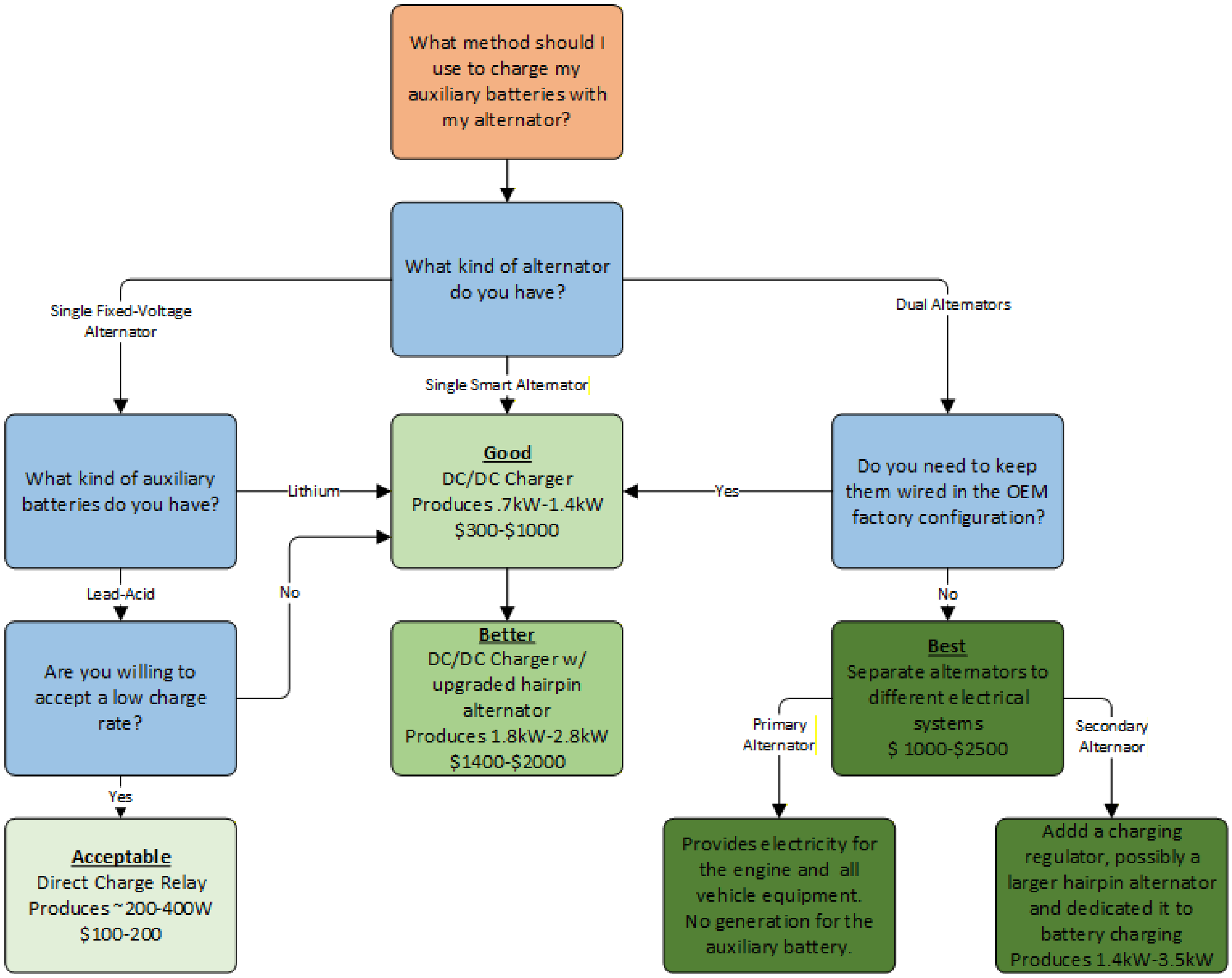
Knowing the continuous reserve capacity of the vehicle can lead to sizing an auxiliary charging system. Multiplying reserve capacity by the desired drive time, compare it to the anticipated battery debt to determine if the alternator has the capacity to power a charging system that can satisfy needs.

> Compute:
>
> 1) Average drive time (in hours) x reserve capacity (in Watts) = Average generation (in Watt-hours)
>
> 2) [1 - Average SOC prior to a move (percent as a decimal)] x Battery Bank Size (in Watt-hours) = Average Battery Debt (in Watt Hours).
>
> If the average generation is ≥ Average Battery debt, you have enough reserve capacity to support a charging system. If you don't, you need to increase the capacity of your alternator, preferably with the same size or a slightly larger hairpin alternator.

A larger battery bank may have a larger debt, and a larger alternator may provide more capacity, or vice versa. Use data from the equipment on hand and the normal travel practices to make an assessment.

Charging Connection Options

After determining the amount of alternator continuous reserve capacity and determining that it is sufficient for your needs, it's now necessary to determine how that electrical power can be safely moved into your auxiliary batteries. This has some serious potential downsides and is where serious thought and study become involved. Lithium batteries can cause extremely high current flows that can damage equipment or wiring. Their use requires additional equipment to have a reliable, consistent system. There are three common methods.



* If your vehicle is equipped with a 'smart' alternator (typical after 2011), it operates at an output voltage too low to produce adequate charging. The only workable solution is a DC/DC charger.

*Smart alternator systems details: remy_smartchargingsystem_guide.pdf

1) **Direct Relay Connections** are only helpful if you have older equipment and don't need much charging. They are cheap, don't offer substantial charging capacity, and are incompatible with Smart alternators or LFP batteries.

There are several different devices that fill this role. All have a similar purpose with similar shortcomings. The most common, called a 'split charge relay,' is a continuous duty, high current relay that connects the auxiliary battery to the vehicle battery/alternator any time the ignition is on. By not connecting when the ignition is off, it avoids discharging the starting battery when the camper system is being used. There is a diode-based semiconductor 'battery isolator' that is always connected but simply prevents current flow from the camper back to the vehicle with no switching involved. A 'voltage sensitive relay' automatically closes the relay based on the vehicle system voltage rising on engine start, rather than a wired ignition-source trigger. Trailer connectors have a low-current version of a split charge relay that provides electrical power through the trailer cable when the ignition is on, but is limited to ~20A. One of these options is likely provided in some form with most vehicular RVs and can be added to truck campers and trailers.

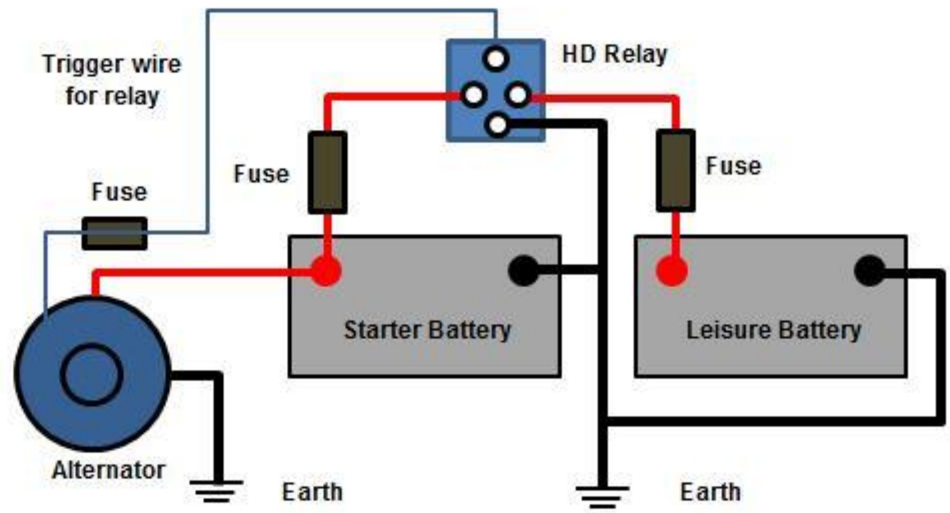


Figure 2: Split Charge Relay Schematic

The ‘voltage sensing’ type (VSR) connections;

- Typically close at 13.3V-13.7 and open at 12.8V.
- Rarely connect with Smart alternators because the majority of Smart alternator operation is at or below 13.2V. At this low voltage, there is very little charging that COULD occur even if the relay did close.
- The higher voltage of LFP batteries can allow the relay to close at a vehicle voltage that is lower than the actual auxiliary battery voltage, allowing reverse current flow.
- May be difficult or impossible to manually force off.

Depending on RV type, there may also be a manual momentary switch that closes the relay when the engine is off to provide a ‘jump start’ from the auxiliary batteries to the starting batteries if the starting batteries are discharged.

This connection type has several problems:

a. Direct relay connections violate a key premise of battery charging in almost every case. The batteries in a ‘bank’ (which results when the relay closes) must be of the same size and type to charge evenly. While the starting battery will be lead-acid and the auxiliary battery MAY be lead-acid, similar chemistry alone does not ensure they are the same ‘type’ and size. A starting battery has a large number of thin plates that present ~50mΩ resistance to allow high-current discharges. The ‘deep cycle’ auxiliary battery has fewer, thicker plates that present ~100mΩ resistance to allow low current, long duration discharges. The higher resistance of the auxiliary battery and the added resistance of the necessarily longer cabling connecting them to the alternator significantly reduces the possible charge rate. This system CAN provide some charge and generally does so safely, but the rate is typically low.

b. If the auxiliary batteries are Lithium Iron Phosphate (LFP), in a vehicle equipped with a fixed voltage alternator producing ~14V, the same dissimilar battery problem exists but in reverse. LFP batteries have a significantly different operating voltage range (10V to 14.6V) than a system with an operating alternator (~13.8-14.2V). With ~1mΩ resistance, the much larger voltage differential can result in the battery drawing as much power as the automotive system can deliver, likely overheating wiring or the alternator. For example;

   - In the worst case, the battery is at 0% SOC (10V) and the alternator is producing 14V.

Assuming a single 100Ah auxiliary battery with ~1mΩ and a cable network with ~10mΩ resistance. Charging current would be; (14V-10V)/11mΩ = 364A. This exceeds not only the battery's maximum charge rate (by a lot) but also the alternator's capacity (also by a lot) and any associated cabling.

- In an average case, the battery is at 50% SOC (12.8V), and the alternator is producing 14V. Charging current would be; (14V-12.8V)/11mΩ = 109A. This still exceeds the battery's 1C maximum (100A) and almost certainly exceeds the alternator's continuous reserve capacity.
- The problem does not improve with more batteries in parallel. Two 100Ah LFP batteries in parallel, each having a resistance of ~1mΩ, have a combined resistance of ~.5mΩ. Adding the cable resistance, the network resistance drops slightly to 10.5mΩ increasing the already hazardous current.
- SOME RVers have installed LFP batteries, then run simple experiments to determine charging suitability. Because they didn't 'let the smoke out' the first time, they think their system might be fine. In 'engineering ease,' this is called 'anecdotal data' and is never used in serious evaluations. Anecdotal data is an experiment with a known outcome but mostly or totally unknown test conditions. It typically only works for a narrow, 'friendly' set of circumstances, and almost always fails nearer the extremes. Typically, they have long cable runs from the alternator to the trailer that raise the network's resistance enough to reduce the current at moderate temperatures and medium to high SOC's. While this may be acceptable when the batteries are not deeply discharged, it usually overloads when they are mostly discharged. This is not a controlled system because the circumstances are neither known nor controlled nor are the limits understood. IMHO, it is guessing with the potential for a serious failure, which WILL eventually occur.
- All of these unfavorable results are why the lithium battery industry repeatedly states that using LPF batteries with alternator charging <u>requires</u> a current-limiting device. If you have a high-resistance cabling system, current limiting may not always be needed, but it will be needed sometimes.

c. The wide-ranging operating voltage of Smart alternator-equipped vehicles (~12.4V to 15.5V) creates an even larger problem when paired with the wide-ranging voltage of LFP batteries (10V-14.6V).
   - When the alternator voltage is low (~12.4V) , no charging will occur. Because simple connections are not intelligent enough to measure both alternator and battery voltage, when it connects, and the battery voltage is higher than the alternator output, power can flow from the auxiliary batteries into the automobile, discharging them.
   - When the alternator voltage is relatively high (as high as 15.5V) and/or the battery voltage is relatively low (~10V), the charging current will also be very high, probably overheating the alternator even in the short term.

Issues with the Battery Isolation Manager

Some RV's have installed a 'Battery Isolation Manager' made by Precision Circuits. It solves some of the voltage connection problems of voltage-sensitive relays, but creates others.

The general problem of alternator overheating with a direct connection has given rise to a product produced by 'Precision Circuits' called a 'Battery Isolation Manager' (BIM) for lead-acid systems and a 'Lithium Battery Isolation Manager' (Li-BIM) for LFP systems. Both products do the same thing with different voltage thresholds.

These products attempt to solve both the large dissimilar voltage and alternator overheating problems. I mention this device because I believe there are likely a number of users of this product with whom I would like to share my perception of its serious shortcomings. Although their solution is better than an unlimited, continuous charge connection, I believe it is a poorly controlled solution because it neither limits current nor monitors alternator temperature. One of which is necessary. I don't believe it's single strategy can be successful for a wide range of equipment under widely varying environmental conditions.

The more sophisticated voltage-sensing in the Li-BIM relay does solve the voltage problem by only allowing the relay to connect when voltages are appropriate (I won't go into specifics). This results in less frequent connections and less charging (than the two following solutions) but no accidental discharging.

There are two remaining issues;

- When the voltage sensing circuitry allows the system to connect, and large currents flow, the BIM implements a time-based duty cycling that allows connection for 15 minutes and disconnects for 20 minutes alternately. While this does reduce the heat load on the alternator, there is no way to know if that reduction is enough or too much because the timed cycle is fixed regardless of the equipment. Both are problems.
  - With a large battery bank and a small alternator, it is probably not enough, because the small alternator can still overheat in under 15 minutes of operation and does so every 35 minutes.
  - With a small battery bank and a large alternator, it is probably too much. The large alternator can provide the current needed without overheating, yet is still forced off 57% of the time.
- The second and most important problem is the creation of a large voltage spike in the alternator. Every time it disconnects, it results in a 'load dump'. Alternators under heavy load produce large magnetic fields. When the load suddenly disconnects, the field collapses, turning the rotor and stator coils into the equivalent of a 'spark coil'.
  - Load dumps produce a high voltage 'spike' in the alternator that, if not damped, will travel through the entire electrical system of the vehicle.
  - The larger the load, the larger the magnetic field, the larger the spike when the field collapses.
  - Vehicle equipment, operating at far lower current, routinely switching on and off, producing smaller but still dangerous spikes. The alternator is equipped with 'avalanche' diodes, designed to ground out spikes in the stator for the sizes of load dumps the designers anticipate.
  - The rotor coil has no similar damping device and relies on the robustness of the voltage regulator components to survive.

I just don't believe a spike-damping system designed for a typical 10-20A load dump is going to be as successful as necessary with loads 10x as large (up to 225A, the rating of the Li-BIM), especially when it recurs every 35 minutes. If a buyer knew before the fact that;

- The 'normal' operation of the BIM causes the alternator to create high voltage spikes.
- These spikes are going to be far larger than any his vehicle is designed to handle.
- The spikes had the potential to damage vehicle electronics everywhere inside the vehicle

I don't think many owners of expensive RVs and prime movers would accept the risk that using this device entails. That's why it's never discussed.

The bottom line on the direct relay connection: Only use it if you have lead-acid auxiliary batteries and don't expect or need to get much charge.

2) Dedicated 2nd alternator, directly charging the auxiliary battery with a charging regulator

This is my solution, but it's not for everyone. If you already have dual alternators, you should do this. If you only have one alternator, adding a 2nd alternator system can be done, but it may be expensive and complicated. Searching junkyards to recover the whole second alternator system from a wrecked truck identical to yours (what I did for $175) MAY be relatively inexpensive. If you want the most power and the best control possible, this is the way to go.

OEM dual alternator systems use the primary alternator full-time and switch on the secondary alternator only when the primary is unable to maintain adequate system voltage. When additional loads are added to OEM dual alternator vehicles, both alternators do not share the load equally. Additional loads first put a heavy demand on the primary alternator, the same one that operates all the vehicle systems. The secondary alternator only turns on when the primary can't maintain system voltage, probably indicating its overheating. The benefit is that the second alternator can take over when the primary fails, and you probably won't even know.

An excellent solution is to separate the secondary alternator from the vehicle's electrical system and dedicate it to charging the auxiliary batteries. The primary becomes lightly loaded, only supporting vehicle systems, likely increasing its lifespan and reliability. The secondary can be effectively managed by an external charging regulator that operates it as a dedicated battery charger. External charging regulators often have temperature and current sensing (ARCO Zeus senses current and temperature separately for both the alternator and auxiliary battery) to maximize charging and prevent overheating. They are programmable and can execute custom charging profiles that maximize charging and safeguard the alternator. I prefer the ARCO Zeus because it has more sensors, external controls, and a better Bluetooth app. The Wakespeed has less of everything but is the same price. Both are excellent products.

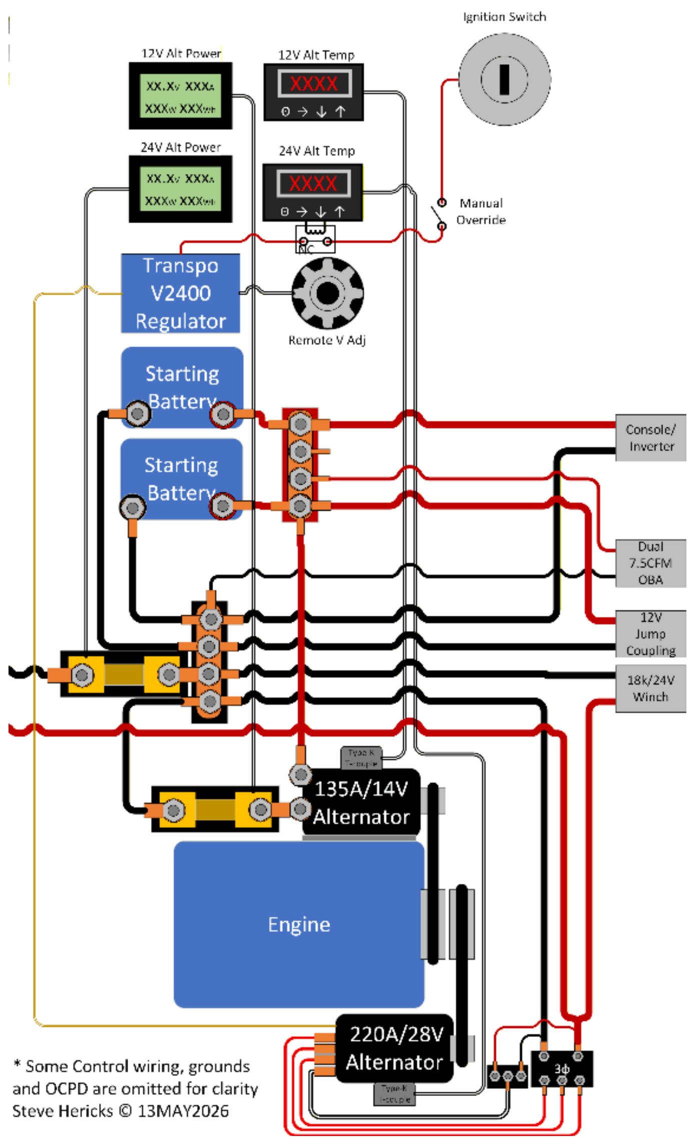


Figure 3 Maximus' Dual Alternator System

DIY Thermal Safety/Load Shedding

It's not hard to rationalize: If high alternator temperature is the specific problem to avoid, then monitor the alternator temperature and shut off the load causing overheating when it occurs. Problem solved. Return to charging when the temperature decreases. This is known as 'load shedding'. It really is that simple. I'm not sure why NOBODY does it. Possibly because it's too cheap to make any money on.

Building an automatic, thermally activated, load-shedding device is as simple as mounting a KSD-9700, 120C activation, normally closed (NC) thermal switch (a $3 part) by epoxying it with metal-filled epoxy (‘JB weld’) directly to or near the alternator stator laminations (preferred), or to a bracket bolted to the alternator (as shown). Wire the switch in series with the control wire for the direct relay charge device, DC/DC charger ignition wire, or power input to an external regulator. This method can and should be used as a ‘failsafe’ to prevent even a good design from encountering environmental conditions that overload the alternator. This is inexpensive and ‘fool-proof’.

I use something similar with an industrial thermal controller because it has a temperature display and is programmable. Instructions for several methods are here: alternatorthermal-protectionv216apr26.pdf

Figure 5: Thermal switch on an alternator

Planning to operate an alternator at a higher-than-normal capacity already creates additional risk for load dumps. The biggest one is if the BMS shuts down. This risk can be mitigated by the addition of spike protective devices near electronics, made from a Transient Voltage Suppressor and a small fuse. I use these in my system as insurance against load dumps that may happen unexpectedly. The ~$10 cost of doing so is cost-effective and may protect my voltage regulator, ECU or fuel injection control module.

surgesuppressioninaugmenteddcsytems.pdf

3) **DC to DC Charger**

A DC/DC charger is an electronic device that converts a variable low-voltage DC input power to a controlled, high(er) output voltage and amperage to charge a battery bank. They limit the current to their maximum capacity (or a reduced setpoint) by providing only slightly higher output voltage than the battery.

Some DC/DC devices can operate either as chargers or ‘power supplies’ (aka ‘converters’). There are also simpler, purpose-built converters in two varieties, those that boost or those that reduce (’buck’) the output voltage from a different voltage DC source. An example is a 5V supply for USB-powered equipment that can draw from a variable ‘12V’ automotive source.

The price advantage of dedicated converters over chargers is large and may provoke thoughts of using a converter over a charger. Converters with 13.8V output are readily available and can theoretically operate very similarly to an FVA. They can provide good charging to lead-acid batteries but are less suitable for LFP. The primary problem is that inexpensive converters are designed to either boost (raise) or ‘buck’ (reduce) input voltage, but not both. Additionally, simple converters are not designed to operate on similar input and output voltages. They generally require an input to be at least 1V different from the output. This creates a conflict for using an ‘automotive 12V’ source (10.5V-14.4V) to charge a 12V battery (needs 13.8-14.4V). DC/DC equipment that can be either a charger or a converter is a more sophisticated construction than simpler boost or buck converters. This enables it to also operate on similar input and output voltages.

More details on using converters in RVs at; https://youtu.be/N6VWKQm5w1g?si=EWjt4z2J0EDiZt3i

A DC/DC ‘charger’ is a microprocessor-controlled ‘converter’, specifically meant to charge a battery. ‘Charging’ is a process of changing voltage, and in response, amperage, based on the battery’s state of charge. The microprocessor in a charger allows selecting a battery type from an internal library that provides standard operating parameters. Within the parameter set, some may be user-adjusted.

Options available on some DC/DC charger models.

- **Isolated Input/Output** types have separate ground cables because internally, the charger uses a transformer to prevent direct electrical connections between the input power system and output power system. This is almost exclusively used in marine applications. Potential benefits are corrosion reduction and electronic noise reduction (for sensitive electronics such as communications radios and radars). Negatives are that the device costs more and will be 6-8% less efficient because of additional hardware. There is rarely a benefit for RV applications.
- **Operation as a ‘power supply’** prevents the microprocessor from varying the output voltage and provides a stable, fixed output to power equipment, not charge the battery.
- **Adjustable output power** rather than fixed at maximum output power. This makes it an ideal tool to reduce the output from a charger if the alternator is overheating (requires measuring alternator temperature). It also offers the ability to deliberately adjust output seasonally. In sunnier, warmer seasons where solar produces more, reducing generation demand on the alternator and tilting the generation balance from the alternator to solar. In cooler seasons where there is less solar and better cooling, increasing the output power can tilt the demand balance back to the alternator.
- **Solar Charge Input** means the charger feeds from two sources of generation, using maximum solar input and augmenting with alternator power to always provide the maximum output.

- **Bidirectional Charging** permits the starter battery to be charged from the auxiliary battery if the camper system is at a high state of charge (such as from excess solar charge).

Voltage control' (meaning depressed voltage) in a vehicle is a method to force equipment to draw less current by lowering system voltage. This is the main VVA strategy, to force the vehicle to use less overall power to increase fuel economy. Current flowing through a resistive load will decrease when the voltage decreases and increase when the voltage increases.

The electronic mechanism in a DC/DC charger does not operate as a resistive load and does not draw less current when the system voltage drops. This 'electronic load' will deliver the maximum output as long as the battery requires it and electrical energy is available. When the voltage drops, the charger draws MORE current to maintain constant power input. This phenomenon is unique to electronic loads and has several important negative effects.

- When the engine is at cruise speed, the combined load of the vehicle and charger (being properly designed) loads the alternator at less than its continuous capacity, so everything is fine.
- As soon as the engine RPM drops, the alternator's capacity drops below its continuous capacity but is still within its full capacity. Generation still provides electricity at an unsustainable level, so heating accelerates. If it stays at this RPM for long, the alternator will overheat. This is why automatic thermal load shedding is important.

If the engine RPM drops to idle, the combined demand exceeds the alternator's full capacity. The alternator can only supply most, not all, of the demand. The alternator's temperature rises rapidly, and voltage drops, starving vehicle systems. The charger and vehicle will both begin drawing power from the starter battery as the voltage continues to drop. If this continues for long, not only will the alternator overheat, but the starter battery can become discharged and unable to operate or start the vehicle. Some DC/DC chargers have minimum input voltage standards to stop this from happening, but not all do.

If a DC/DC charger is the right tool for your situation, sizing it is the next question to answer. This seems like it should be easy but it's not that straightforward.

Compare the alternator's continuous reserve capacity (in watts), to the maximum input demand of the chosen charger. Charger manuals should specify maximum input power, but often they do not. A charger may advertise output in amps, but is usually 'rated' by power. It will draw a fixed maximum power almost all the time, which can be a problem. If the vehicle is idling, it will draw the same maximum, but if the alternator cannot produce enough, it will draw the rest from the starter battery.

Calculating the continuous reserve capacities of a vehicle with a 170A alternator, which has an FVA, it offers 813W. If it has a VVA, it only offers 701W. Compared to the maximum demand on a 700W ('50A') capacity charger with a minimum efficiency of 93% = 749W demand. The FVA has enough capacity to operate safely, but the VVA does not. This difference may be viewed as 'close enough' because our planning factors were based on conservative estimates, but because of the way the VVA voltage is managed, the lower capacity is real and should be respected. For a VVA, drop to the next lower charger size (or detune output in the programming) to work within the usable continuous reserve capacity.

A basic schematic for the installation is below, with general notes guiding materials and installation. Specific calculations to size equipment are below the schematic. This schematic is likely different from most installation manuals. Specifically, charger manuals specify connecting the charger input to battery terminals (because it's convenient). Doing so has a number of potentially negative outcomes

Problems with Connecting the Charger to the Starter Battery

If the charger instructions say to connect at the battery terminals, there are several potential problems.

Problem #1: Overloading the OEM cable between the alternator and battery. It's likely that the charger manual will specify using 6AWG everywhere. BUT, because they say to connect the positive lead to the battery, which is away from engine heat, it does not require more than 7” to reach the OCPD and therefore does not need the 3 ft sheathed 4AWG cable calculated in the cabe sizing example. This is all technically correct, it is not practically correct because to work, it makes assumptions that are likely not true.

- Assumption 1: The OEM design for the alternator cable’s capacity is for a light continuous load (~45A), and intermittent battery recovery surges lasting only a few minutes. No OEM plans a continuous load other than engine operation that needs either high capacity or continuous operation. There is no equipment in the vehicle requiring it. By adding a high-power, continuous auxiliary battery charging load connected to the battery, the alternator cable will likely be significantly overloaded.
- Assumption 2: How big does the OEM think the alternator cable needs to be? The OEM alternator cable is likely several sizes too small to support the combined continuous load of vehicle and charger. If 45A is the max continuous load (not all will be continuous) the OEM designers planned for, resulting in a (x 125% =) 56A design load, they could barely use an 8AWG but more likely a 6AWG@125C wire can carry 77.9A, sheathed, in engine space.
- Calculate the alternator to battery cable: The combined load for this charger installation carries 60.4A for the charger and up to 45A for the vehicle. BOTH are continuous loads and subject to the 125% requirement (105.4A x 1.25 =) 132A design load.
- Is the alternator cable running singly in open air? or is it ‘bundled’ (anywhere)? OEMS really like to sheath (tape or corrugated wire loom) cables.
  - If it is single and not bundled, then, using ABYC E-11 Table IV-A to find a cable size yields a 4AWG@105C (our welding cable) that supports 136A or a 4AWG@125C (typical of GXL wire used in automotive engine bays) that supports 151.3A.
  - If it IS sheathed or bundled, then, using ABYC E-11 Table IV-B to find a cable size yields a 1AWG@105C (our welding cable) that supports 145.8A or a 2AWG@125C (type GXL wire) that supports 140.2A.

Summary: This calculation shows that IF the charger input cable is attached to the battery, the vehicle's positive alternator cable must be substantially upsized. IMHO, the installation is far better off, NOT relying on any OEM wiring or getting involved in modification to it that adds cost, complexity, and may void the warranty. That is why I recommend direct connections to the block and alternator.

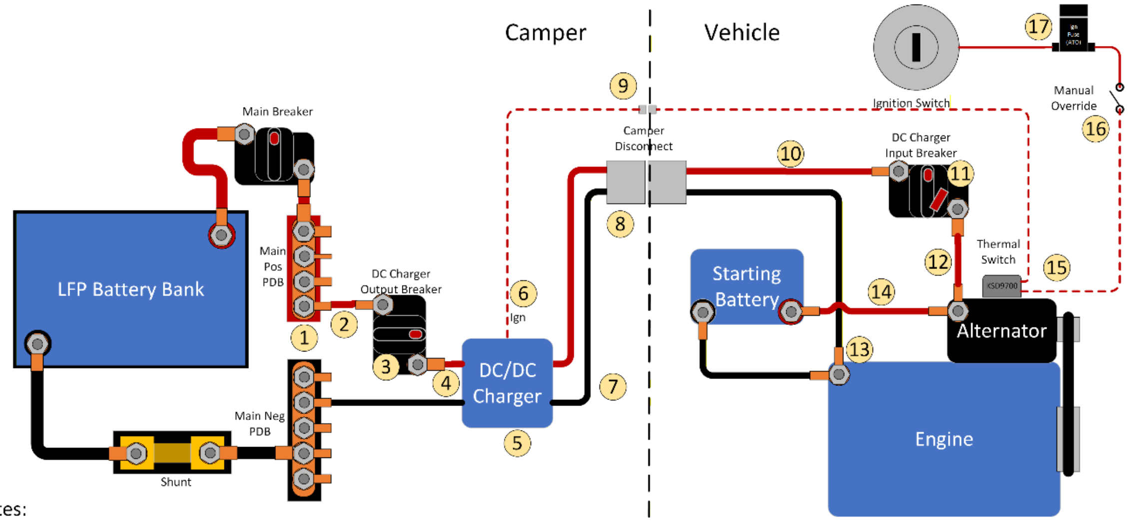
The negative cable between the battery and engine is almost certainly adequately sized because it supports the starter.

Problem #2: Connecting the charger's input negative cable to the battery terminal. Assuming this is a smart alternator-equipped vehicle, there will be a current sensor either at the negative battery terminal or somewhere on the negative cable from the engine block to the battery. This sensor is part of the smart charging system and is used to detect the charge current going to the starter battery. The vehicle engineer’s intent is that the BCU will adjust the voltage down if it sees low current going to the battery, assuming it's charged enough. By connecting the charger load on the battery side of the current sensor, it will make it seem like the starter battery is never satisfied and keep the alternator voltage higher, likely ~13.2-13.5V. This will benefit the charger but confuse the vehicle.

Forcing the VVR to a higher output voltage is probably intended by the charger designer to deliver more power. Different manufacturers use the current sensor on the negative terminal to feed into their power management strategy differently, so the precise effect of this manipulation is likely to differ by vehicle brand. In any case, the effect was not foreseeable nor intended by the OEM engineers.

I believe it is less likely to produce problems by connecting to the alternator and engine block. I say this specifically because I believe that in most cases, the charger’s positive lead will overload the vehicle’s alternator cable and the charger’s negative lead will affect the vehicle's management of the smart alternator.

Wiring Schematic for a DC/DC Charger with Thermal Unloader



Notes:

1) Connect the input cable lugs to the main camper Power Distribution Block (PDB), not interruptible by the battery cutoff switch.

2) Per ABYC, the distance from the 'source of stored energy' to the OCPD should not be more than 7 inches when unprotected wire.

3) The Over Current Protective Device (OCPD) can be either a fuse or breaker but a breaker, providing an easier disconnecting means, is frequently necessary. Deenergize the circuit before disconnecting the coupler (#8) and insure it remains deenergized when disconnected. OCPD size is planned to be 80%-115% of the maximum ampacity of the minimum cable.

4) An unsheathed cable must be sized for 125% of the maximum current per ABYC E-11 Table IV-A. If sheathing is used, size at 125% of the maximum current per ABYC E-11 Table IV-B. Input current and output current are different as is the insulation requirement so cabling may be different. Wiring 'inside engine spaces' requires insulation rated 75C or above. Wiring 'outside of engine spaces' may be 60C or above. Welding cable rated at 105C is recommended as the most, durable, economical and available option.

5) Locate the DC/DC charger where it has a moving, temperate air flow. An enclosures should be specifically ventilated, if possible by a powered air circulation fan. Chargers typically have passive heat sinks on the back usually requiring it to be mounted vertically upright. Avoid other orientations. Do not mount in the engine compartment. Placed as close as possible to the auxiliary battery.

6) Some chargers can activate based on elevated voltage, sensed when the alternator starts generating. While convenient, this undermines needed control. Circumstances often require manually disabling by wired control. Place a manual override switch near the drivers position. Prevent potential overheating by shutting off the charger when idling, climbing hills, in hot weather or when solar charging is assumed to be adequate. If used, wire the alternator thermal safety switch in series. Use 75C or better wire insulation for engine spaces.

7) Positive and negative cables are not required to be routed together but it is often helpful. They must not be sheathed or bundled unless designed to 125% of the maximum current by ABYC E-11, Table IV-B .

8) If the cable uses a disconnect, be able to remove power from both sides before uncoupling. Use connectors such as Anderson Power SB series connectors (available in 50A, 120A, 175A, and 350A sizes). Use terminal covers when disconnected.

9) If the power cable is equipped with a disconnect, the ignition signal cable also requires one. A single, small wire can use ¼" fully insulated Quick Disconnect (QD) terminals.

10) Cabling 'inside engine spaces' requires 75C or higher insulation.

11) OCPD inside the engine compartment is at high risk of nuisance tripping due to heat. Locate the OCPD where it is not directly subject to engine heat. A breaker is recommended to allow de-energizing the disconnect coupler prior to and while disconnected.

12) Connecting directly to the alternator B+ terminal prevents overloading OEM wiring that is not designed to handle high continuous loads. If locating the OCPD less than 7" from the connection is not possible due to engine heat, place the OCPD in a temperate location and use a cable 'sheathing' to extend the maximum distance to 40". Use ABYC E-11, Table VI-B at 125% of max current for wire sizing.

13) Connect the negative cable to the same location as the engine block ground. It is undesirable/problematic to connect to the negative battery terminal because 'smart' alternator systems use a hall effect current sensor on the negative cable near the battery. If the sensor registers non-vehicle loads, vehicle electrical operation is affected.

14) The OEM alternator cable is designe only for high intermittent loads from an engine start. It is typically NOT large enough to meet the 125% capacity required for a continuous charger load.

15) Mounting a KSD-9700 on the alternator in the ignition signal line to provides a thermal unloader should the alternator overheat. As with any wiring 'in engine spaces', the insulation on this wire needs to be 75C or greater. Type GXL (90C) or silicone (125C or 200C, likely used on the KSD9700), is suitable. Most 'primary wire' sold in automotive stores is type GPT (60C) and is NOT suitable.

16) A means of manual shut-down of the charger is necessary to turn it off in conditions such as hot weather, passing, hill climbing, high ambient temperature, etc. It should never be left permanently on.

17) Any additional circuitry needs protection from short circuits. This circuit flows negligible current so a 5A ATO fuse is adequate.

To determine the sizing of equipment associated with the installation of a DC/DC charger, it seems more helpful to demonstrate it on a notional '50A'/700W charger rather than discuss it in general terms. Normally, the manual that comes with the charger will specify Over-Current Protective Device (OCPD) and wire size. These are likely minimally acceptable but often result in the SYSTEM being undersized because they ignore the vehicle wiring. I've found their 'prescription' typically violates ABYC standards in several areas. The most significant involves the negligence of considering the added continuous load on the OEM alternator to battery cable or employing a disconnect between the vehicle and camper.

Requirements established by the American Boat and Yacht Council (ABYC), E-11 electrical standard, which is the de facto regulatory agency for DC systems. The manufacturer's specifications only address the added parts associated with their equipment and cannot have the required knowledge of all parts of the vehicle system that will be affected by the new load. ABYC standards are likely more robust.

Cable Sizing

A '50A DC/DC charger' is a general product name where the product spec sheet specifies it as a 700W output, not a 50A output (50A x 14V = 700W). The reason is that the charger varies both current and voltage based on a fixed power standard. It does not always or even usually deliver 50A, nor does it draw 50A. Cable design, however, is based on maximum current, so to determine cable size, investigate the limit condition to determine cable design requirements.

ABYC uses two parallel methods to calculate wire size. Absolute ampacity as determined by derating tables and voltage drop calculations that factor in a maximum voltage drop of 3% or 10% based on the criticality of the load (determined by the user) and cable length. Voltage drop calculations are best handled by online calculators, but there are also ABYC tables. Voltage drops require knowing/estimating cable lengths. Use the largest cable resulting from either calculation. [#1 best Marine Voltage Drop Calculator ABYC Wire Sizing Tool]. Blue Sea Systems has a phone app that will also provide calculations.

- Maximum Output Current: The maximum charge current will occur when the battery is at it's lowest SOC. When the battery being charged is at 0% SOC (~10V), the charger will output only enough voltage to cause the maximum current to flow. A 700W supply operating just above 10V can deliver (700W/10V =) ~70A. The voltage rise needed to cause 70A to flow through a ~1mΩ resistance (the battery) is 70A x 1mΩ = .07V…..so the charger outputs 10.07V, and 700W/10.07V = 69.5A will flow.
- Maximum Input Power: If the charger is providing 700W to the auxiliary battery, the INPUT to the charger must include the output + the electricity wasted in conversion. Victron rates its charger at '97% maximum efficiency,' which is an interesting but useless statistic. The maximum efficiency is irrelevant; The <u>minimum</u> efficiency is what's important. With a 700W output at (assume a typical) 93% minimum efficiency, the worst-case input is 700W/.93 = 749W.
- Maximum Input Current: From the worst-case input power, calculate the worst-case input current. Worst-case input current occurs at the lowest system voltage. In 'Smart' alternator-equipped vehicles, system voltage is often as low as/most frequently 12.4V. With an FVA, it's 13.8V. Assuming the VVA, the charger will draw 749W/12.4V = 60.4A.
- Continuous or Intermittent Duty: The charger operates at a steady state for potentially a long time, depending on the size of the battery bank. Is it 3 or more hours at a time?

  For reference, a 100Ah LFP battery has 1280Wh capacity. This requires the operation of a 700W charger for (1280Wh/700W =) 1.8 hours to recover a full charge (assuming 100% battery charge efficiency, which it is not, but close). Operating with only 1 battery would allow classification as intermittent duty, but with 2 or more batteries (which is typical), the charging duration could easily exceed 3 hours. So in most cases, it will be considered a 'continuous duty' circuit, (operating for more than 3 hours in 24 hours).

- Cable ampacity standards are based on a combined current consisting of no more than 80%(4/5) continuous and up to 20%(1/5) intermittent duty. In this case, there is no intermittent current. It is all continuous. Cabling, therefore, must be designed such that the maximum current does not exceed 80% (4/5) of the cable's capacity. Said in another, easier to calculate (equivalent) way, choose a cable rated for 125%(5/4) of the maximum current.

Calculate the input cable in sections first, since each section has different requirements.

- Ampacity Calculation: From the alternator to the OCPD section (Item 12, positive only). The input cable, with 60.4A continuous current, must use a wire capable of carrying (60.4A x 1.25 =) 76A. To select a cable, the insulation's rated thermal capacity must also be known. Since this portion of the cable IS 'in engine space', a cable with insulation of 75C or greater must be used. Heavy cable with good abrasion resistance is needed. 'Welding cable' is a popular choice for this role. The rubber insulation of welding cable has a 105C rating. Using a cable with a higher insulation rating may allow use of the next smaller cable (saving $).

  Additionally, since this cable connects to the alternator in a high-temperature area of the engine space and the OCPD must be located in a cooler space, probably more than the ABYC minimum of 7" for an unsheathed cable but hopefully less than 40" away ABYC allows for a 'sheathed' cable. Assume a sheath will be required. A sheath holds in heat, requiring the use of a different ampacity table. Selecting this cable will use ABYC E-11, Table IV-B to find the required size in the 'Engine Room' column; 16mm^2 @ 80A is the best fit. 4AWG @ 95A is the nearest readily available US equivalent. Only the length of the positive cable from the alternator to the OCPD needs to meet this requirement because it is the only portion sheathed.
- Ampacity Calculation: From the OCPD to camper disconnect section (items 10 & 13, positive and negative): Since the input cable is long, more economical choices should be examined. The remaining portion of the input cable, from the engine bay OCPD, to the connector (the next cable end), does not need a sheath so cable can be selected from ABYC E-11, table IV-A in the 'engine room' column, to see if a smaller size can be used; 10mm^2 @ 85A is the best fit with 6AWG @102A being the nearest readily available US equivalent. This cable can also be used for the negative cable from the engine block to the connector (both have identical requirements).
- Ampacity Calculation: From the disconnect to the charger (Items 7 & 8, both positive and negative). This cable may also be economically resized since it is 'not in engine space'. Use ABYC E-11, table 1V-A again, this time for non-engine space; 8AWG @80A is the best fit.
- Voltage Drop Calculation: On the entire length from the alternator to the charger using the actual maximum 60.4A current. The calculation is a bit problematic because there is a combination of 'in engine space' and 'outside engine space' but toggling the selection in the calculator shows no change in result. Using an estimate of 20' one- way cable length (40' total length) and up to 10% allowable voltage drop (because the charger can compensate for the voltage drop on the input), a 6AWG cable provides 8% voltage drop. For curiosity's sake, if using 3% limits, the wire size becomes 1/0 with only a 1.5% voltage drop. It would be expensive and difficult to upgrade this much.

Merging the ampacity and voltage drop calculations. The voltage drop calculations require the input cable to be a minimum of 6AWG everywhere, but the ampacity calculations require the alternator to OCPD section to be increased to 4AWG. Welding cable rated at 105C is selected.

Moving on to the output cable;

- Ampacity Calculation: Output cable with 69.5A continuous current, must use a cable capable of carrying (69.5A x 1.25 =) 87A. To select a cable, the insulation's rated thermal capacity must also be known. Since this cable is 'not in engine spaces', a cable of 60C or greater can be used.

Because durability is key, and cable commonality is desired. Using 105C welding cable is chosen. Select an appropriate cable size from ABYC E-11 Table IV-A, assuming, even though both cables will follow the same routing, they are short and will not be bundled (nor cable-tied together); 10mm2 @ 100A is the best fit, with 6AWG @120A being the nearest readily available US equivalent.

- Voltage Drop Calculation; Output cable using 69.5A current, 2ft one-way length, 'not in engine space', and using a 3% voltage drop allowance (because voltage sensing between the battery and charger is important), the calculator allows 8AWG with a 1.5% drop.

In summary, for the output cable to optimize efficient wire and terminal selection, using 6AWG for the very short length seems prudent and reduces the voltage drop, which is beneficial.

The final plan is to use ~3' of 4AWG red welding cable with a braided nylon sheath from the alternator to the OCPD, and 22' each of black and red, 6AWG welding cable everywhere else.

OCPD Sizing

The OCPD sizing process is based on the maximum ampacity of the smallest capacity wire in the circuit, with rating factors applied.

- If a circuit is constructed from wires with different wire gauges and different temperature-rated insulation, use ABYC E-11 table IV-A or B, to evaluate the ampacity of each different material/installation. Compare all results. Choose the lowest ampacity wire rating.
- Multiply the lowest ampacity wire rating by the minimum (80%), desired (115%), and maximum (150%) current limits.
- Evaluate the available OCPD that fall within the 'minimum to desired' range. If there is more than one device is available, choose one based on any criteria you may wish to apply.
- If there are no OCPD that fall within the minimum to desired range, expand the range to include the maximum limit and choose from the expanded candidates.

Using our 170A-rated FVA and 700W charger example;

- To select OCPD size, identify the minimum cable ampacity of the acceptable range. The low limit is 80% of the maximum cable ampacity of the smallest cable. Since we have selected 6AWG @105C cable, there are two different installation cases. 120A outside engine space and 102A inside engine space. Use the smaller: 102A @105C. 80% of the lowest maximum is: 102A x .8 = 82A.
- The desired upper limit is 115% of the lowest maximum cable ampacity: 102A x 1.15 = 117A.
- The maximum upper limit, to be used only when a common OCPD size does not fall between the lower and desired limits, is 150% of the ampacity; 102A x 1.5 = 153A.

Between 82A and 117A, standard breaker capacities of 90A, and 100A are available within the desired range, and 120A,135A and 150A are available above the desired range. I find standard values by checking BlueSea.com product pages. Since 2 options are available in the desired range, none of the higher value devices should be used. Keeping a centrist approach (closest to but below 115%), I recommend the 100A breaker.

OCPD selection notes;

- While assuming the use of breakers, fuses are also acceptable and use the same rated capacity. Fuses may be available in a wider variety of capacities.
- As a general rule, breakers are considered to 'trip' at 130% of their rating (as do fuses).
- ANL fuses have a specification problem that results in a performance problem. Their trip ratings are often FAR more than 130%, and every size is different. Blue Sea Systems has a chart explaining the differences as well as advice on using them. Once you consult their ACTUAL 'blow

point' table, and back calculate to determine an equivalent nominal rating, (Blue Sea's 'blow point' ÷ 1.3), They will work fine (but feel weird). Choosing Circuit Protection - Blue Sea Systems. For this reason, I recommend avoiding ANL fuses.

Terminal Considerations

- Bolted ring lugs are needed for all cable ends, with the possible exception of the charger connection. Measure the stud sizes for each ring mount and buy lugs individually to precisely fit the stud and wire size.
  - Do not drill out 'too-small' rings.
  - Do not place washers on 'too-large' rings.
  - Do not over-crimp 'too large' wire sockets.
  - Do not strip strands from wire to fit in 'too-small' wire sockets.

JUST DON'T….get the right size parts. Every bad thing that happens in a high-current circuit is invariably the result of shortcuts.

- Different terminal connector types are used on DC/DC chargers. Studs with nuts or bolts are the best. Be sure to observe torque standards specified in the charger manual.
- Clearance for the width of the lug tab is a concern if mounting is closely spaced terminals (common on cheap hardware). If interference occurs, either between rings of the same polarity or insulation separators, it is critically important to clear it. Cut or grind away only the necessary material from the side of each ring to allow fitment. Doing this because the ring was oversized to begin with is a virtually guaranteed problem down the road.
- Install a double-wall, adhesive-lined heat shrink along the full length of the ring lug barrel to an equivalent length on the wire.
  - Do not allow heat shrink to extend onto the ring because it may prevent the ring from making good electrical contact.
  - Color-coding heat shrink is optional because the wire is already color-coded.
  - Shrink it with an electric heat gun, not a flame.
  - Heat-shrink has a much higher temperature rating than cable insulation. Flames can easily melt or scorch the wire insulation.
- Clamp-type sockets are also common, and they have size limits. If the chosen charger uses sockets, check the spec to MAKE SURE the sockets will accept wire the size calculated (in our case 6AWG) before you buy the charger.
- Because welding cable is a finely stranded wire, a ferrule should be used over the wire end before insertion into a socket, which adds to the needed socket size.
  - A ferrule may not be usable if the wire used and the maximum wire allowed are the same, but try.
  - Square or rectangular sockets will usually accept 4-sided ferrule crimps. Sockets that are round typically do not and require 6-sided ferrule crimpers (a more premium tool).
- If the socket does not accept the wire size calculated, 'reducing pin terminals', either concentric or offset, can be used to terminate the cable and allow fitment in the socket. Their use is rare, which is good because pin reducers are hard to find and expensive. Car audio sources are the best place to find them. DO NOT use a fabricated/modified substitute. Using an intermediate PDB to change wire size is commonly done but unless the connection of other cables is needed, it is inferior to a reducing pin terminal.

- ➢DO NOT PLACE STAINLESS STEEL hardware (washers or nuts) between lugs or buss-bars in the ‘conductive path’. Washers of ANY TYPE, may only be applied directly under a clamping nut. Copper has a relative conductivity of 100%, aluminum is 71%, brass is 25%, steel and lead are 12.5%. 304SS, used in most bolts, nuts and washers, has a relative conductivity of 2.5%. Normally, bolts and nuts clamping two copper conductors together are not part of the conductive path, and almost no current flows through them but if a washer is placed in the wrong place, it becomes a high-resistance connection and gets very hot.

Post-Installation Checks

After all wiring is installed, there is a specific procedure for verification and startup. The main concern is preventing reverse polarity to the charger, which it may not be protected against. This is just a general safety check to avoid ‘letting the smoke out’ and provide an overview of the process. This is not a substitute for following the manual directions.

1) Check the positive power cables: Using a digital multimeter (DMM) set on voltage, check the voltage of both positive cables at each OCPD input to a known ground (not the new negative cable). Both should read positive voltages in the 12’s.
2) Check the negative power cables: Using the DMM set on voltage, check the voltage from the input of each OCPD to the nearest negative connection of the new cable, not a chassis ground. Both should read positive voltages in the 12’s.
3) Check the ignition control wire: Probe the ignition wire input at the charger.
    - With vehicle ignition off, and the manual override ‘disabled’ (off/open), verify no positive voltage is present.
    - Turn on the vehicle ignition on, with the override ‘disabled’, verify no positive voltage is present
    - Turn on the vehicle ignition, with the override ‘enabled’ (on), verify positive voltage in the 12’s is present.
4) Passing these tests verifies the correct polarity of connections. Next, close (only) the input OCPD to apply power to the charger. The charger should power up and allow programming. Follow the charger setup in the operator manual.
5) When the charger setup is complete, measure and record the voltage of the auxiliary battery. Close the output OCPD and start the vehicle. Check voltage at the auxiliary battery. It should be higher than the initial check, indicating it is charging.

Software Setup

Because a specific charger is not being cited, the terms below are generally what should be available and how the setting should act. * Indicates a function only some equipment will have.

<u>Required</u>

- ➢**Operation type*** selects between two modes of operation. Some equipment can operate either as a charger or as a ‘power supply’ (aka a ‘DC/DC converter’). This is one role where you might want to supply a single device or your entire camper with ‘regulated’ 12V power (from a source that may operate anywhere within the ‘12V automotive’ range (10.5-14.4V). The ability to set an output voltage enables ‘dialing down’ the entire camper voltage to serve multiple ‘regulated 12V’ devices, like most CPAPs.
- ➢**Battery type** should be set immediately after the charger receives power, before the output OCPD is closed. Each type of battery has preferred voltage thresholds. Once the battery type is set, defaults will be loaded from memory. Unless you have a specific reason for changing a particular voltage threshold and a good understanding of the effect, accept the defaults.

Optional

- **Alternator type** (fixed or smart) allows the device to understand what voltage to expect when the alternator begins operating. The device will load the voltage threshold default settings related to each device.
- **Output Limit*** sets either the maximum current or the power the device will produce. It is not always necessary for it to operate at full power, and depending on the cabling, alternator capacity or battery charge rate, reducing it below the maximum may be desirable.
- **Startup/Shutdown Detection** involves a number of voltage and timer settings that are different by brand. I do not think voltage sensing of the automotive system is a complete or even a good solution to manage charging. There is just too much voltage variation going on in modern Smart alternator-equipped vehicles for it to work correctly all the time. Voltage 'sensing' is likely to allow the charger to operate at times when the alternator is not producing enough power, which likely will result in overheating.

IMHO, this is another instance of developing 'half a solution' that ends up overcomplicating things. If the manufacturers of these devices wanted to enact a good control mechanism, it would monitor alternator temperature and use that to enable/disable output, preventing overheating.

I believe the charger should never be left on in all driving conditions. The driver should have a manual override that only works with the wired signal cable. The charger should be on only for highway driving because that is when RPM is high enough to produce the peak output that it takes to power the charger and cool the alternator. If your solar system is working well, it should be off more than it's on anyway.

I see no good reason not to install a thermal shutdown switch on the alternator that requires the use of the wired signal lead.

$\mathbf{V_{lockout}}$ Make sure your battery doesn't get drained accidentally. This can happen under a number of conditions, mostly involving low-speed driving. This is the input voltage at which the charger will stop to prevent over-discharging the starter battery. It's typically set at ~12.5V. The problem is that starter batteries in Smart alternator-equipped vehicles are intentionally partially discharged most of the time. I cannot provide a specific cutoff voltage recommendation because I think it will vary by vehicle.