The Case for Augmented Suppression of Alternator Spikes for DC Systems

Effects of More Electrical Demand

For some time, there has been a lot of attention paid in the RV community about surge (voltage spike) protection from AC shore line sources but there could be an equal threat in DC power systems. With the drive for more battery and charging capacity to operate off grid longer, RVers are making significant modifications to vehicle DC systems to accommodate larger alternators and charging systems. Switching off large loads in an automotive alternator supplied electrical system causes voltage spikes that can travel throughout the entire power system. Under load, alternators develop powerful magnetic fields when operating the vehicle and added equipment. Shutting off a large load causes the large magnetic field to collapse, generating significant voltage spikes in both stator and rotor.

The larger the alternator or load, the larger the spike will be. The use of large banks of lithium batteries greatly increases charging amperages. Rapidly switching these large currents by either use of a BIM, directly charging where a breaker or isolation relay can trip or the BMS can disconnect when fully charged can produce spikes in the vehicle system that will not have been anticipated by vehicle designers. While these spikes likely won't cause an immediate failure, occurring repetitively may result in a failure eventually.

Spike Creation

A 'load dump' is a term often used to incorrectly describe two different events. The first and most accurate 'load dump' is to describe rapidly turning off a substantial (>20%) 'load' on a power system supplied by an alternator. Rapid switching of high current loads produces a voltage spike (surge) and should be avoided. The most hazardous examples are; 1) BMS disconnect, 2) Tripping a fuse or breaker on the primary power cable, 3) Use of a relay to disconnect battery charging such as an isolation relay or BIM. B2B chargers, although high current devices, disconnect by slowly tapering of the charge and for this reason, regardless of size, are rarely problematic.

The other event is more accurately called a 'battery dump', which is when the system's battery becomes disconnected. For an alternator to remain in control, it needs a stable power buffer that is also a voltage reference, which the battery and only the battery, provides. A battery dump results in the entire system becoming unstable. Erratic voltage follows as loads in the system vary, adding to the instability. For this reason, automotive manufacturer rarely place over current protection devices between alternator and battery. A battery dump is of such low probability in a system with a lead acid battery, expending effort to defend against it is probably better spent preventing it.

Adding high capacity alternators lead to switching larger currents that produce higher energy spikes than the automotive designers expected. While an argument can be made that the larger capacity of the alternators avalanche diodes and the 'excess damping capacity' in the vehicle's systems has worked before and will work again, may be true but it only has to fail once to have catastrophic effect. I believe it is prudent, that when increasing the size of power equipment, the size (and quantity) of the spike protection equipment should also be planned.

Analyze the Situation

In my case, I run a second, 220A/24V fixed voltage alternator that directly charges my 17.5kW lithium battery at 100A (~3kW) with no lead acid battery in the circuit. It cannot be disconnected by the BMS (as all drop in replacement lithium batteries can) and the charging can be safely terminated, if the battery is full or the alternator exceeds 120C, by shutting off the regulator. The big battery and alternator also support operation of my 18k pound, 24V winch which is a definite spike producer when switching on and off at 24V/267A (~6.5kW) max. Switching either of these will produce significant spikes in a power system that also includes two AC inverters and three DC converters so I am concerned about those as well.

I have made major changes that I know require additional spike suppression. While your situation may not be as adverse as mine, if you have significantly increased the alternator size, that may be reason enough to be concerned. Every situation is different. My desire is simply to make you aware that this potential exists and there is an inexpensive method to reduce its effect on your equipment.

'Transient Voltage Suppressors'

Alternator spikes is the reason that automotive manufacturers build 'Transient Voltage Suppressors' (TVS) into the power and signal inlets to most automotive electronic equipment. A TVS is the electronic equivalent of a very fast acting 'pressure relief valve'. Alternators, as the source of these spikes, are (typically) equipped with 'avalanche' diodes (a rectifier and TVS in one) that allow voltages above their 'reverse breakdown voltage' to flow backward through the diode to ground. This intends that high voltage spikes will flow to ground before leaving the alternator but at the cost of momentary (a few milliseconds) doubling of the output voltage. Using a common Littlefuse 5KP TVS (15V) as an example; Suppression begins at ~16.7V and may rise to a maximum 'clamping voltage' of 24.4V @209A. Typically, higher operating voltage avalanche diodes are used (~24V) which behave similarly. For an unclamped system, voltages can exceed 100V.

Electrical Characteristics (T_A=25°C unless otherwise noted)

Part Number (Uni)	Part Number (Bi)	Reverse Stand off Voltage V_R (Volts)	Breakdown Voltage V_{BR} (Volts) @ I_T		Test Current I_T (mA)	Maximum Clamping Voltage V_C @ I_{PP} (V)	Maximum Peak Pulse Current I_{PP} (A)	Maximum Reverse Leakage I_R @ V_R (μ A)	Agency Recognition
			Min	Max					
5KP15A	5KP15CA	15.0	16.70	18.50	5	24.4	209.0	2	X

Adding a (some) 'relief valve(s)', can be placed anywhere but some places are better than others;

1) At the point of creation; This is the way automotive engineers think by installing avalanche diodes in an alternator; dissipate the spike created BY the alternator, IN the alternator. This is the best strategy. Bigger alternators have heavier windings, generating more energetic spikes that last longer, travel farther and take more time and effort to dissipate. Dissipation subjects the entire vehicle system to higher voltages that can reach the 'maximum clamping voltage' if the spike is large.

2) At the point of potential damage; Surges travel throughout the electrical system (on both power and signal lines) and can enter a sensitive device. Signal lines are the least subject but they are almost always, more susceptible. Most OEM hardware (control units) in a vehicle is already hardened to some extent (against threats the designers know about) but they may not be as well protected against the more energetic spikes produced by high output alternators.

3) Lead acid batteries that remain in the system can also add to spike dissipation but they are much slower acting and typically only capable of providing protection to equipment near them. Equipment that is distant from the battery or closer to the alternator than the battery should also be considered.

Making and incorporating a TVS devices to augment protection provided by the manufacturer is something easily and inexpensively done. An appropriate voltage and sized device can be constructed with readily available components. The device consists of the TVS diode and an appropriately sized fuse. The diode provides the voltage clamping capability but if it fails in overload, typically by shorting, a new problem is created. Suppressing most of a spike but creating a short that cannot be relieved can lead to wire overheating and possibly starting a fire. Placing a fuse in the circuit to open on a TVS short can prevent the cascade failure. The fuse need only be small ~5-10A but within the largest current capacity of the circuit on which it is installed. Fuses act slowly and even with the high current/energy of a spike, will not function during the spike because of its short duration.

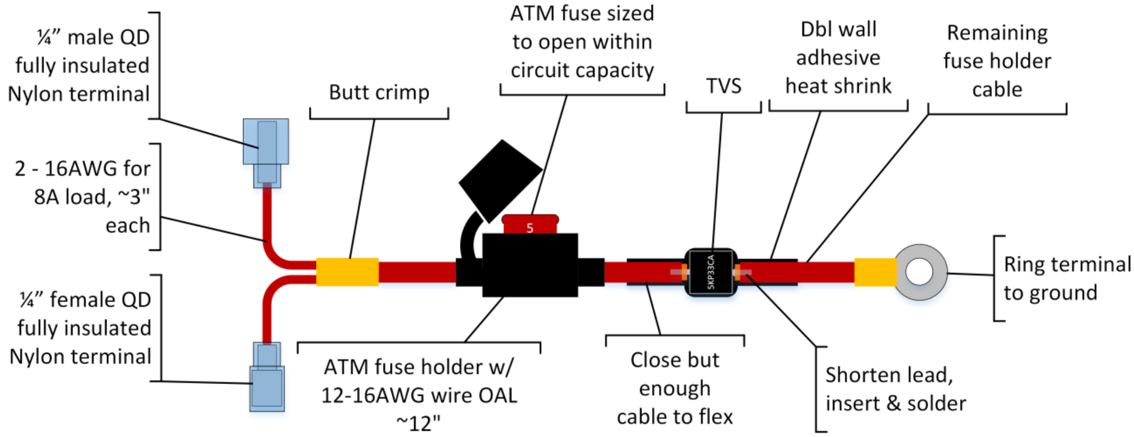
Lots of semi conductor manufacturers make TVS diodes. Littlefuse (my preferred) makes several families of bi-directional TVS at small voltage increments. Part numbers are of the form (Series)(reverse stand-off voltage)(polarity). The 'series' P6KE (<$1ea, 600W), 1.5KE (~$1.5ea, 1.5kW), 5KP (<$3ea, 5kW) where the rated energy dissipation occurs over ~1ms, 'reverse stand-off voltage' is the two or three digit peak system operating voltage the TVS should normally experience, 'polarity' is CA for the bi-directional version. These are available from Mouser, Digikey, Allied Electric, etc. In small quantities, eBay or Amazon suppliers frequently have the best price and free shipping.

Before making your choice, verify the 'reverse stand-off voltage' in the part number is correct to the specs in data sheet, especially if you purchase a different manufacturer part. They are sometimes different. For instance; My P6KE18CA has a 'reverse stand-off voltage' of 15.3V. This works fine with my 12V fixed voltage alternator running at 14.2V maximum. It may not be OK with your variable voltage ('Smart') alternator which can go as high as 15.5V-16V. The next larger device, P6KE20CA, has a maximum standoff of 17.1V which is more appropriate.

There are higher capacity device series (15KP, 20KPA, 30KPA) but they have high 'leakage' at low voltages desired for a 12V system, making them undesirable. Higher capacity can be achieved by using multiple smaller TVS in parallel.

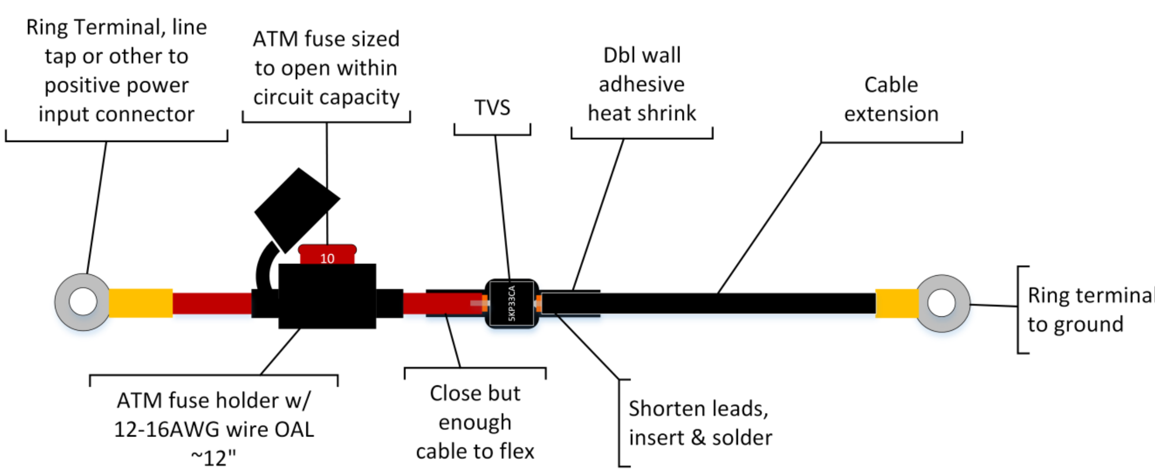
I use P6KE36CA, 1.5KE33CA and 5KP33CA TVS with 5 or 10A mini-ATO fuses in my 24V system that operates up to 29.4V, P6KE18CA with a 5A or 3A fuse in my 12V (14.4V) alternator system.

TVS Assemby 1 for Automotive Spike Protection



+ An example of a TVS assembly designed to tap into an alternator external voltage regulator's field lead with ¼" QD male terminals.
+ The spike occurs in both the stator and rotor. The stator spike is mostly damped by avalanche diodes. The rotor spike is smaller due to a smaller coil. The 'first victim' of a powerful spike is typically the voltage regulator. Internal regulators are difficult (but possible) to similarly modify.
+ The external VR also has 'ignition' and 'battery' (sense) terminals which would also benefit from this protection.
+ The fuse size is the next size LESS than the maximum ampacity of the circuit to which it is installed but need not be over 10A. ATM fuses are available in 2,3,4,5, 7.5 and 10A. ATO/ATC are available in 1,2,3,4,5,7.5 and 10A.
+ Using a Blue Sea 'Easy ID' ATC fuse (and ATC holder) provides an LED indicator to detect an open fuse that results from a shorted TVS. When the TVS shorts, the fuse opens and the indicator illuminates.

TVS Assemby 2 for Automotive Spike Protection



+ An example of a TVS assembly designed to provide equipment input suppression at the equipment main power terminal. The positive termination can be any that allows it to be stacked with the input power cable. A line tap may also be used.
+ This design can vary in length by extending the grounding tail to reach a good ground. This device is only as effective as the grounding terminal. Insure the grounding surface is clean and use a grounding washer ('star' washer) if possible.
+ The fuse size is the next size LESS than the maximum ampacity of the circuit to which it is installed but need not be over 10A. ATM fuses are available in 2,3,4,5, 7.5 and 10A. ATO/ATC are available in 1,2,3,4,5,7.5 and 10A.
+ Using a Blue Sea 'Easy ID' ATC fuse (and ATC holder) provides an LED indicator to detect an open fuse that results from a shorted TVS. When the TVS shorts, the fuse opens and the indicator illuminates.