A disclaimer first: I am not a qualified tradesman. I have technical interests and before retirement worked in technical areas in aviation. I like to dabble. As far as auto electrics and solar are concerned, I am self-taught (with early help from my father) from a lifetime of experience supplemented with diligent research.

Circuit diagrams in this blog are simplified block diagrams. For simplicity I have left out details like fusing, diode suppression of relays, etc. Feel free to use my ideas, but please consult a qualified tradesman for such things as fusing, surge supression and negative wiring. (On some newer vehicles it is prohibited to wire a negative back to the crank battery negative. On those vehicles all extra negatives must be wired to a chassis earth.)

This blog is just a description of what I did on my vehicle. It is not a definitive "how to". Nor is it a set of instructions. No responsibility will be accepted by the writer for any damage to property or injury to persons arising from any attempt to copy or install this or a similar system. What you do, you do at your own risk.

Recently I posted in the forum an account of my experience with a failed alternator in a remote place and how I was able to power the tug from my Kimberley Karavan and drive five and a half hours to have it repaired. I was then asked by one of the more senior members of ExplorOz to write a blog to give others an idea of my system so that they could, if they wished, benefit from my experience and the solution I worked out.

When I designed the auxiliary electrical system in my tug, a 2007 120 Series Toyota D4D (common rail) Prado, I had two major considerations. First was the low voltage output by the alternator – never more than about 13.8 volts and it quickly drops to 13.1 volts or so soon after start up.

Secondly, my Kimberley Karavan had a substantial battery pack, 320 amp-hours of AGM batteries. I wanted to build in some flexibility to the system so that if ever something went wrong with the Prado's electrics or my modifications I could, if appropriate, use the big battery pack in the Karavan to help get out of trouble.

Design Parameters

1. A dual-purpose second battery in the Prado and a means to optimally charge it while driving.
2. A means to optimally charge the Karavan battery pack while driving.
3. An isolator to control the charging systems and to protect the crank battery. Also, I did not want the Anderson to the caravan to be live when the key is off.
4. Our Prado is an automatic common rail diesel, electronically controlled. We travel solo to out-of-the-way places. I want to always have a source of power to start my car if the crank battery won't do it. My philosophy is "as much as reasonably possible keep the aux battery fully charged as a back-up to the starter battery". Camping loads, including the car fridge, should be borne by the Karavan battery and its charging systems.
5. In the event of a mishap or mis-management (we grey nomads have been known to have the odd "seniors' moment") where both vehicle batteries are flat, power should be readily available to the vehicle from the large Karavan battery pack.
6. Alternator load analysis to determine whether or not the 80 amp alternator was up to the job.
7. The Karavan is power-hungry and should have an efficient charging system, both while being towed and while camped up.

Implementing the Design Parameters

1. ***Second Battery and Its Charger***

A second battery in a 4WD tourer is usually a deep cycle or dual purpose type. For many of these batteries the alternator charging system is not optimal, and in fact may be detrimental to battery life. So battery and charging system must be chosen together.

There is a lot of heat under the bonnet of modern vehicles. While some expensive sealed (AGM or gel) batteries may be able to withstand the heat, I was advised that a flooded battery is better in those circumstances. I chose a 110 amp-hour Supercharge Allrounder dual-purpose flooded “maintenance-free” battery. This battery can serve as both a deep cycle and as a crank or winching battery.

The manufacturer’s documentation says it requires an absorption voltage of 15.6, way above the 13.1volts that the Prado alternator typically delivers.

The documentation also says that for best life and performance the maximum charging current should be about 10% of its amp-hour capacity – ie about 11 amps. Again, the alternator’s output is unsatisfactory – when the battery is significantly discharged the charging current would likely be too high.

In any case, the two batteries being of different chemistries will always have different charging requirements. Enter the DC-DC charger. These devices are usually multi-stage chargers that accept any nominal 12V supply and convert it to deliver the right voltage for the target battery.

Particularly in the high temperature under-bonnet environment, charging voltages should be temperature compensated - higher voltages for cold batteries, lower for hot – and charging should be stopped at battery temperatures above 50 degC. This was a major consideration in my search for a DC-DC charger.

I chose a Ranox Battery Booster which can do all these things, one of the few available at the time. Sadly it is no longer available but there are other suitable products on the market now.

This device can be programmed to exactly suit whatever 12V battery you choose to install.

I have programmed it to deliver a maximum current of 11 amps, an absorption voltage of 15.5 and a float voltage of 13.4 – ideal parameters for my Allrounder battery. It provides temperature compensation and stops charging when the battery temperature reaches 50 degC. Just as well, because it also records the maximum battery temperature it detects between resets. I have seen 62degC recorded.

2. ***Karavan Battery and Its Charger***

Compared with under-bonnet temperatures in the Prado the temperature considerations in the

Karavan are insignificant. However the discrepancy between alternator output, controlled by the crank battery, and what the Karavan batteries want merit the same voltage considerations as those for the second battery in the tug, especially considering the long cable run between the alternator and the Karavan batteries, around 7 metres. (Long cable runs induce voltage drop which can severely affect charging of the remote battery.)

The clear choice here was another DC-DC charger, which for me was a second Ranox.

Because of its programmable flexibility it has also proved itself to be near perfect for my recent upgrade of the Karavan batteries from AGM to Lithium.

3. ***Isolator***

The purpose of the isolator is to protect the crank battery from discharge by disconnecting the charging systems for both the auxiliary and the Karavan batteries when the key is off. This may be done with either a simple ignition-operated “dumb” solenoid or a more sophisticated “smart” voltage-sensing solenoid.

I opted for the simple ignition controlled dumb solenoid. (The explanation for this is a bit complicated, so for those interested I have left it to the end of this blog.)

Because I am using DC-DC chargers, the isolator is not switching the extra batteries directly into the alternator charging system as in a conventional set-up. Instead, it is just acting as a heavy duty, ignition-operated switch to power the two DC-DC chargers when the key is on.

In fact, what it does is switch a 12 volt supply rail to the Ranox in the Prado, to the car fridge and auxiliary power outlets at the back and to the towbar Anderson which then supplies the Ranox in the Karavan.

4. ***Keeping the Prado’s Second Battery Always At Full Charge***

I run my car fridge as a freezer set to minus 19 (its coldest and most power-hungry setting) while travelling and minus 10 (for 12 volt economy) when camped. Because the charger for the second battery is set to 11 amps max, I don’t want half of that being soaked up by the freezer running at 5 amps, so I have installed a load-switching relay in the car fridge circuit. It works as follows:

When the key is off for short-term stops the fridge runs off the Prado’s second battery. When the key is on it runs off the crank battery/alternator system. This leaves the second battery with no load on it so the Ranox can do its thing without being affected by the fridge load cycling on and off.

Perhaps more importantly, it also means that when the battery temperature exceeds 50 degC and the Ranox stops charging (as it frequently does at ambient air temperatures above about 25 degC), the battery will not be pulled down by the fridge.

And when camped we unplug the car fridge from the car and plug it into the LOAD outlet on the Karavan’s GSL MPPT solar regulator (see item 6 below).

5. ***Emergency Power Feed Forward From The Karavan***

This was easily achieved with a switch (**A**) between the output from the isolator and the towbar Anderson, as Figure 1 shows:

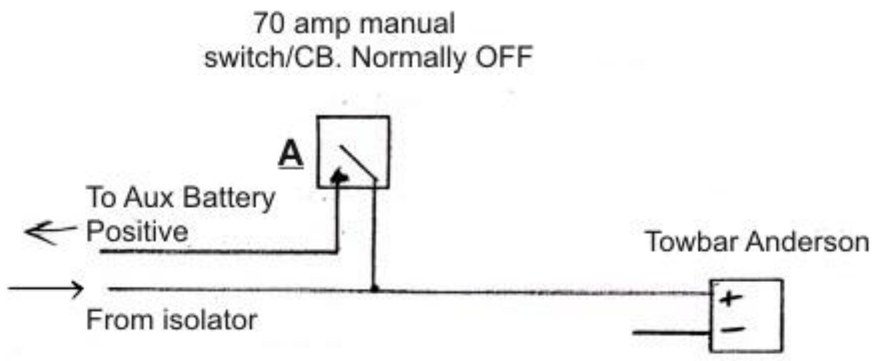

Figure 1

With the manual switch/CB (**A**) closed and power from the Karavan applied to the Anderson via a heavy 6 B&S Anderson extension cable, the Karavan and tug's auxiliary batteries are paralleled.

Additionally I have a 200 amp battery switch (**B**) between the crank and auxiliary batteries to facilitate winching off both batteries – see Figure 2 below. It can also be used to facilitate cranking off the auxiliary battery in the event of a flat engine battery and additionally can be used together with Switch (**A**) to place all three batteries in parallel, providing 12V power to the tug's complete electrical system from BOTH the auxiliary and Karavan batteries.

Figure 2 below is a diagram of the complete system:
(*Note: For simplicity and clarity, fuses and other details are not shown*.)

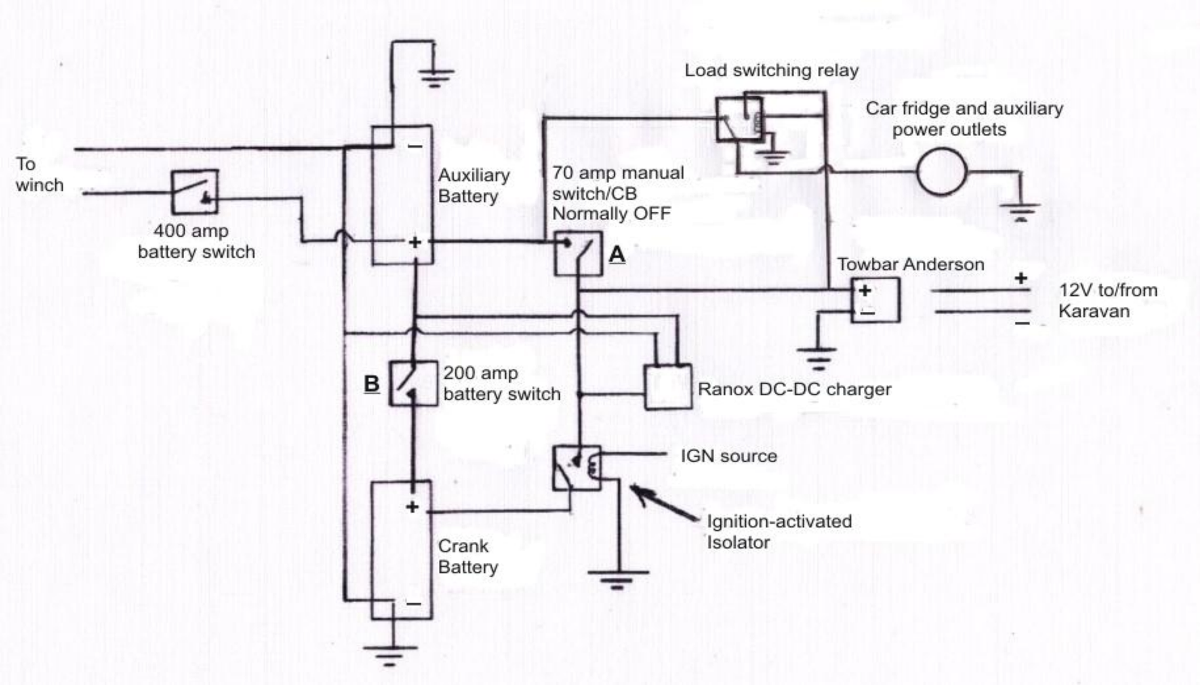

Figure 2

Switch **A** also provides another measure of redundancy: if the DC-DC charger for the auxiliary battery fails, then by closing Switch **A** the crank and auxiliary batteries are placed in parallel via the main isolator and the auxiliary will get some charge, albeit not optimum, direct from the alternator.

6. ***Alternator Considerations***

Early in my ownership of the Prado I had the electrical system tested as a free service by my dealer. They used a Toyota tester of some kind and gave me a printed report. The alternator capacity was 80 amp. What interested me was the electrical current required to keep the diesel engine alive – about 14 amps. Not bad for a compression-ignition engine!! That's computers and electronic injectors for you!

The Ranox in the car draws about 12 amps to provide 11, and the one in the Karavan draws 30 to provide 25. So in normal daytime running the maximum total load on the alternator is 14 + 12 + 30 = 56 amps. This gives a margin of 24 amps and increasing as the batteries charge up and require less charging current, which I thought and still think was quite ok. The alternator has been running my system for a period of six years. It did not fail electrically. Its over-run clutch-driven pulley failed mechanically and just free-wheeled, depriving the alternator of drive from the serpentine belt.

I considered the extra loads in worst case conditions – a wet night requiring wipers, headlights and aircon for de-misting. The Prado quickly ran out of amps.

To address this, and not shown in Figure 2, is a means of reducing load on the alternator. I have a 100 amp CB/switch between the crank battery and the isolator as normal electrical protection. By manually opening that switch/CB the whole secondary charging system is isolated, returning the 56 amps used by the chargers for use by the tug's own systems.

I replaced the broken 80 amp alternator with a genuine Denso rated at 130 amps.

7. ***Karavan Charging System***.

In addition to the Karavan's own Ranox powered by the tug and providing up to 25 amps if necessary, there are four 50 watt panels on the Karavan roof in a series-parallel arrangement feeding a GSL MPPT 30-2 solar regulator..

The series-parallel configuration keeps the solar input voltage well above the GSL's minimum MPPT tracking voltage of 18 volts, thereby maximising the efficiency of the solar charging system.

I chose the GSL for two reasons. Firstly, most solar regulators rely on convection cooling and must be mounted vertically. I did not have room for that in the Karavan's battery compartment. The GSL is fan-cooled, with the fan speed controlled by load and internal temperature. It can be mounted horizontally, which is what I needed for my application.

Secondly, it is an Australian product, designed and wholly manufactured here in Sydney.

The GSL and the Ranox seem to happily co-exist. In favourable sun the GSL will add another 10 or so amps from the rooftop solar panels for a total of 35 amps going into the Karavan batteries while driving.

The picture to the left shows the battery box (cover removed), the new 360 Ah lithium batteries and above them their BMS and the GSL's remote display. The regulator itself can be seen to the top right of the battery box. Its LOAD socket, referred to elsewhere, is hidden from view.

When camped I have an additional 240 watts of solar to deploy, for a total of 440 watts of solar. Because of sloping roof panels on the Karavan, parking orientation and inevitable shade, I rarely get the full benefit of the rooftop solar when camped. But we regularly see in excess of 20 amps going into the batteries – enough to satisfy our substantial needs, especially aided by our recently installed Lithium batteries. They are so good, but that's another story!

Our fallback for extended cloudy weather is a Honda EU20i 2kVA inverter generator to power the OEM Xantrex 40 amp mains charger. We rarely use it.

A diagram of the Karavan charging system is shown in Figure 3 below.

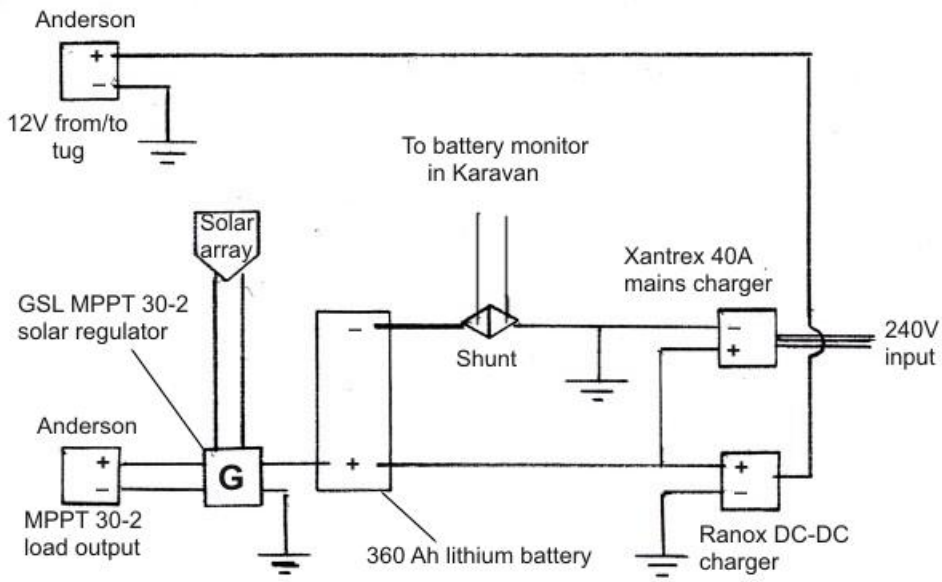

Figure 3, Karavan charging system

Cabling

The winch draws 400 amps under maximum load. Cabling to the winch is starter cable as supplied by Warn. The negative cable between the two batteries and the positive cable via the 200 amp manual isolator (**B** in Figure 2) are the same gauge as the Warn cables.

Cabling to the Anderson is 6 B&S throughout. Cabling to the car fridge is 8 B&S.

Lithium Batteries in the Karavan

This Prado-Karavan combined system has been set up and working for about six years with the manufacturer's AGM battery pack in the Karavan. In fact it was the second pack. The first lasted only two and a half years, but I suspect was abused by the first owner in the first 12 months of the van's life; it died about eighteen months after I bought the van. The tug's system was designed and built before the lithium batteries were ever considered. But let me say that the addition of the lithiums only recently has been a most happy enhancement!

You can read my blog on lithium batteries in my Karavan at LINK

Conclusion

This system is built upon electrical capacity and redundancy so that most electrical problems encountered when away from help can readily be addressed with a work-around or re-configuration of the system.

- The tug's two batteries can be paralleled primarily for winching. But that can also be used to start the vehicle from the second battery if the crank battery fails or is flat.
- The second battery is interchangeable with the crank battery if necessary.
- The DC-DC chargers for the tug and the Karavan can be interchanged if necessary.
- Not discussed earlier, but the Prado's DC-DC charger can be simply switched out if it fails and the system re-configured to charge the auxiliary battery directly from the alternator.
- The vehicle can be powered from the aux battery if necessary.
- The vehicle can be powered from the Karavan battery if necessary.
- There are multiple, independent charging sources, all of adequate capacity to deal with the total load.

Why the Isolator Is An Ignition Activated Solenoid and not a Smart Solenoid (VSR).

It was originally a Redarc SBI12 smart isolator.

Following the lithium upgrade to the Karavan batteries I found that after a relatively short period of driving the Karavan batteries would take on the lithium equivalent of a surface charge.

If we then encountered a period of low engine revs, eg stop-start traffic with low alternator output, the two Ranoxes would pull the crank battery voltage down and the VSR would drop out. And of course, it would also drop out if we stopped for a break.

When the engine revs came up again, or the engine was re-started, the isolator would re-connect. The Ranoxes would see the high voltage from the surface charge of their batteries and delay re-starting, even though the respective batteries might have been only partly charged. This was most evident in the Karavan's old AGM battery pack but was even more pronounced with the new lithium batteries. Lithium batteries seem to hold their equivalent of a surface charge for much longer than lead-acid batteries, even under a cycling load such as the Karavan's compressor fridge. And especially when assisted by the rooftop solar.

As a result the DC-DC chargers weren't always starting and the batteries were not always getting the full benefit of the chargers in the available driving time.

Changing the smart (VSR) solenoid to an ignition-activated dumb solenoid minimised this because the chargers remain connected to their source continuously, except for engine-off stops. Additionally, the Karavan's Ranox has had a software update to address the accentuated effect due to the lithium batteries.

How We Drove Five And A Half Hours Home With A Failed Alternator.

The alternator failed in the bush miles from anywhere – some hours to the nearest help. By closing the manual 200A isolator in the positive line between the two batteries (**B** in Figure 2) to parallel them up we were able to get to our camp. Both batteries were then well down, showing about 11 volts. We stayed for the planned four days and were blessed with perfect sunshine. This allowed the Karavan batteries to always be fully charged by midday.

Leaving the Prado's batteries in parallel, I closed the normally open 70A CB/switch (**A** in Figure 2). This connected the towbar Anderson direct to the two paralleled batteries in the Prado.

When the Karavan batteries were fully charged each day I plugged a heavy duty Anderson extension into the LOAD output of the GSL solar regulator on the Karavan and plugged the other end into the towbar Anderson on the Prado. This effectively placed the Karavan's lithium batteries and the two batteries in the Prado all in parallel. They equalised and were charged or maintained by the 440 watts of solar in the Karavan system. At night I disconnected the cable to the vehicle and re-connected each day at midday. By the end of our camp all batteries were charged as much as they were going to be. Not optimally, but pretty full, close to 100%.

After switching off the Prado's isolator so as not to have the Ranox DC-DC charger confuse things, we minimised electrical load (no aircon, and it was HOT) and drove home in this all-parallel configuration – 5.5 hours – again in full sun. The exception in the configuration was that the portable panels were packed away so we relied on the 200 watts of solar on the Karavan roof to feed the system.

We were able to continuously monitor the vehicle's battery voltages. They stayed above 12V at all times. On arrival the battery monitor in the Karavan showed 10% discharge, about 36 Ah.

The fall-back position was to strap the generator onto the firewood rack on the Karavan drawbar and run it to power the Karavan's 40 amp mains charger while we drove, but that proved to be unnecessary.