NISSAN SILVIA S13 ELECTRIC VEHICLE CONVERSION (2008-09)

STEVE GATES

WHY:

I gradually became interested in electric vehicles after seeing “Who Killed the Electric Car”, seeing displays by the Electric Vehicle Association and YouTube EV videos, plus having a serious concern about peak oil, rising fuel prices and greenhouse gas emissions. The other strong appeal of it was the dramatically lower maintenance required – no plugs, filters, belts, oil changes, etc. I had been using my electric bike and radio-controlled aircraft for years and was very impressed with them.

My move to an electric vehicle began by looking for a donor car, but shortly after, my 1990 Nissan Silvia blew a head gasket, and it seemed logical to consider diverting money from repairing it (about $3,000), to converting it to electric. It was in good condition, has generous boot & engine bay space and I enjoy driving it.

The catalyst to convince me to convert the Silvia in 2008 was an offer to help by a friend and very capable Mechatronic Engineer, Ian Hooper of EV Works, Perth. I also had some welcome and helpful advice from Dan Booth of EV Shop, also in Perth.

PREPARATION;

Before starting the conversion, there were some preparation and decisions needed:

Design Rules & Application to modify

When one modifies a vehicle, there are Australian Design Rules to be followed and these are available online at the Australian Transportation Dept and are required by the local transport regulations. They cover considerations such as weight and handling, battery constraint in high-G decelerations such as crashes, ground clearance and approach/departure angles, and others. Some modifications may require structural and safety checks by a certified Engineer so it is a good idea to contact your local transport department for recognised Engineers.

Performance and Range

The object of the Silvia EV conversion was to have a moderately sporty vehicle able to cruise on the freeway, with a range of 80+km per charge, to suit my typical commute when not taking the bus! To get an idea of what power is needed to do this, I wrote a spreadsheet which calculates the air drag, rolling resistance and hill-climbing power needed at various speeds. It also gives an idea of energy needed per km travel to size the battery pack. To verify the calculations, I verified it agreed also with the rule of thumb of energy consumption of 0.200kWhr/km for that size/weight vehicle.

Costs and Comparison with ICE

Based on the performance desired, the cost of the batteries and other components were determined, with the exchange rate of about AU$1.00 = US$0.70 at that time. The total conversion was estimated at $22,000 with about half that being the batteries. My cost tradeoff between operating the Silvia on petrol at $1.35/litre plus annual engine-maintenance essentially equalled the cost the battery plus cost of electricity at AU$0.20/kWhr over 10 years. (Assuming my average annual driving distance of 8,000 km. With higher driving distances the payback time is shorter).

So, the net cost of the Silvia conversion over 10 years is $22,000 less $11,000 less $3,000 = $8,000, assuming no increase in fuel or electricity prices, and excluding finance or lostopportunity costs. However, by largely charging the vehicle from my roof solar PV system, my electricity prices are cheaper and fixed for the 25 year warranty life of the panels, so the economics improve.

In actual fact, through some of the inevitable prototype development hurdles and reworks, the actual cost was about $4,000 higher, but of course any further conversions of this make and model would not have these costs.


The Silvia ready to convert


The orignal Silvia engine bay


Ian Hooper pulling out the ICE


A trailer with some of the ICE parts no longer needed.


The boot before cutting for the rear battery pack.


Plenty of space for electric motor and batteries.

 Trial fitting a mockup of the rear battery pack.	 The motor and battery mockups trial-fitting.
 The rear battery box bare.	 Front battery boxes and motor mockup.
 Motor adaptor/mount before welding.	


Aligning motor adaptor and gearbox.


Motor adaptor and coupling.


Custom rubber motor mount.


Custom rubber mount secured to original engine mount.


Conversion complete.


Programming the Soliton1 speed controller.

Mocking up the instrument panel mod for the energy meter.

Approximate fit of the energy meter.

Giving rides at the EV Works public open day at the RAC test track.

More rides at the open day.

…and more testing.

DECISIONS:

AC or DC?

The choice between AC or DC motor drive came down to simplicity and cost versus range and efficiency. While AC drives have fewer wearing parts, are more efficient and can also regeneratively charge batteries, they are more expensive and understanding the torque-speed characteristics is more complex. As the DC system appeared to meet the performance and range needs, it was decided to use a DC drive system. In future applications however, AC systems will be the norm.

Lead-Acid or Lithium Battery?

Lithium Iron Phosphate (LiFePO4) batteries offer several benefits over lead acids. For the same energy capacity, Lithiums are only 40% of the weight and have about 4-5 times the cycle life, as well as no range-sapping Perkut effect, and they have a very low self-discharge rate of only 2% per month. Both lead-acid and lithiums' power output are reduced somewhat by low temperatures such as 10 deg C and less. This is noticeable in winter weather and could be compensated by over sizing the pack slightly to make up for it. The LiFePO4 batteries have been factory demonstrated to be extremely safe even when dramatically abused, and fail relatively benignly.

Besides the above reasons, to achieve the range I wanted, there was little choice to make as the weight of lead acid batteries would have been impractical, as the back seats would have to be removed to remain within weight allowance. Using Lithiums allowed me to keep the full capacity of 4 people also.

Although Lithium batteries cost 2-3 times that of lead acids, the added range and discharge cycle life of Lithiums gives a significantly better value for money, but of course at a higher up-front cost..

Direct drive or via gearbox? Clutch?

I chose to keep the Silvia's 5-speed manual gearbox to maintain a wide speed-torque versatility, given that I live in the Hills region of Perth which have some incredibly steep (17+%) grades in places, and at the same time wanting a top speed of over 100k/hr, even with a relatively low battery voltage. The efficiency penalty for this is essentially 2 gear meshes or about 4% total, typically. The additional weight of about 40kg is not much different from the additional weight of a larger motor needed to give sufficient low-end torque without a gearbox, so that doesn't factor much in the decision.

In considering whether to use a clutch, a tradeoff was made between rapid shifts and simplicity. As I was not looking for a high-performance shifting, it seemed appropriate to take advantage of the unique characteristic of electric motors which is the low inertia and lack of compression torque, which allows the gearbox synchros to match motor and gearshaft speeds without disengaging the motor.

Power steering?

The Silvia normally has power steering, so to replicate that a Holden Astra electric power steering pump was chosen from an auto wrecker, only to discover that it requires an electronic drive which was more of a challenge than I needed, so a Toyota MR2 12 VDC power steering pump was used and works well. However, it is a little noisy, runs continuously and draws a fair amount of energy (3-5% of my typical commute energy). Although it is fully functional, I generally don't use it and, apart from making tight turns, it is much the same feel. I am considering either adding a switch on the dashboard to turn it on when needed, or a more sophisticated method would be to put a strain-gauge on the steering shaft to generate a signal to drive the pump at a speed proportional to the steering torque.

Airconditioning/heating:

The original a/c system remains in the car, but have not yet reinstalled the compressor. I did not want the significant added weight of a dedicated motor to drive it, so plan to mount it atop the drive motor to which a pulley has been added on the front. It cannot be direct-driven because the rotation is opposite.This does mean however, that when the motor is stopped, there will be no cooling unless I shift into neutral and run the motor. Fortunately, the Soliton speed controller has provision to run an a/c compressor as if the 'engine' were idling.

The original heater core was replaced with a 1.5 kW ceramic air heater from EVSource. (While one can use an electric water heater and pump it through the original core, this adds more complexity than is needed to do simply heat air). The electric heater is powered from the traction battery pack via a relay which is controlled by a microswitch actuated by the standard hot water valve for the original water core. I was concerned that because this is either on-or-off, it might 'hunt' but it has not shown this tendency. The amount of heat put out is just sufficient to keep the car reasonably warm with about 4 degree C outside temperatures.

Components

Motor:

The motor chosen is a well-known NetGain Warp 9" as suggested for the Silvia weight, and is quite adequate for sporty performance and allows me to climb grades of 17-22% in 3^{rd} gear even starting from a stand-still, and in 40 degree C ambient temperatures. It has performed flawlessly so far. Initially, there was a fair amount of commutator noise from the factory but has become quieter since the brushes have bedded in.

Controller:
During the conversion, it was discovered that one of the prime candidates for performance and quality, Zilla (with at least 1,000 amp output), had stopped production temporarily. Fortunately, as Ian had been developing his own 600 amp prototype controller, it was decided to use that to start with. This controller worked well but acceleration was marginal and when eventually other options such as the Logisystems 1000 amp controller became available I leapt at it. Unfortunately it had serious overheating problems and a jerky start which could be disconcerting when reversing. It self-destructed under normal driving conditions twice, and I looked for an alternative.

Finally, the Evnetics Soliton1 (1,000 amp) and the Netgain controller both came on the market about the same time and appeared to be well-designed units. The Soliton1 was chosen because it is able to run with air-cooling only under most conditions, which helps to retain the elegant simplicity of Evs. The microprocessor-based controller has many 'tuneable' parameters and datalogging outputs easily accessible via LAN connections, which I hope to use at some point to verify the performance calculations.

The throttle setting is a contactless sensor provided by Evnetics and is controlled by the footpedal cable. The null point and various other parameters are programmable in the speed controller.

Traction Battery Packs:
The battery pack is made up of 160 Amp-hr ThunderSky monoblock cells (LFP-160AHA) in series, giving 132 volts, nominally. (16 in the engine compartment and 24 in the boot ex-fuel tank and spare tyre space). The rear pack was originally flush with the original boot floor so did not affect the carrying capacity at all. However, the bottom of the pack just impinged on the departure angle (a line drawn from the radius of the rear wheels to the bottom of the rear bumper) so it was raised 40mm to be safe. I don't carry about a spare tyre as in the last 20 years driving in the city I have not had a puncture.

The individual cells are wedged into aluminium boxes securely bolted to the structurally-robust parts of the chassis and body. The cells are held in place by polycarbonate shear strips bolted along the tops of the cells, and protected from dust and moisture by polycarbonate covers. It is important to make sure that the cell terminals are wire-brushed immediately before bolting on the interconnection copper jumpers to remove the thin layer of aluminium oxide. A very small layer of oxide can create enough resistance (therefore heat) to melt the terminals into the tops of the batteries, as well as reducing the range. There are also some antioxidation pastes such Noalox which are worth considering applying before bolting the jumpers.

As the photos show, there is plenty of room for more batteries under the bonnet and it is tempting to add another 5 cells to boost the voltage for higher top speed, performance, range and efficiency, and yet only add about 30kg of weight.

Battery Management System (BMS):
The TS-90 BMS used is manufactured by EVPower Australia and is intended to safeguard all the cells from under- or over-voltage as this can rapidly destroy them.

The system has a cell monitor on each battery and a master unit which monitors all the cells with a simple daisy-chain signal wire. If any cell goes out of range the monitor gives an audio alarm and a red dash-light. This is a useful backup indicator of how much load is being placed on the batteries as it will temporarily alarm under high load. Provided the alarm goes off when power is backed off, the cells are ok.

If any cell should fail, I can bypass it by bolting a jumper around that cell to get home, but as I accidentally found out (before I had my 'idiot red dash-light' alarm) one can actually continue to drive with 3 cells discharged! The only trouble is that it tends to destroy the discharged cells, as I learned. The moral is that if you want to listen to the stereo system, have a warning light on your dash!

Charger:
The 2 kW Zivan NG3 charger is mounted under the rear window shelf in the boot and is able to charge the battery at a rate of about 10% per hour, from a standard 10-amp 240VAC power point. One point to plan for is cooling ventilation of the unit if charging in the summer, with the car in the shade or sun. The temperatures can get very high and I have found it necessary to either fold the rear seats down and leave windows open, or pop the boot open slightly.
DC/DC Converter:
The 12VDC system is kept charged from the main traction battery by an Iota DLS-45 DC-to-DC converter, also mounted under the rear window shelf in the boot. As such, both the charger and converter are not noticeable and don't affect the boot space.

Instrument Panel:
There were a few status lights which were no longer necessary such as oil pressure, temperature and exhaust temperature, so these were disabled, and the fuel guage was replaced with an energy meter (TBS Link 10 by Xantrex). This meter able to be adjusted for the battery pack capacity and monitors the percent battery

DESIGN

The electrical traction drive circuit is fairly typical of EVs, with the following features:

- Fused at front and rear packs
- Accelerometer switch to shut off the circuit in the event of a crash or rollover
- Panic button to shut off the circuit in case of runaway motor/speed controller
- Charge door interlock so the car cannot be driven while charging
- Speed controller delay for capacitor slow chargeup (part of the Soliton controller)

The motor mount/gearbox adaptor and motor coupling are critical to get right to minimise vibration and wear. The adaptor is aluminium and designed to bolt to both engine mounts. The original rubber shock mounts could not easily be used, as they would have interfered with the bottom of the front battery boxes. Instead, a simple rubber-sandwiched mount was made up and serves to keep the small amount of motor and gearbox vibration from transmitting through the chassis and body. The motor was originally mounted rigidly but I found the minor vibration to be irritating, detracting from something which is otherwise so quiet.

The adaptor motor mounting surface was flycut parallel to the gearbox mounting flange to keep the two shafts parallel, and radial alignment was achieved by removing the gearbox, tilting it vertical, and lowering the motor with coupling onto the gearbox input shaft with overhead chain block. The adaptor flanges were then match-drilled to the gearbox.

The coupling uses the female spline from the old clutch plate to fit the gearbox input shaft and this is welded to a roundbar which is final-machined to an interference-fit bore and it is then heat-shrunk onto the motor shaft. It is critical that the inside of the coupling also provides centreing for the gearbox input shaft as it has only one support bearing in the gearbox. Failure to support the shaft will result in severe vibration.

VEHICLE MODIFICATIONS & MOCKUPS

Before removing the ICE components from the car, it is important to note a few points:

- Record the original gearbox location and angle relative to the chassis because with the alignment of the driveshaft to the rear wheels can affect vibration and resonance.
- Get a detailed (shop manual) electrical schematic and wiring harness diagram. This is particularly important for new cars, and be prepared to understand how to work with the control systems.
- De-gas the airconditioning unit.
- Check the weight and distribution and plan the distribution of batteries to avoid the need to change suspension springs. The Silvia specs (unloaded) are: Original 1220kg and 55/45 front/rear. With the EV conversion it is now 1260kg and 49/51.

Driving the Silvia EV:

When turning on the ‘ignition’ there is a feint buzz of the electric vacuum pump until the necessary vacuum is reached. After a couple of seconds, the speed controller contactor is heard to close and the car is ready to drive.

Driving it takes a little getting used to. Starting in 3rd gear is suitable for all hills and starts. Initial acceleration is fairly gentle, but quickly builds to about 1/3 G continuous, up to about 75km/hr, when the back-EMF of the motor gets up to pack voltage, and it tops out at about 90km/hr.

The shifting time is on the order of a second, depending on how different the motor and gearbox shaft speeds are, and the technique is to hold a firm force on the gearshift lever until the gear meshes synchronise. This does take some practice and patience but becomes natural after a while, and besides it happens so rarely for most driving.

From 3rd gear I usually shift into 5th, which reaches a top speed of just under 120 km/hr on the level with 4 people.

Starting in 1st or 2nd gear demonstrates how ‘torquey’ the electric drive is and it will spin the tyres, but the speed quickly tops out.

The range on a charge is between 85 and 120km, theoretically, because one does not drive it to full discharge. Stop-start traffic and/or highway speeds consume the most energy. My average commute uses 50% of the battery charge but I have taken it to as much as 85% discharge. My typical commute is pretty demanding as the last part of the trip is to climb a 200m high hill with grades of up to 17% in 40 degree C temperatures in Summer, and it does this comfortably. Nearing low battery charge, there is some drop off in voltage however, when needed, the batteries still put out enough power to climb the hills in my area in 3rd gear.

Waiting at stop lights, with no noise, vibration or energy use is relaxing, and no gearshifting around town is simple and convenient. In Winter, the electric air heater gives instant heat - a pleasure for comfort and demisting windows.

The satisfaction of driving a car which is almost fully charged by solar and wind energy, highly efficient, and virtually maintenance free, is immensely satisfying!