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Test requirements for 42 V battery systems☆

M.J. Weighall*

MJW Associates, 12 Low Stobhill, Morpeth, Northumberland NE61 2SG, UK

Abstract

The introduction of the 42 V PowerNet imposes new performance requirements on the battery. The required performance parameters will vary dependent on the application and to what extent the power train is hybridised, with additional features such as start–stop, launch assist etc. This makes it more difficult to specify relevant laboratory test procedures. This paper reviews the vehicle electrical system developments and the impact these developments will have on the battery performance and testing requirements. Suitable test equipment from Digatron/Firing Circuits is discussed and reviewed.

Keywords: 42 V PowerNet; Battery testing; Battery test equipment

1. Introduction

The existing 12 V automotive battery has two main uses in the vehicle: for engine cranking and to support electrical systems when the engine is not running (e.g. key-off loads for long parking intervals). The key performance parameter is the cold cranking current, typically tested at a temperature of −18 °C. With modern engines and automotive electrical systems the starter motor only needs to turn over for a few seconds—even at low temperature—for the engine to start. During normal operation, the battery may experience shallow discharges, e.g. if it is supplying part of the electrical load during start–stop operation in heavy traffic. The charge acceptance is also important in determining the ability of the battery to accept charge from the alternator when in a partially discharged state. Typical performance tests for existing 12 V batteries will include:

- reserve capacity test at 25 A and typically 25 °C;
- cold crank test at −18 °C;
- charge acceptance from 50% state of charge at 0 °C;
- life cycle test, e.g. SAE J240 test at 40 or 75 °C.

Other tests may also be carried out dependent on the battery type and application.

The cold crank current rating of the battery at −18 °C will be dependent on the test specification used. For example in SAE J537, the cold crank current is the current that will maintain a voltage above 7.2 V (1.2 Vpc) for 30″. In IEC 60095, the cold crank current is the current that will maintain a voltage above 8.4 V (1.4 Vpc) for 60″.

The 42 V PowerNet and resultant changes in automotive vehicle design and electrical systems (e.g. combined starter-alternator (CSA) or integrated starter generator (ISG)), will impose new performance requirements on the batteries, including:

- idle stop operation requiring high peak power;
- regenerative braking;
- boost/launch assist;
- shallow cycling in partial-state-of-charge (PSoC) condition.

2. Vehicle electrical system developments and battery applications

There is now an almost bewildering range of possible vehicle electrical system developments, each of which will make different performance demands on the battery:

1. 42 V with extra power for accessories, but no stop start;
2. 42 V with stop–start (ISG) (no HEV functions);
3. 42 V launch assist soft/mild hybrid: may also have regenerative braking;
4. 42 V power assist: functions as HEV to boost engine power when required;

☆ Presented on behalf of Digatron/Firing Circuits, Firing Circuits Inc., 30 Shelton Technology Center, Shelton CT 06484; Tel.: +1-203-446-8000; fax: +1-203-446-8015; e-mail address: info@firingcircuits.com, and Digatron Industrie Elektronik GmbH; Tel.: +49-2-4116-8090; fax: +49-2-4116-6465; e-mail address: info@digatron.de.

* Tel.: +44-1670-512262; fax: +44-870-056-0376.
E-mail address: mjweighall@battery1.demon.co.uk (M.J. Weighall).

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5. high voltage power assist, e.g. Toyota Prius (48 V or higher);
6. parallel hybrid: can function as pure EV: >50 kW required.

For options 1–3, power requirements will range from about 4 kW to about 15–20 kW.

Vehicles will also incorporate one or more of the following features:

- combined starter-alternator (CSA) or integrated starter/generator (ISG);
- electric power steering;
- electric brakes;
- brake-by-wire;
- steer-by-wire, etc.

All these possible options result in considerable challenges for the battery designer and in establishing an acceptable battery test regime.

3. Cold cranking requirement for the 42 V PowerNet

A potential benefit of the higher voltage is that this will result in a lower cold cranking current, all other things being equal. For example, a cold crank current requirement of 500 amps for a 12 V battery could be reduced to about 167 A for a 36 V battery. This will have the benefit of a significant reduction in cable sizes. (The heating effect in the current carrying cables is proportional to the square of the current.) However, the implementation of idle-stop operation in conjunction with the 42 V PowerNet, may require higher cold cranking performance than originally anticipated.

The development of a low cost starter-alternator (SA or CSA), or the more expensive integrated starter generator (ISG or ISA) has enabled start–stop options to be considered in future electrical system architectures. When the vehicle stops, the engine cuts out, and restarts again almost instantaneously when the accelerator pedal is depressed. This has obvious benefits in terms of pollution reduction and fuel economy.

3.1. Start–stop with starter-alternator

Start–stop can be implemented with a low-cost air-cooled starter-alternator (SA or CSA) rated at 3.5 kW continuous output power. A special wide high-strength belt transfers power between the SA pulley and the engine pulley. SA retrofits into existing engines and eliminates the starter motor and flywheel teeth, thus improving reliability. It is suitable for gasoline engines up to 3.0 l, diesel engines up to 2.0 l. Air-cooled starter-alternators rated at 3.5 kW continuous output will be available from nearly every traditional supplier of alternators.

3.2. Start–stop with ISG (ISA)

The more expensive integrated starter generator (ISG) enables start–stop mode on idling, launch assist, power assist and regenerative braking. It is typically rated at 6 kW continuous output power, up to 10 kW short-term power. ISG fits into the space reserved for the flywheel. It takes up more space than the flywheel, so some engine redesign may be necessary. Both the alternator and starter motor are eliminated, improving reliability. Because of the higher cost of ISG, and the higher power requirement, it is less likely to be fitted to mass-market vehicles than the belt driven CSA.

The ISG system requires the use of advanced battery technology. The battery needs to sustain vehicle electrical loads during engine off periods, accept high levels of regenerative energy during braking, and provide for engine torque boosting.

Siemens [1] quote the following battery performance requirements for the ISG:

- 4 kW maximum continuous power;
- up to 10 kW short term power;
- cold cranking 6 kW for 10 s.

4. Battery performance parameters

Typical battery performance parameters for the 42 V PowerNet include:

- maximum kW output;
- average and peak power (W);
- power performance W/kg and Wh/kg;
- power output over wide SoC range.;
- power output over wide temperature range (ideally +50 to −20 °C or −30 °C).
- charge acceptance;
- cycle life for shallow and deep discharges;
- cycle life in PSoC operation;
- calendar life.

5. Implications of idle-stop operation

Vehicles fitted with an integrated starter generator allow stop-go movement in city traffic and assist the engine in normal running (boost/launch assist). The ISG enables regenerative energy to be returned to the battery during vehicle braking. The battery will experience shallow discharge cycles in partial state of charge (PSoC).

However, the problem for the battery manufacturer is to determine what test regimes to use when determining the battery parameters, as the battery may be subjected to a wide variety of duty cycles dependent on the vehicle electrical system and to what extent the battery is required to assist the power requirements of the vehicle (boost/launch assist, power assist, etc.). Parameters that need to be specified include the duty cycle, the average state of charge, the

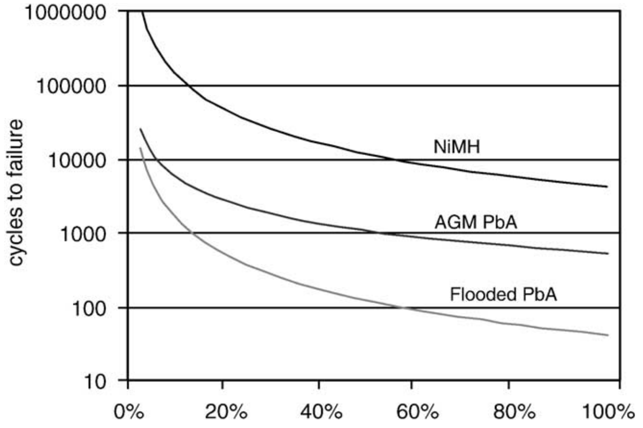

Fig. 1. Depth of discharge based on nominal capacity.

average level of discharge around this SoC, and the required number of shallow discharge cycles.

It has been suggested by Ford Motor Co. [2] that the battery should be sized so that stop/go driving can be handled without exceeding ±5% SoC. Also, the vehicle system controller should manage stop/start events so that consecutive loss of SoC does not accumulate to more than 15% of nominal. In that presentation at AABC01, DoD versus battery life was also compared for NiMH and Lead-acid chemistries (Fig. 1) [2]. This showed that life performance of NiMH is substantially better than presently availablelead-acid, particularly at shallow discharge depths.

6. Power performance

Power performance of the battery needs to be considered as well as specific energy. The specific energy of VRLA is relatively low compared with NiMH or Li-ion. However, the power performance of low impedance VRLA designs is very good, and is comparable with that of NiMH and Li-ion. Output power and input power are directly related to battery state of charge as shown in Fig. 2 [3]. This figure indicates the relationship between output power and input power at different discharge depths from 10 to 90% for a Yuasa lead-acid battery designed for HEV operation. Maximum power output is achieved at full charge and remains fairly steady to 40 or 50% discharge depth, after which it declines more steeply. At 90% DoD, power output is only 50% of that available at 10% DoD. Input power is the reverse of this, but with a much steeper curve. At 10% DoD, maximum input power is quite low, doubles from 10 to 20% DoD, and at 90% DoD is 4× that at 10% DoD. This latter aspect is important when considering regenerative braking, e.g. with the ISG system.

7. Peak pulse power

Peak pulse power is a key parameter for the 42 V PowerNet and hybrid electric vehicles. The requirement is higher for a vehicle fitted with ISG than for one fitted with CSA. The current is required for a very short time (e.g. 0.4 s), however for start–stop operation the battery may be required to deliver a large number of these high current pulses. For a “mild hybrid” ISG in which the battery is used to boost acceleration, the high current pulse may be needed for up to 30 s. These differences will influence battery sizing for different applications. This confirms the difficulty of designing and interpreting a standard shallow cycle test, as the duty cycle will be dependent on the application.

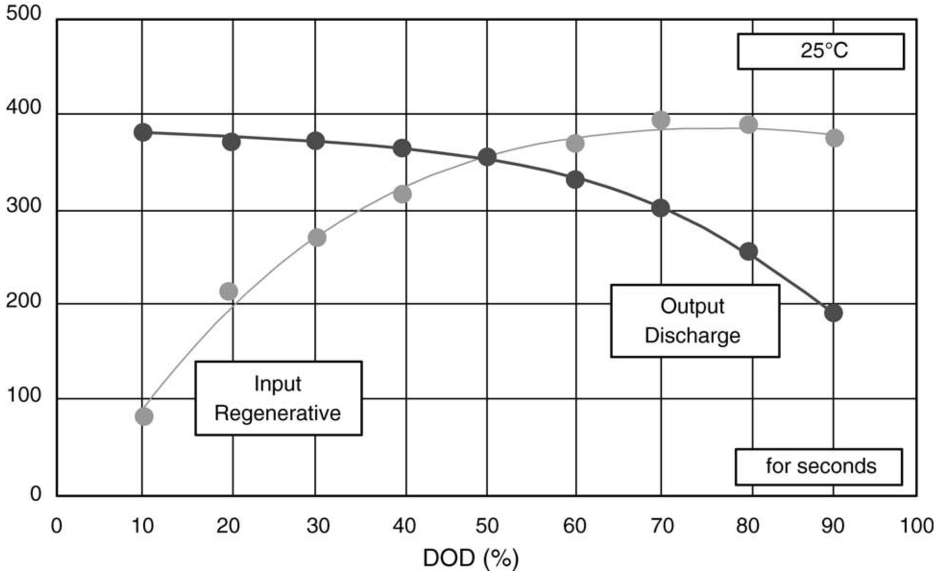

Fig. 2. Output/input power performance.

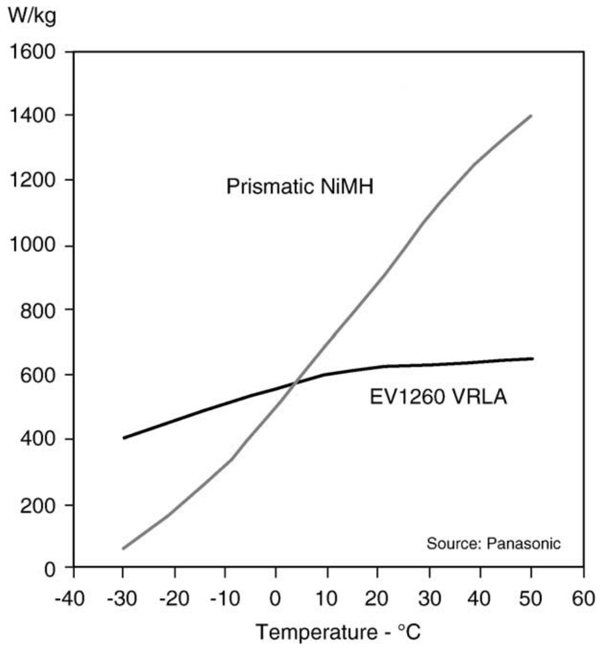

Fig. 3. Battery temperature comparison.

8. Influence of battery temperature

The battery temperature has a significant influence on the specific power available from the battery, and the effect is different for different battery systems. An example of this is shown in Fig. 3 [4]. This compares a Prismatic NiMH Panasonic battery with a Panasonic EV VRLA battery. The slope of the temperature versus W/kg curve is very steep for the NiMH battery, much shallower for the VRLA battery. At 25 °C the NiMH battery has a specific power of 1000 W/kg, compared with about 600 W/kg for VRLA. The "crossover" point occurs at about 4 °C, where both batteries have a specific power of about 580 W/kg. At −20 °C, the specific power of NiMH has dropped to less than 200 W/kg, while VRLA is still at about 450 W/kg. The VRLA battery still has a specific power of 400 W/kg at −30 °C, while for NiMH the specific power has declined almost to zero. This data indicates that lead-acid is essential for cold temperature starts in all 42 V architectures, supporting comments made by JCI at AABC01 [5].

9. Charge acceptance

Charge acceptance is more critical for the 42 V PowerNet than for conventional 12 V SLI batteries because of regenerative braking. Charge acceptance from high inrush currents may be a problem with the VRLA battery, particularly if it is already at high SoC. It may also be a problem with NiMH at high temperatures. To overcome this problem, the battery management system may need to "switch off" regenerative braking when the battery is in a high SoC.

10. Standardisation issues

It was originally thought that the first vehicles using the 42 V PowerNet might appear before the International Standards have been finalised. However, delays to vehicle programmes utilising the 42 V PowerNet mean that this will probably not be a major problem. The relevant ISO standard is Technical Programme TC22/SC3/WG14 (Document ISO/WD 21848). The ISO committee draft is due for publication December 2002. The Draft International Standard (DIS) is due mid 2003, and the International Standard (IS) in 2003/2004. Up to date information concerning the relevant standards can be obtained from the website addresses: http://www.iso.ch; http://www.sae.org.

11. Possible 36 V battery requirements

Possible performance requirements for 36 V batteries for the 42 V PowerNet include the following [6,7]:

- 4 years life;
- SoC control/PSoC operation (e.g. SoC range 50–70% or 70–90%);
- discharge power:
  - 6.5 kW for 10 s @ 25 °C,
  - 15 kW for 0.2 s @ 25 °C;
- cold start: 6–10 kW for 10 s @ −30 °C;
- braking: charge acceptance ~6 kW for 5 s;
- airport test: discharge power drain of 0.25 W for 30 days;
- discharge rate max 15 C;
- charge rate maximum 8 C.

The battery performance requirements will be dependent on whether the battery supplies energy for start–stop, mild HEV (M-HEV) or power-assist HEV (P-HEV). Table 1 below is an extract from the FreedomCAR 42 V Energy Storage System End-of-Life Performance Goals (August 2002), and shows the USABC performance targets for these applications:

12. Existing battery test schedules

Some of the existing test schedules may be more appropriate for full electric vehicles or "strong" hybrid electric vehicles than for 36 V batteries for the 42 V PowerNet. They include:

- ECE 15L;
- power assist profile;
- idling stop system (ISS) (Japan);
- US06 power profile;
- PNGV battery test manual;
- USABC FreedomCAR battery test manual;
- New European Driving Cycle, etc.

Table 1
USABC "FreedomCAR" 42 V performance targets

42 V targets review August 2002	Start–stop	M-HEV	P-HEV
Discharge pulse power (kW)	6 (for 2 s)	13 (for 2 s)	18 (for 10 s)
Regenerative pulse power (kW)	N/A	8 (for 2 s)	18 (for 2 s)
Engine-off accessory load (kW)		3 (for 5 min)	
Available energy (Wh @ 3 kW)	250	300	700
Recharge rate (kW)	2.4 kW	2.6 kW	4.5 kW
Energy efficiency on load profile (%)		90	
Cycle life, miles/profiles (engine starts)		150 k (450 k)	
Cycle life and efficiency load profile	Zero power assist (ZPA)	Partial power assist (PPA)	Full power assist (FPA)
Cold cranking power @ −30 °C on cold-start profile (kW)		8 (21 V min)	
Calendar life (years)		15	

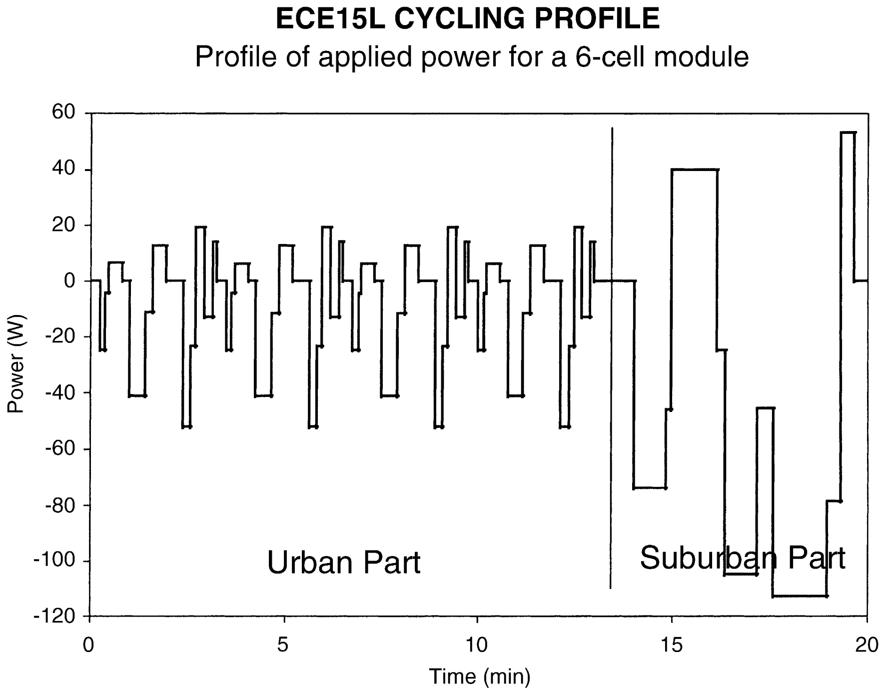

Fig. 4. Life cycle test for EV.

By way of example, Fig. 4 shows the ECE 15L life cycle test while Fig. 5 shows the power assist profile for cycle life testing. Fig. 6 shows the New European Driving Cycle.

13. Battery design options

Battery design options for the 42 V PowerNet need to be considered, as this will influence the battery test requirements. Part of the vehicle electrical system needs to stay at 12 V (e.g. lighting). The most likely option, which is favoured for the initial implementation of the 42 V PowerNet, is to have a 2-battery system in which one battery is the "power" battery and the other is the "energy" battery. For example, a 36 V VRLA "power" battery with thin grids or spiral wound design, and a 12 V energy battery with cycle capability.

The second option, which is likely to be the favoured long-term option, is to have a single "Universal" 36 V battery with a DC/DC converter for the 12 V loads. The battery will need to be a compromise between a "power" battery and an "energy" battery. This has the advantage of lower cost, weight and size.

As automotive systems move to ISA (ISG) and regenerative braking the battery used for engine starting will also experience some cycle duty. This tends to negate the argument for a dual battery system.

14. Example of battery requirements for a mild hybrid system

The Toyota THS-M mild hybrid system used in the Toyota Crown [8] and shown in Fig. 7 uses a motor generator

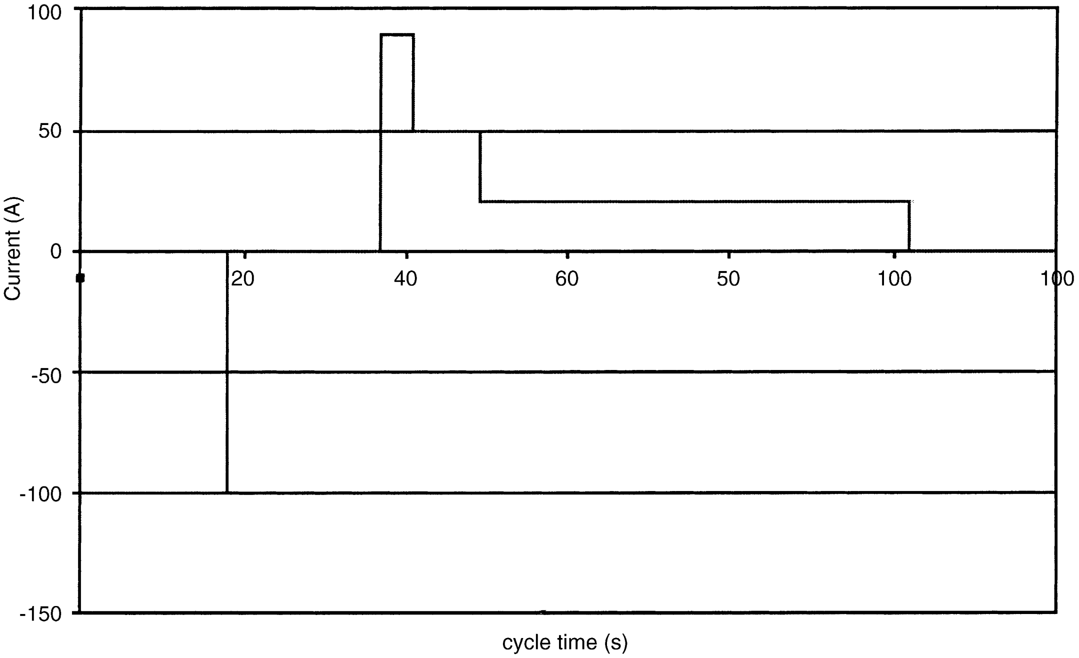

Fig. 5. Power assist profile for life cycle testing.

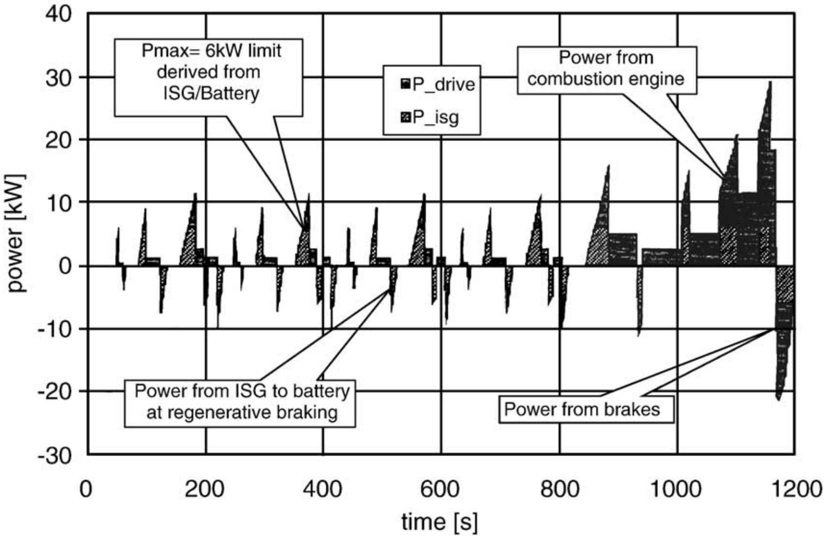

Fig. 6. New European Driving Cycle (NEDC) showing power draws from the heat engine and battery in 42 V ISG operation.

powered by a 36 V battery that can act either as a motor or a generator. This enables idle stop operation and initial vehicle acceleration. A separate 12 V battery is used for engine starting. When accelerating from rest, the 36 V battery is used to power the motor generator for vehicle acceleration, while the 12 V battery restarts the engine. During cruising, the engine drives the vehicle, and the battery is charged from the motor generator.

This example is shown because unusually for a 2-battery system, the 12 V battery is used for engine starting and the 36 V battery is used for acceleration. This contrasts with the accepted wisdom for a 2-battery system in which the 36 V battery is used for engine starting and the 12 V battery is used for low current loads.

15. Test equipment requirements

It can be seen from the discussion above that the battery peformance and test requirements for the 42 V PowerNet are quite complex. Test requirements will be dependent on to what extent the battery is required to perform additional duties such as stop–start, power assist, etc. Also, whether the vehicle is fitted with CSA or ISG, the requirements for

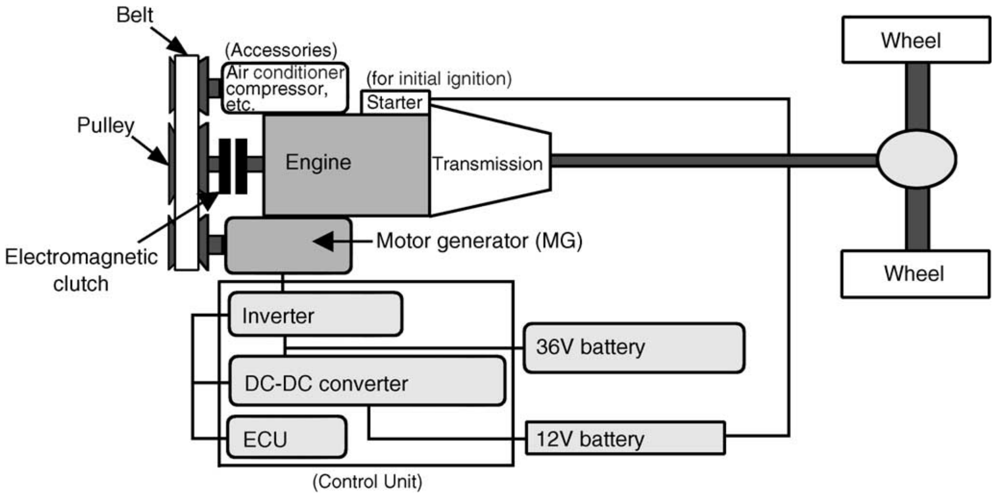

Fig. 7. Toyota THS-M mild hybrid system.

regenerative braking, etc. Because the battery test specifications have not yet been finalised, it is essential that the test equipment is flexible enough to carry out a wide range of different tests. Suitable test equipment is available from Digatron/Firing Circuits, and is capable of dealing with the full range of test requirements:

Standard applications:

- cycling;
- life endurance;
- charge acceptance;
- other tests, e.g. ISO standard.

Special applications:

- cold cranking;
- starter-alternator or integrated starter generator load simulation.

A typical test equipment specification includes the following:

- central control through host computer;
- control of current, voltage, power and resistance, ramp function;
- switching parameters during charge and discharge:
  - ○ time, voltage, current, Ah, Wh, temperature;
- functions:
  - ○ charge, discharge, pause, cycles, cycle in cycle;
- up to 3000 program steps;
- temperature sensor option.

The technical data for the UBT-50-60-6 test equipment is given in Table 2.

For special applications, the test equipment BNT700/250-60 is available, and the technical data for this equipment is given in Table 3:

A number of options are also available with this equipment:

- MBT pulse control for slew rates <5 ms;
- temperature measurement −30 to +100 °C;
- datalogger interface;
- CAN interface;
- climatic chamber interface;
- relay output board;
- six channel 700A multiplexer to connect to UBT-50-60-6.

Table 2
Technical data for UBT-50-60-6 test equipment

Charge/discharge current range	0.05–50 A
Charge voltage range	10–60 V
Discharge voltage range	5–60 V
Accuracy in the range of	
10–100% FS	±0.5% of readings
<10% FS	±0.05% FS
Resolution	±15 bit
Data acquisition rate	100 ms
Transition charge/discharge	Contactors, 3 s
Technology	Transistors
Cooling	Fans
Power supply	3-phase 50/60 Hz (∼24 kVA)
Dimensions ($H \times W \times D$)	1950 mm × 700 mm × 1100 mm
Weight	∼500 kg

Table 3
Technical data for BNT700/250-60 test equipment

Charge current range	0.3–250 A
Charge voltage range	8–60 V
Discharge current range	
Pulse discharge 10 s	Maximum 700 A
10 s to 3 min/cranking	Maximum 500 A
Discharge voltage range	45–8 V
Continuous power	15 kW
Data acquisition rate for I and V	100 ms
Transition charge/discharge	Electronic, <300 ms
Technology	Transistors
Cooling	Fans
Power supply	3-phase, 50/60 Hz, ∼20 kVA
Dimensions ($H \times W \times D$)	1950 mm × 700 mm × 110 mm
Weight	∼500 kg

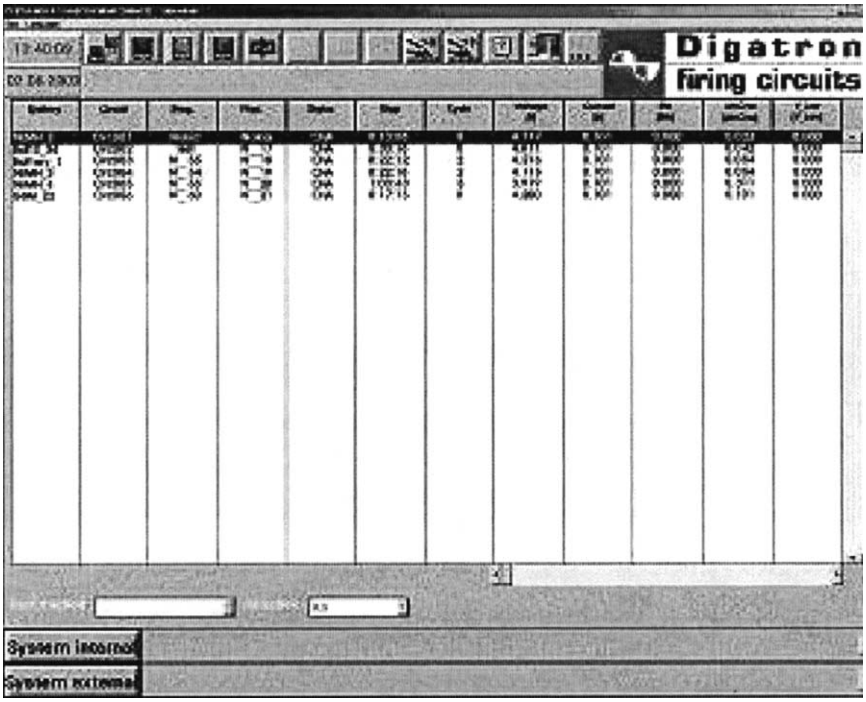

Fig. 8. Main control screen.

16. Battery test software

The key to modern automated test equipment is the software that is used to control the test circuits [9]. The best software needs to be both technically advanced and simple to use for varying levels of expertise. It also needs to be compatible with a variety of test equipment configurations. Key features include:

- ability to save and repeat procedures quickly and with little user input;
- ability to save and store intricate procedures for fast, uncomplicated reuse at any time-even while another test sequence is utilizing the same procedure;
- easy generation of a variety of standard reports and supporting graphics;
- utilisation of user-designated parameters in the creation of custom reports and graphics;
- built-in database of preset battery identification numbers. The test program takes all of the parameters from the identification number and calculates the correct current and voltage set points;
- software flexible enough to be used for a large variety of battery types, e.g. PbA, NiMH, Li-ion, etc.

Fig. 8 shows an example of the main control screen. All significant parameters are displayed at the same time on this main control screen so that the user may monitor multiple test sequences as they run. Additionally, the user can relinquish control of the background processes to the software in order to concentrate on the most important test factors displayed on this main screen.

Fig. 9 shows the software's main program editor. Here, the user has the ability to set the parameters for the entire test sequence from a single screen. Commonly used sub-routines can be inserted with a single command instead of requiring time-consuming repetition of steps.

Fig. 10 shows a typical graphics display. Advanced data processing capability means the difference between software that can adequately test batteries and one that can provide truly powerful results, information, reports, and accompanying graphics. Here, different user-defined parameters are displayed for a specified time interval selected from the archived test data.

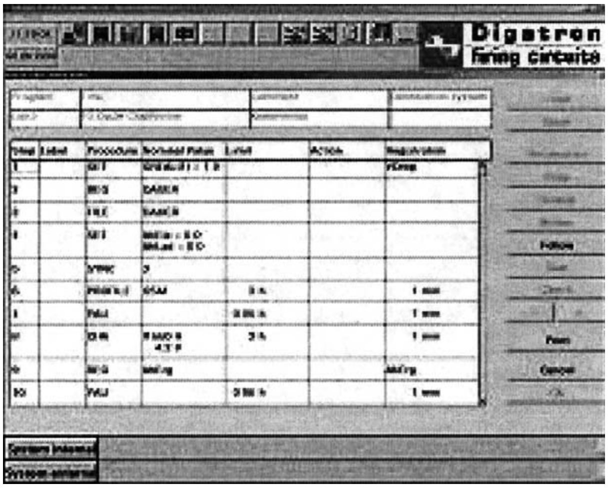

Fig. 9. Main program editor.

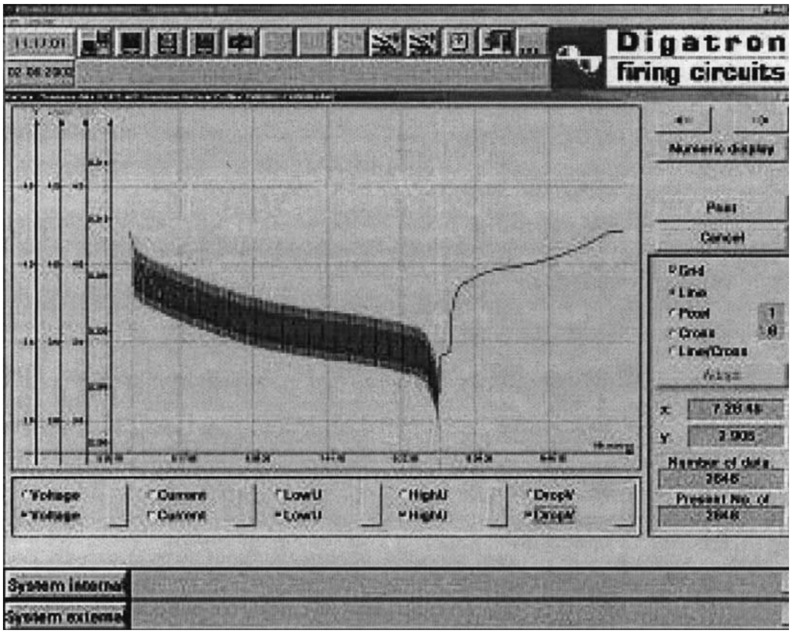

Fig. 10. Typical graphics display.

Acknowledgements

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