CHAPTER 4

POWER SUPPLY DISTRIBUTION AND GROUNDING
SCHEMES FOR TRACKED VEHICLES

4.1 INTRODUCTION

An electrical ground is a low impedance plane of reference potential to which all the systems & circuits can be related. Grounding is a technique which provides a low resistance path between electrical, electronic equipments and earth the common reference low impedance plane to shunt the fault currents (US Army 1979). Thus the grounding (Denny 1993) is an absolute essential element to ensure protection of the equipment and personnel from electric shock. This also helps to prevent insulation puncture or flashover in the event of lightning, short-circuit and also reduces electromagnetic interference. A resistance below 1 milliohm at operational frequency represents good grounding for the equipment (Hasse 1992).

4.2 GROUNDING PRINCIPLES AND EARTHING STANDARDS

The electronic and electrical equipment have to generally confirm to the MIL STD 454 C for the AC and DC Systems. Physical effects of the same are given below as indicated in Table 4.1.
Table 4.1 Electric shock hazardous current levels

<table>
<thead>
<tr>
<th>Alternating (60 Hz) Current mA</th>
<th>Direct Current (mA)</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5-1.5</td>
<td>0-4</td>
<td>Perception</td>
</tr>
<tr>
<td>1-3</td>
<td>4-15</td>
<td>Surprise</td>
</tr>
<tr>
<td>3-22</td>
<td>15-88</td>
<td>Relax Action</td>
</tr>
<tr>
<td>21-40</td>
<td>80-160</td>
<td>Muscular inhibition</td>
</tr>
<tr>
<td>40-100</td>
<td>160-300</td>
<td>Respiratory block</td>
</tr>
<tr>
<td>Over 100</td>
<td>Over 300</td>
<td>Fatal</td>
</tr>
</tbody>
</table>

The resistance of the human skin is usually somewhere between 500 and 7500 ohms. Battery driven system usually does not require any grounding except for lightning arc prevention.

At frequencies above 300 Hz, the current levels required to produce the above effects begin to increase due to skin effect. Above 100-200 kHz, the sensation of shock changes from tingling to heat or burns. They are seen in the event of electrical phenomena such as EMP (Janes Defence 1999).

4.3 EARTH CONDUCTOR AND ELEMENTS IN MOBILE VEHICLE

A good conductor such as copper or silver distribute the flow of current over an area large enough to reduce the voltage gradients to safe levels. In a tracked automobile, the chassis is used as return conductor provides good ground conductor (Hughes 1983). The
operating voltage is either 28 V DC, 42 V DC, 115 V 400 Hz AC, 380 V AC etc, depending upon the type of application for land vehicle. In the present case 28 V DC system, the current is being controlled by a main relay rated at 1000 A. This relay is mounted on silver plated bus bar so that the ground resistance is reduced to a low value.

4.4 POWER SUPPLY DISTRIBUTION

Figures 4.1 shows power sources and current flow diagram. The Figure 4.2 depicts the power distribution scheme for the tracked fighting vehicle. The generator is rated 700 A that charges battery bank. The battery bank acts as a reservoir of energy. It gets charged during running of the main engine. It supplements the generator and gives back the energy to the system in the event of peak loads on demand.

Fig 4.1 Power sources & current flow diagram for vehicle
Figure 4.2  Power supply distribution in tracked vehicle scheme
4.5 CATHODE PROTECTION

All ground electrode metals are subject to corrosion i.e. to react either chemically or electrochemically with its environment to form a compound which is static in the environment. The two processes for corrosion are

a) Galvanic Corrosion: Develops from the formation of a voltaic cell between the two different metals with moisture acting as an electrolyte.

b) Electrolytic corrosion: Develops when two metals are in contact through an electrolyte.

The best methodology is to use metals with low electrochemical activity such as tin, lead, or copper. The method suggested by Denny (et al 1993) was utilised in improving the grounding within the vehicle. All the joints were electronically welded and fused together to reduce corrosion.

4.6 SINGLE POINT GROUNDING

In single point grounding scheme (4.3) by Denny each sub-system is grounded to separate ground planes (structural grounds, signal ground, shielded grounds, AC primary and secondary power grounds). These individual ground planes from each sub-system are finally connected by the shortest path to the system ground point of reference potential.

The ground plane noise voltage poses a threat to circuits and equipment referenced to the ground plane. In mobile vehicles operating
at low voltage levels (28 V) use frequency analog information for the driver’s station and hence are more susceptible to the ground noise.

![Diagram of single point grounding](image)

**Figure 4.3 Single Point Grounding**

In the tracked vehicle the operational voltage being low of the order of 28 V DC, this scheme provides a solution against common-mode problems. The physical length of the inter-connecting system is small compared to the wavelength of frequency of operation. The multiple point grounding behaves well at high frequencies where dimension of grounding scheme is large compared to the wavelength of the frequency of operation. In the hybrid grounding schemes the ground appears as a single point ground at low frequencies and multipoint ground system at high frequencies.

The noise present in the primary can enter the ground system as a result of improper wiring, faulty system, insulation leaking or magnetic induction.

The single point grounding is used in military vehicles to have protection against EMP fields produced by nuclear detonations. It is characterized by a very short rise-time, high peak intensity 50 kV/m
and short duration (250 ns), are repetitive in nature as indicated by Hughes (et al 1983). Most of the energy is concentrated at frequencies below 10MHz where magnetic effects predominate. Electromagnetic pulse protection methodology calls for single point grounding as applicable to land vehicles.

In this zonal concept of grounding (Figure 4.4), one and only one ground connection interconnects the zonal boundaries. A zonal boundary a well defined & controlled interface or wall that offers some degree of electromagnetic Shielding to an Electromagnetic wave in Zone ‘0’ (vehicle body). No ground connection passes through a zonal boundary; it must terminate at the boundary and the internal grounds to a zone begins at the boundary. Zone 0 represents the outside boundary. Zone 1 is mildly attenuated region inside the vehicle walls (Module casing). Zone 2 is further attenuated region in the enclosure. Zone 3 exists inside equipment enclosure or in compartments within the equipment (Component housing).

Figure 4.4 Zonal concept of grounding
4.7 CABLE SHIELD GROUNDING

The shielded cable is used during interconnection of subsystems with each other and shield must be grounded at both ends. Edward (et al 1978) indicated that the grounding can be at one end (asymmetric) or both end symmetric or grounded at intervals of the cable. The effectiveness of grounding of the above methods depends on electromagnetic coupling mode and the electrical length of cable (l/λ) used for the interconnection (Mauro et al 1996),(Fowler 1992).

The modes of electromagnetic coupling in the cable:

a) Electric field coupling – incident wave is polarised parallel to the conductor length.

b) Magnetic field coupling – incident wave is polarised normal to the loop formed by the cable and the ground plane.

A cable with both ends grounded is more efficient for E-field excitations at low frequencies where as for H-field excitation; one end grounded is more efficient as it avoids current formed by cable and ground plane.

4.8 SHIELDED CABLE EXPOSURE TO EMP

The tracked vehicle has some mission critical equipment fitted outside that gets exposed to electromagnetic interference. The size of the vehicle determines the resonant frequencies normally lie in MHz range.
An EMP will induce current transients on the wiring two cases are visualized as

1) Transmission line attached to deliberate antenna and
2) The normal wiring within the vehicle.

The second case the current transients that are induced due to EMP on the cables are either one or more damped sine waves. In case the cables are directly exposed to the electromagnetic wave, the cable harnesses can get excited at its resonant frequencies. The vehicle cable harness length lies in the range of 1m to 10 m, their resonant frequencies lie in the range of 10 to 100MHz (Goedbloed 1987). The average cable current transients is about less than 1A . The cables connected to antenna, the peak amplitude of the cable bundle current does not exceed 10 A . Thus a 10 A damped sine wave (Q=6) can be used to represent a worst case cable current (Dinallo et al 1982). The NEMP wave constitutes both horizontal as well as vertical polarization.

### 4.9 GROUNDING MEASUREMENTS ON BOARD THE VEHICLE

The EMI measurements( et al Miltary standards) were carried out on the vehicle at several locations after optimising the various modules with reduced voltage drops. These measurements were carried out using micro ohmmeter in hot condition in majority of cases. The grounding points within the vehicle are shown in the schematic diagram in Figure 4.5. The measured values in the vehicle are indicated in the Table 4.2 below. Multiple point grounding is being adopted to ensure better performance at both high frequency and low frequency also.
Table 4.2 Measurements made in situ in a tracked vehicle for the power distribution for the various power modules

<table>
<thead>
<tr>
<th>Module</th>
<th>Paths *</th>
<th>Measured Value (m Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main battery relay and chassis</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Slip ring assembly to the chassis for the turret supply</td>
<td>3</td>
<td>0.03</td>
</tr>
<tr>
<td>Power ring of the slip ring assembly</td>
<td>3</td>
<td>0.32</td>
</tr>
<tr>
<td>Relay- main contacts</td>
<td>1</td>
<td>0.0315</td>
</tr>
<tr>
<td>Cable resistance of 7.5 m power cable</td>
<td>3</td>
<td>1.3</td>
</tr>
<tr>
<td>Harnesses with power cable connector resistance</td>
<td>3</td>
<td>0.37</td>
</tr>
<tr>
<td>Earthing studs between rotating turret and chassis</td>
<td>8</td>
<td>0.067</td>
</tr>
<tr>
<td>Starter motor ground leads</td>
<td>1</td>
<td>0.028</td>
</tr>
<tr>
<td>Box mounting Power connector VG 95319 (contact size 0/500)</td>
<td>1</td>
<td>0.2</td>
</tr>
</tbody>
</table>

* indicating channels/parallel path

The vehicle bus is regulated by electronic regulator at 28.3 ± 0.3 V as per MIL STD 1275A (Military standards). The values clearly indicate the compliance of the same to the specifications. Bonding resistance is specified and measured, not bonding impedance. The bonding resistance is not necessarily an indicator of the impedance of the bond that plays a vital role for the reduction of the Electromagnetic interference. The electromagnetic emission measurements confirm the same under various conditions indicating that the ground impedance plays a predominant role for the control of EMI in a vehicle. The Figure 4.6.1 shows module layout in vehicle and Figure 4.6.2 shows the photo of surge arrestor used for grounding in vehicle.
Figure 4.5  Grounding Scheme of the vehicle
FIGURE 4.6 Electrical Modules as fitted in a tracked vehicle

Figure 4.6.1 Surge suppressor with pigtail
4.10 MODIFICATION OF POWER SYSTEM

The present power supply uses ‘positive’ terminal lead battery relay based power cables routing which is provided with isolation with chassis for critical system. The two wire system is adopted for signal systems to achieve the same. The earlier system used chassis as return system with ‘negative’ battery control mechanism which picks up ground noise. A small inductance is used to connect the signal ground to chassis which is pass band in operational frequency. This provides galvanic isolation against the unwanted vehicle ground noise. A processor based automated controls for the power and signals helped to reduce the EMI in power supply. Similarly using better grounding techniques aids in the control of EMI in tracked vehicle at system level, subsystem level, module level and component level as per the laid down standards.

4.11 POWER LINE CONDUCTED TRANSIENTS

4.11.1 Introduction

The experimental study was carried out for conducted transient data on power line (28 V DC) due to switching actions created by number of electrical and electronic loads in a combat tank. Power quality in a combat tank calls for strict adherence to MIL STD 1275A as number of sensitive electronic subsystem and large current devices are connected in the same bus. The transient data acquired and recorded are analysed in this chapter, after necessary improvements to power system by means of controlling the transients and by proper layout, redesign of power bus architecture. EMC performance of sensitive electronic equipment after
EMI hardening and a study of transients were carried out on distributed power architecture to ensure power quality.

Goedbloed et al (1987) stated that regulation of power supply is an important factor and transients are one of the EMI causes in low voltage supply networks for a vehicle. The tracked vehicle uses chassis as return conductors for all its major loads due to space constraints and tactical requirements of vehicle. Due to common power supply bus for various electrical and electronic loads in a combat tank, generally a poor voltage regulation exists in the 28 VDC battery based power distribution system. The power resources in the vehicle are used in conservative manner for tracked vehicle as given below broadly to cater for various loads.

(a) Battery mode without engine on (called as Standby mode)
(b) Battery in parallel (Normal mode) with engine driven generator and along with vehicle load sharing
(c) Battery in parallel with auxiliary power plant (called as Silent watch mode) on with the main generator

Common mode source impedance is the primary cause for conducted EMI (Kimball 1986). The instantaneous bus voltage of electric power supply varies with loads and other factors. The power supply internal impedance (about 1-10 mΩ) plays a vital role in the above. The ON / OFF transient of loads cause EMI that is very sensitive to electronic equipments can cause malfunction (Shin et al 1983).

In the present case a tracked vehicle hydraulic pump motor draws a load current of over 2700 A for a short duration (300 ms). In case the
battery is floating across generator source has high internal impedance, then this manifests into poor terminal voltage regulation. The power to critical electronics is also drawn from the same bus obviously ends in severe EMI problems. The supply distribution schematic is shown in the Figure 4.6.

The vehicle is powered by battery 24 V, 400 AH that floats across generator rated 28.3±0.3 V. The power is distributed to vehicle mobile hull by high performance junction boxes, Raychem cables etc. The rotating turret(upper) has the power fed via an assembly called as slip ring assembly to various loads in a open architecture. Thus, in case there is fault in one subsystem it gets isolated and becomes isolated from main vehicle supply.

4.11.2 Power Supply as Per MIL STD 1275A

According to MILSTD 1275A, following technical parameters are to be met in any land based military vehicle containing electrical and electronic loads.

(a) Ripple at no load 8% (< 2 V )
(b) Ripple at full load 8% (< 2 V )
(c) Ripple frequency 200 kHz
(d) Spikes with no load < 2.5 time supply voltage, 250 V DC
(e) Spikes with full load < 2.5 time supply voltage, 250 V DC
(f) Minimum voltage dip permitted for electric loads at power supply input end, 9 V
(g) Minimum voltage dip permitted at critical module viz computer input 16 V
(h) Voltage O/P at rotating Platform (turret) when engine is cranked 6 V

(i) Engine cranking cycle as per Figure 4.7

4.11.3 Automobile switching over voltages

The conducted over voltage in the fighting vehicle can be due to various reasons as indicated below which require adequate suppression (Melville 1984).

1. Switching ‘ON’ of the main engine blower motor rated 11kW on the positive bus.

2. Switching ‘ON’/‘OFF’ of the two dust ejector, provided to ensure clean air supply to the main engine, rated at 1.1 kW, 10500 rpm for engine.

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![Figure 4.7 Engine cranking and voltage dip for 28 Volts vehicle](image)

Figure 4.7 Engine cranking and voltage dip for 28 Volts vehicle
3. Switching ‘ON’/‘OFF’ of the rotating loads (turret) rated at 550 A, 3 s Duty Cycle, \( I_{peak} = 2400 \) A, 200 ms.

4. Switching ON/OFF of the main engine of the power pack.

5. Noise produced in the slip ring assembly, slip ring assemblies that provide continuous rotating, 360° power/signal paths between the two disjoints masses namely mobile hull and rotating turret weapon platform. Noise produced by the ignition system of the vehicle for the Auxiliary power pack.

6. Over voltages caused by short circuits, earth faults etc.

Fowler (et al 1992) has indicated that the interconnecting cables and connectors are one of main reasons for the EMI. Hence proper choice has to made on the type of interconnecting connectors and cable, along with the method of diagnosis and reduction of conducted noise emission. The tracked vehicle uses shielded Raychem make cables along with conventional ones for distribution onboard the vehicles. The Raychem cables have given excellent performance along with ITT cannon make connectors for the conducted and radiated emission performance. The added advantage is that NEMP protection during induced currents can be inbuilt feature of connector itself.

Dinallo (et al 1982) has indicated the methodology in his studies cables to conform to the stipulated limits for the tracked vehicles. The transients on board the vehicle were studied under various conditions for the EMI levels.

In case of successful starting of vehicle the voltage builds up gradually after charging the battery to the normal level as shown in the
Figure 4.8. During starting sometimes the main engine fails to start due to mechanical gear disengagement, this reflects failure to build up the minimum voltage as shown in Figure 4.9. The onboard critical subsystems are already made ‘on’ and are working during this period and these transients needs to addressed positively.

The regulated power supply bus voltage (Figure 4.10) and its ripple voltage is seen to be well within the margin i.e. 28V ± 0.3 V (300 mV) for a tracked vehicle (Figure 4.11). Starter motor is a DC series motor that gets itself engaged with main engine whenever the drivers starts the vehicle though means of vehicle battery. The transients referred as ‘starter glitch’ that arise during this process are shown in Figure 4.12. The switching ‘on’ of heavy inductive loads (18 kW) causes dip in the mains bus voltage from 28.1 to 9v for a period of about 300 ms as depicted in the Figure 4.13.

The electrical transients discussed are repetitive in nature; owing to system requirements this implies that proper EMI countermeasures such as filters etc needs to provided to counter the same.
Figure 4.8 Voltage build up during starting

Figure 4.9 Starter motor transients
Figure 4.10  Regulated Positive Bus Voltage

Figure 4.11  Ripple Voltages
Figure 4.12  Starter Motor Voltage Dip in Power Supply

Figure 4.13  Power Supply Dip during Loading
4.11.4 Compatibility of power supply and utilisation equipment

There shall be no influence by utilization equipment, which would cause the electrical system to depart from the limits specified in the detailed requirements. In the event of generator failure, battery is still in the circuit to cater for the emergency loads.

4.12 CRITICAL SUBSYSTEM MODULE ANALYSIS

The following critical subsystems were experimented for record of transients at power points in the vehicle.

(a) Stator motor (Engine ON / OFF)
(b) Hydraulic pump motor
(c) Dust ejector motor
(d) Fuel pumps
(e) Starter motor etc.

4.13 POWER SYSTEM MODIFICATION FOR EMC

The module schematics layout was evolved and modifications were carried out in the DC bus to maintain power quality as enumerated below.

(a) The control logic stipulates that either an auxiliary power unit or the main generator comes in parallel with vehicle battery at any point of time.
(b) All voltage sensitive electronic devices are supported by a back up battery of 24 V, 23 AH capacity to cater for the dip in power supply during operation of heavy loads.

(c) All less sensitive devices are fed from the output of main generator or auxiliary generator.

(d) Directional protection is provided to back up battery to avoid unnecessary drain to heavier loads at input end. In addition individual loads are hardened for conducted EMI with transient protection.

4.14 DISTRIBUTED POWER ARCHITECTURE

(a) Distributed power architecture (DPA) replaces multiple central power sources.

(b) DPA provides small size, lighter weight, and better operation with battery power and more efficient subsystem isolation and redundancy.

(c) DPA allows a single 28 V bus and battery bank rather than running redundant wiring for each voltage level.

(d) DPA allows upgradation of separate subsystem in without making major changes onboard the vehicle.

(e) DC-DC converter provides very close regulation of output voltages in spite of fluctuations in input voltage and heavy load.
(f) Transformers in DC-DC converters provide electrical isolation making it easy to build in redundancy and to protect the whole system from effects of isolated failures.

4.15 TRANSIENT DATA ANALYSIS

The 28 V DC powers several critical electronic onboard modules. The generator floats across the battery bank. Figure 4.14 shows the variation of the current and voltage of electronic module 1 when the engine was started in standby battery mode along with the transients. Figure 4.15 shows recording when the engine and nearby electronic module 1 (close to the power source) were already switched on, the transients arising due to switching on of heavy duty motors were monitored and recorded for analysis.

The second case studies were based on distant onboard electronic module unit 2 (close to load end), voltage and current variations were studied with engine and DUT already on, but hydraulic pump motor switched on later as a source of transient. The transient waveforms recorded are shown in Figure 4.16. Since it was drastically effecting the voltage regulation to electronic module 2, a battery backup was substituted across the bus near the electronic module 2 and again the measurement was repeated. The backup battery maintained the voltage to limits without allowing them to drop below safe levels. These measurements were repeated for voltage and current variation as depicted in the graph shown in Figure 4.17 after EMI hardening.
4.16 TEST DATA INFERENCE

Figure 4.14 the electronic module 1 draws an additional current of 420 mA from its normal current of 24 A for the duration of 80 ms during the starting of main engine. The observed positive bus voltage dips from 24 V to 17.6 V. The transients were recorded with the hydraulic pumps switched ‘on’ as shown in Figure 4.15. The electronic module 1 draws 410 mA for 22 s with engine already kept on. This is well within the MIL STD specified limits and will not cause any malfunction.

However the voltage glitch is severe in the case of electronic module 2, at the time of switching ‘on’ of the motor with main engine on. The current in the electronics module 2 varied from 0.1 A to 24.3 A in different amplitudes for duration of almost one second as in Figure 4.16, the voltage varies from 15.1 V to 18 V during the same period. The vehicle encountered malfunction during this period at the electronic module 2 which tripped several times. The onboard system does not permit occurrences of such events as the module gets reset or switched off.

A modification was carried out on the vehicle, with the battery backup, which was separately installed to cater to the dip in power supply. The backup battery of 24 V, 23AH (Ni-cd) was connected across the electronic module 2 (Figure 4.19). The transient voltage at input end of module 2 was observed as 0.4 V (from 27.1 to 26.7 V) while the unregulated output at source end remained 16.5 V. The current drawn by the module 2 remained consistent at 7.06 A (Normal current) and there was no impact on the electronic module 2. The module level system performance was monitored during the transient period, due to switching on the hydraulic pump motor ref. Figure 4.17. EMI techniques such grounding, welding of ground points etc done on vehicle enhanced the performance. The bus voltage is maintained at stipulated levels as per standards.
Figure 4.14 Starter motor transients at Electronic module 1

Figure 4.15 Transients recorded at Electronic module 1 due to switching on of the hydraulic motor drives
Figure 4.16 Transients at Electronic module 2 due to switching of heavy duty motors

Figure 4.17 Transients at Electronic module 2 after installation of auxiliary battery enhanced layout and adoption of EMI hardening
4.17 VEHICLE RING BUS TOPOLOGY

An improved distributed architecture (Figure 4.18) supply ring system wherein the idle voltage of the power and communications bus is regulated by a fault tolerant power supply circuit, and portions of the bus coupled to devices located in a crush zone of the vehicle may be decoupled from other portions of the bus in the event of a short circuit across the wires of that portion of the bus. The power and communications bus comprises two wires (signal and ground) and the bus ground wire is weakly biased to a reference voltage. A boost power supply referenced to the bus ground establishes the nominal voltage of the signal wire, and supplies charging current over the signal wire to the energy reserve circuits of various devices coupled to the bus.

The power supply is transformer-isolated from the bus, and the feedback circuitry for controlling the operation of the power supply senses the bus voltage as coupled through the transformer. Consequently, the power supply retains the ability to regulate the bus voltage in fault conditions where the ground or signal wires of the bus are shorted to vehicle ground or battery voltage. In such conditions, the bus ground shifts from its normal value, and is detected to provide a warning indication to the operator of the vehicle.

Open circuit failures of the bus wires are addressed by configuring the bus in a closed ring topology, and short circuits across the bus wires are addressed by configuring the bus so that portions of the bus disposed in one or more crush zones of the vehicle can be de-coupled from the rest of the bus.
The ring bus concept gives fault tolerant, short circuit protected, redundant independent power, signal and data bus systems.

**Figure 4.18 Vehicle Ringbus architecture**

**Figure 4.19 Back up battery connected to mains supply to counter the voltage dips - Schematic**
4.18 CONCLUSION

The grounding is an absolute essential to provide protection of the equipment and personnel from electric shock. It also helps in the reduction of hazards that accompany lightning, short circuits etc. The single point grounding, with zonal concept is the most preferred system suitable for tracked vehicle. The ground element measurements clearly indicate the limits that can be achieved with the existing tracked vehicle technology. The transients that arise during various load conditions were monitored and recorded that confirms the power quality to the laid down standards. A sensible and sound technical solution exists where EMI suppression of both heavy duty loads and light duty loads are taken into account independently. EMI hardening aided by better layout has made it possible for the tracked vehicle to MIIL STD 1275A standards.

1. The Single point is adopted for heavy loads using chassis as return conductor.
2. The sensitive digital signals were routed via shielded cables isolated from ground for better high frequency performance.
3. The military grade connectors were used for interconnection among modules.
4. All static heavy duty ground points were welded permanently during initial stage of hull manufacture using silver and gold finish of about 10 micron thickness.
5. The cable inductance (impedance) for transient performance is ensured by using parallel paths in lieu of single heavy duty cable.

The improvement to power quality by means of distributed architecture is a necessity when large number of subsystems, are to share the same dc bus, in the vehicle.