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Technique applied in electrical power distribution for Satellite Launch Vehicle

Abstract: The Satellite Launch Vehicle electrical network, which is currently being developed in Brazil, is sub-divided for analysis in the following parts: Service Electrical Network, Controlling Electrical Network, Safety Electrical Network and Telemetry Electrical Network. During the pre-launching and launching phases, these electrical networks are associated electrically and mechanically to the structure of the vehicle. In order to succeed in the integration of these electrical networks it is necessary to employ techniques of electrical power distribution, which are proper to Launch Vehicle systems. This work presents the most important techniques to be considered in the characterization of the electrical power supply applied to Launch Vehicle systems. Such techniques are primarily designed to allow the electrical networks, when submitted to the single-phase fault to ground, to be able of keeping the power supply to the loads.

Keywords: SLV, Electrical network, Power distribution.

LYST OF SYMBOLS

SLV	Satellite Launcher Vehicle
IEN	Integrated Electrical Networks
SEN	Service Electrical Network
CEN	Controlling Electrical Network
SAEN	Safety Electrical Network
TEN	Telemetry Electrical Networks
OBC	On Board Computer
L+	Positive line of direct current voltage source
L-	Negative line of direct current voltage source
PE	Protection cable
IPC	Insulation Permanent Controller
I_f	Current caused by the direct fault
V_f	Voltage caused by the direct fault
Z_{cp+}	Resistance in the main cable segment, positive line
Z_{c+}	Resistance in the load cable segment
Z_p	Resistance in the protection cable segment
Z_{ICP}	Internal resistance in the Insulation Permanent Controller
Z_{cp-}	Resistance in the main cable segment, negative line

INTRODUCTION

The Satellite Launch Vehicle (SLV), shown in Fig. 1, is currently developed in Brazil by the Institute of Aeronautics and Space (IAE, acronym in Portuguese). The vehicle on board electrical network is sub-divided in Service Electrical Network (SEN), Controlling Electrical

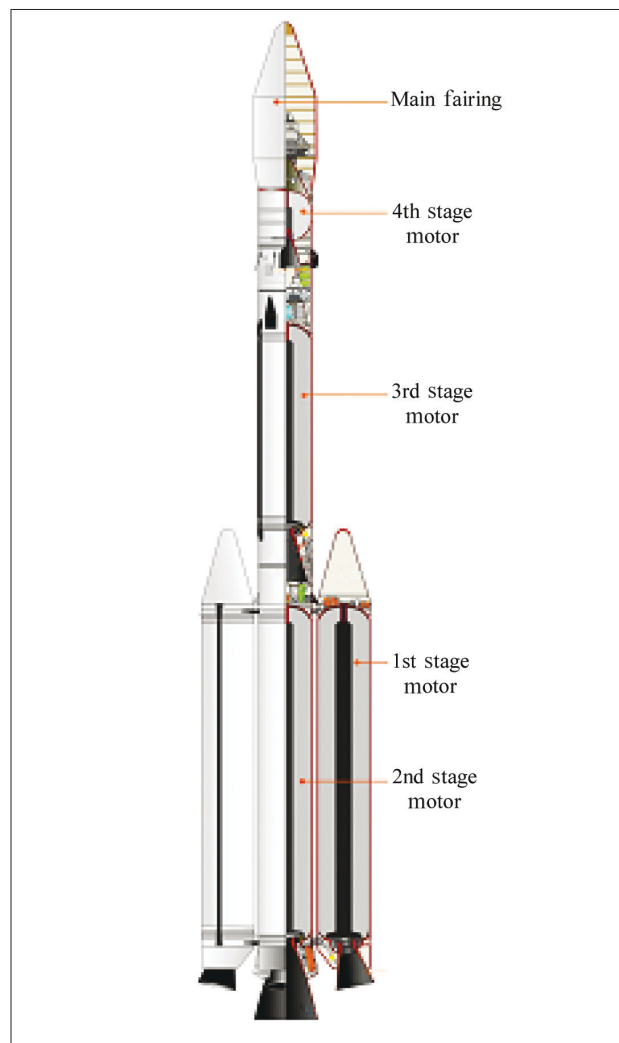


Figure 1: Main SLV subsystems (Palmério, 2002).

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Network (CEN), Safety Electrical Network (SAEN) and Telemetry Electrical Network (TEN) (Palmério, 2002).

The requirements for SEN are: i) to store and provide electrical power; ii) to distribute electrical power; and iii) to perform the safety and the sequence of events during the flight of the vehicle.

The main equipment used in CEN are: i) inertial sensors; ii) On Board Computer (OBC); and iii) electro-mechanical actuators, which allow the vehicle to follow a flight trajectory.

SAEN performs the following functions: i) reception; ii) decoding; iii) command; iv) actuation of remote and auto destruction orders; and v) communication with the ground radar.

TEN performs primarily the following functions: i) conditioning; ii) acquisition; iii) coding; and v) signal transmission to the ground station.

During pre-launching and launching phases, these electrical networks are associated electrically and mechanically to the structure of the vehicle. When integrated into SLV, these electrical networks are called Integrated Electrical Networks (IEN).

The techniques for Electrical Power Distribution (EPD), for launch vehicle, shall be applied to allow the conditions for a proper operation of IEN in normal condition as well in failure mode.

GOALS OF THE WORK

The main goal of this work was to introduce the techniques of EPD for choosing the IEN architecture which will allow maintaining the power supply to the circuits submitted to a single-phase fault to ground and that the fault in one electrical network will not cause direct consequences in a different electrical network and vice-versa.

PROPOSED TECHNIQUES

The two main objectives shall be provided to maintain the power supply to the circuits submitted to first fault to ground and to avoid that the fault in an electrical network does not cause direct consequences in a different network. In order to achieve these objectives, the IEN shall: i) to use grounding scheme which will keep the power supply under condition of single-phase fault to ground, and ii) to use galvanic isolators in the circuits which transfer signals between different electrical networks.

Electrical power distribution

The classification of the EDP is based on: i) Live Cables Scheme, and ii) Grounding Scheme (NBR 5410:2004).

The Live Cables Scheme considers specially the nature of the equipment supplied by the electrical system; in other words, if there are three-phases, two-phases, single-phase etc.

In the Grounding Scheme is given great importance to the connection of the power supply neutral conductor and the association between the metal case of the loads and the grounding reference of the system. Depending on how these connections are, three types of grounding scheme are obtained: TN, TT and IT.

Based on electrical conductivity characteristics and the mechanical structure of the SLV, only the possibility of IT and/or TN schemes for IEN implementation are considered.

IT grounding scheme

The IT is the only scheme which does not require interruptions in the power supply for the load when submitted to the first single-phase fault to the ground (Hofheinz, 2000).

In the IT grounding scheme, there is no point connecting the power supply (L+ or L-) to the ground, but the metal case of the load is directly connected to the ground reference.

Figure 2 presents the electrical model of the IT grounding scheme.

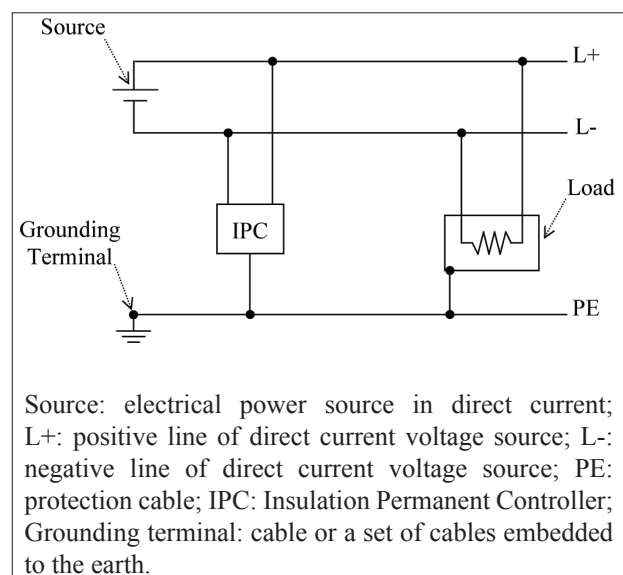


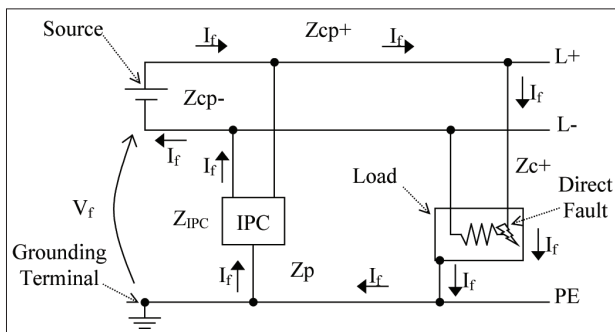
Figure 2: IT grounding scheme diagram.

The loads supplied by the IT grounding scheme must not have connection between their power supply conductors and their respective cases, structures etc.

The occurrence of one single-phase fault to ground, on the IT grounding scheme, will cause a low intensity current flow, because the electrical resistance path is high. Figure 3 shows the path of electric current in the occurrence of the fault on the IT grounding scheme.

Typically, the electrical resistance of the cables in the fault path is low. Nonetheless, the electrical resistance provided by the Insulation Permanent Controller (IPC) is high. These characteristics allow that the IT grounding scheme does not interrupt its power supply with the occurrence of the first single-phase fault to ground.

In the IT grounding scheme, one single-phase fault to ground can be identified by an IPC. This equipment identifies the occurrence of a fault by measuring the electrical insulation of the system. However, this device does not identify the location of the fault in the system. The fault can be located through a manual equipment to search for short circuits.



I_f : current caused by the direct fault. V_f : voltage caused by the direct fault; Z_{cp+} : resistance in the main cable segment, positive line; Z_{c+} : resistance in the load cable segment; Z_p : resistance in the protection cable segment; Z_{IPC} : internal resistance in the Insulation Permanent Controller (IPC); Z_{cp-} : resistance in the main cable segment, negative line; L+: positive line of direct current voltage source; L-: negative line of direct current voltage source; PE: protection cable; Direct Fault: fault with negligible contact resistance; Source: electrical power source in direct current; Grounding terminal: cable or a set of cables embedded to the earth.

Figure 3: Path of the fault current in the IT.

The occurrence of a second fault in a system using IT grounding scheme must be avoided or have their effects minimized by overcurrent circuits protection.

All electronic components in circuits operating in IT grounding scheme must be designed considering the possibility of overvoltage caused by the faults or by the interferences in the electrical system.

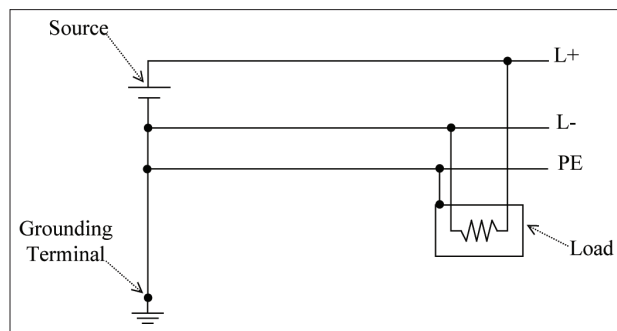
TN grounding scheme

In the TN grounding scheme the power supply is directly grounded and the metal cases of its loads are connected to this same point (Cotrim, 1985).

This scheme can be implemented in three different versions: TN-C, TN-S and TN-C-S. The complementary letters define respectively: i) the neutral conductor is also used for interconnection of the metal cases, ii) the neutral and protection conductors are separated, and iii) the neutral and protection conductors are joined at the beginning of the circuit and are separated from a determined point of the conductors.

Based on the requirement of establishing the electrical connection among all mechanical parts of the SLV structure, the implementation of TN-S grounding scheme was chosen only for the loads that require the connection of the power supply negative line and its load metal case. Figure 4 presents the TN-S grounding scheme electrical diagram.

In the TN grounding scheme, the method to remove a single-phase fault to ground is overcurrent circuit protection.

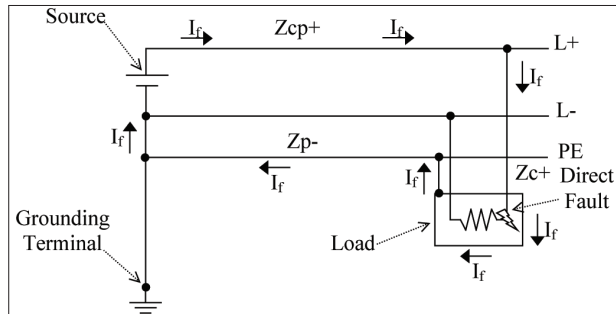


L+: positive line of direct current voltage source; L-: negative line of direct current voltage source; PE: protection cable; Source: electrical power source in direct current; Grounding terminal: cable or a set of cables embedded to the earth.

Figure 4: TN-S grounding scheme diagram.

The advantage of TN grounding scheme is the easy identification of the circuit under fault, which can be determined by its work stoppage due to the overcurrent protection trip. The great disadvantage is the loss of a circuit, which can create a negative effect on the system.

Figure 5 shows an example of path of the fault current, in steady state, for the TN-S grounding scheme.



I_f : current caused by the direct fault; Z_{cp+} : resistance in the main cable segment, positive line; Z_{c+} : resistance in the load cable segment. Z_{p-} : resistance in the protection cable segment. L+: positive line of direct current voltage source; L-: negative line of direct current voltage source; PE: protection cable; Direct fault: fault with negligible contact resistance; Source: electrical power source in direct current; Grounding terminal: cable or a set of cables embedded to the earth.

Figure 5: Fault current path in TN.

On board IT grounding scheme

Statistically, the single-phase fault to ground is the most common failure in electrical systems, regardless of the grounding scheme adopted (Kindermann, 1992), across all the line from the power supply to the load circuit.

Between conventional grounding schemes, IT is the only one which does not interrupt the power supply in case of the occurrence of a single-phase fault to ground.

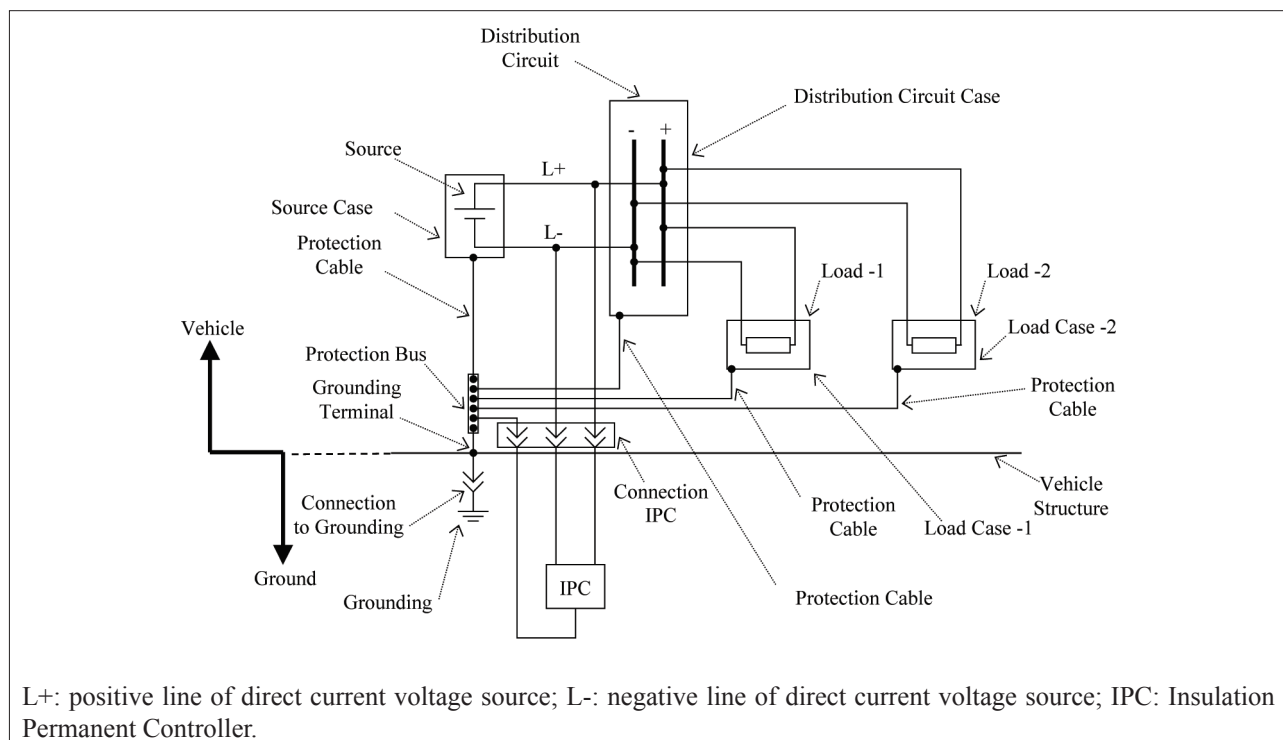
The immunity to the single-phase fault to ground is a great advantage of the IT grounding scheme over the TN grounding scheme.

The IT grounding scheme disadvantage is the difficulty to identify the circuit where the fault occurred, which is usually performed by IPC associated to successive measurements made by the electrical system operator, aided by differential current pinchers.

Figure 6 presents an example of IT grounding scheme for unmanned vehicles.

In the system presented in Fig. 6, the use of IPC only on the ground is foreseen. This will not allow the acquisition of electrical isolation data during the flight of the vehicle.

The behavior of the electrical isolation, during the flight of the vehicle, shall be determined in ground tests using IPC, and simulating the flight conditions.



L+: positive line of direct current voltage source; L-: negative line of direct current voltage source; IPC: Insulation Permanent Controller.

Figure 6: Example of IT grounding scheme.

Galvanic separation

The goal of galvanic separation is to create galvanic isolation among independent electric circuits that can be associated at the same electrical network, with different voltages which could damage equipment or cause undesirable interferences for the system operation.

Normally, in a launch vehicle, can be identified electrical networks with different grounding schemes exchange signal each other.

Figure 7 shows an example of circuit (Cts) which has no galvanic separation; however, it has the function of transferring signals between two electrical networks with IT and TN grounding scheme, respectively.

In Figure 7, R1 resistor, in the IT grounding scheme network, provides analogical signal which is proportional to the level of voltage reached by the F2 power supply to the TR transmitter in the TN-S grounding scheme network, by means of Cts circuit. On normal operation, the absence of galvanic separation in the Cts circuit causes limited interference between

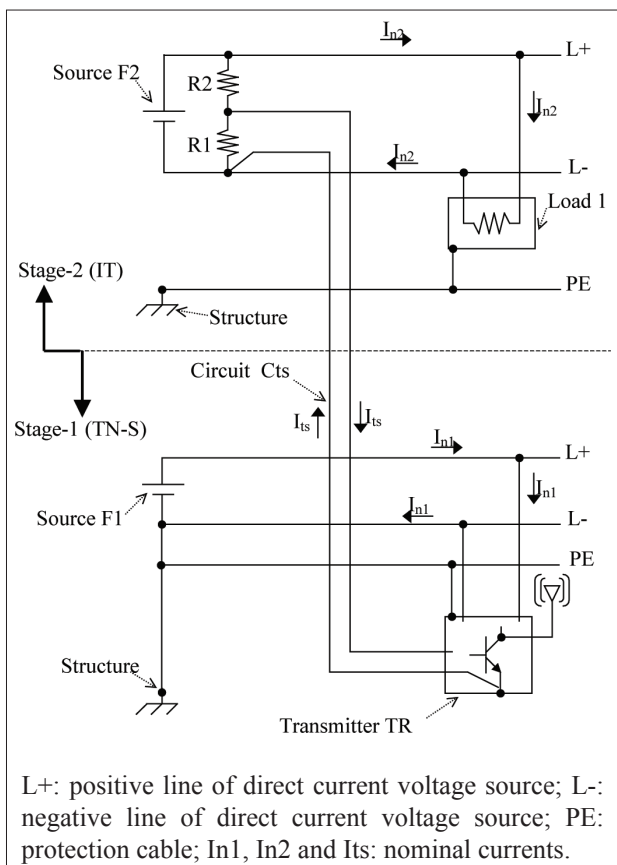


Figure 7: Signals transference without galvanic separation.

the two electrical networks, prevailing the nominal currents (I_{n1} , I_{n2} and I_{ts}).

Assuming that a single-phase fault to the metal case of the Load 1 occurs in the IT grounding scheme, it will cause short-circuit current (I_f) between the components of the electrical networks showed in Fig. 8.

In the electrical network configuration showed in Fig. 8, the occurrence of one fault may cause undesirable consequences.

In order to minimize the consequences of this fault, is proposed the installation of galvanic separators in the circuits of different networks which exchange signals with each other, as shown in Fig. 9.

In the electrical diagram shown in Fig. 9, it can be observed the galvanic separator in the circuit of transference of signals (C_{ts}), restraining the consequences of the fault and allowing the normal operation of both electrical networks.

Figure 10 presents four examples of galvanic isolation circuits which can perform the transference of signals among different electrical networks (Mulville, 1998).

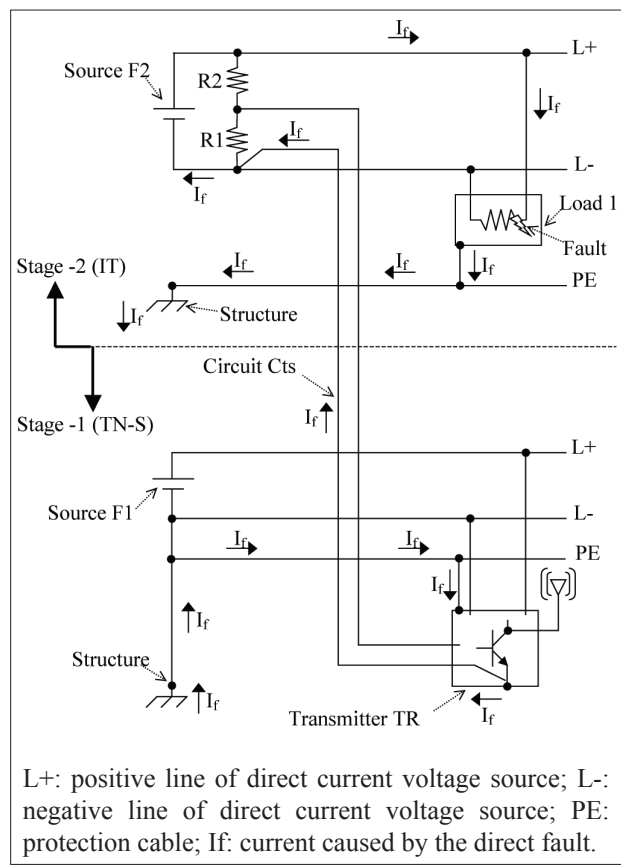


Figure 8: Fault path between the electrical networks.

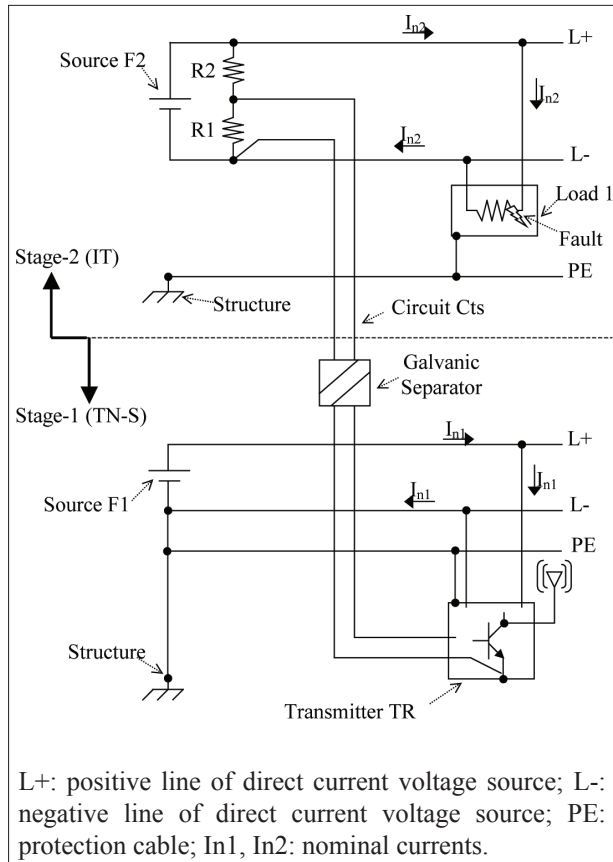


Figure 9: Transference of signals with galvanic separation.

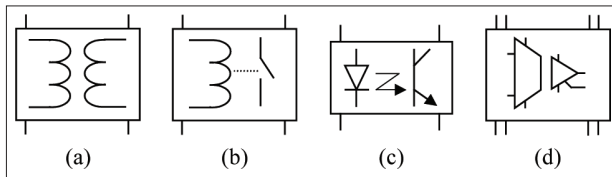


Figure 10: Galvanic isolation circuits.

The transformer, presented in Fig. 10 (a), can be used to isolate the circuits that work with alternate current signals. Their dimensions and weight are characteristics which limit several launcher vehicle applications.

In order to isolate both digital and analogical signals, the relay in Fig. 10 (b) can be employed. The relays have similar limitation compared to the transformer; however, they are robust and simple to implement in the electrical circuits.

The optical coupler in Fig. 10 (c) can isolate digital signals. In most of applications, the weight and dimensions are proper; however, the optical coupler has low robustness when compared to relay.

When the isolation of analogical circuits is necessary, with both direct and alternate current signals, insulation amplifier, as shown in Fig. 10 (d), can be employed. These amplifiers present significant complexity to be implemented in signals transference circuits.

CONCLUSIONS

The application of these techniques in the electrical networks of SLV will cause mainly the following positive impacts: i) it will allow that vital electrical equipment continues to operate under first-phase fault to ground, for instance, OBC and others which do not have redundancies, and ii) the path of fault current will be restricted to the electrical network in which that fault was created, avoiding the involvement of another electrical network.

The complexity to implement the IT grounding scheme in electrical networks is higher compared to the TN grounding scheme. On that context, IT grounding scheme requires specialized staff, galvanic separation systems and usage of IPC.

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