White Paper

Insulation Monitoring Interrupter (IMI) in Aviation

Abstract – This paper describes the Isolation Monitoring Interrupter (IMI) and its application in aviation. These can be fixed wing aircrafts, helicopters, EVtols, drones, or experimental aircrafts with an electrical power and drive train. The paper dives into the ungrounded power system, its benefits, and how the IMI ensures the electrical safety and reliability of said system.

Index Terms — Isolation Monitoring Interrupter (IMI), Ungrounded Power

I. Introduction

The recent rise of Electrical Vehicles (EVs) has given birth to a variety of industries investigating alternative drive trains and propulsion techniques. EVs are spearheading the development and a good number of production-ready vehicles have slowly but surely penetrated the automotive marketplace. Current battery energy densities and charging infrastructure are limiting factors in the widespread adoption of EVs. For electrical aviation to take off, it is generally assumed that a critical energy density of 500Whkg needs to be achieved in a battery to provide adequate flying time and range between charges. It is safe to assume that reaching these milestones is only a matter of time as this has already been demonstrated in various labs. Fuelcell powered systems have also been under investigation and been proposed for aviation-related propulsion. Here, the drawbacks may be the high-pressure hydrogen storage systems needed, while the relatively high energy density would provide adequate flight time and range.

II. Power system of choice

The power system of choice for EVs, and subsequently, for electrical aviation, is ungrounded. The ungrounded system (floating system) has no intentional connection between the high voltage conductors and the vehicle's reference ground or frame. By doing so, the occurrence of high ground-fault currents and, subsequently, fire and shock hazards, are minimized.

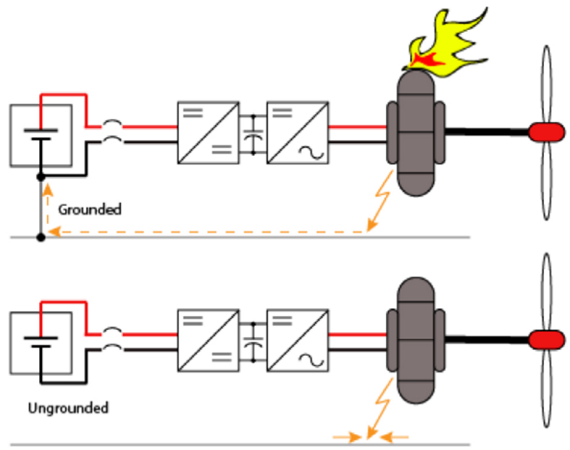

Fig. 1 Grounded vs Ungrounded power configuration

Fig. 1 illustrates the difference between a grounded and an ungrounded power system. In case of a fault between an electrical portion and the frame, the current will take the path of least resistance and attempt to return to its original power source. In the case of grounded power, this path is clear. A low ohmic negative to ground bonding jumper ensures a low resistance path back into the battery. The resulting current is limited only by the fault resistance and can instantly reach many hundreds of Amperes. As a result, overcurrent devices will trigger, and heat and possibly even a fire can be caused, which is unacceptable onboard an airplane. On the contrary, the ungrounded system poses an insurmountable high resistance back into the battery due to its missing negative-to-ground bond. Hence the resulting currents on a first fault basis are miniscule and the system will keep operating. A second fault, however, will take the system down, therefore it is recommended to service an ungrounded system as soon as possible after a first fault has occurred.

III. In the standards

ASTM International addresses electrical safety issues in F2840-14 Standard practice for design and manufacture of electric propulsion units for light sport aircraft. Amongst others, it uses SAE J2344 Guidelines for EV safety as a reference.

Under 6.2 it mentions that the design and construction of the Electrical Power Unit (EPU) shall minimize the probability of the occurrence and spread of fire and electric shock. ASTM further references what the term "isolation" defines. In this case it is the electrical resistance between the battery's (power source's) high-voltage system and any airframe conductive structure. A value greater than or equal to 500Ohms/Volt at the maximum working voltage is defined as isolated. To explain this further, consider the following equation: An aircraft may be equipped with a battery running at 400V max. As per the definition this equates to an isolation value of 400V x 500Ohm/V = 200KOhm. In other words, if the isolation between the HV system and the conductive airframe has broken down to values below 200KOhm, an alarm must be triggered. This is important to note because this provides a measurable reference point that the manufacturer and operator must absolutely adhere to for ensuring safety. ASTM F2840-14 Paragraph 6.2.4 addresses the safety device designed to ensure safety in the electrical system by stating this: Consider incorporation of a ground-fault detection system that provides the pilot or ground personnel a warning if the airframe is no longer fully electrically isolated from the energy storage device.

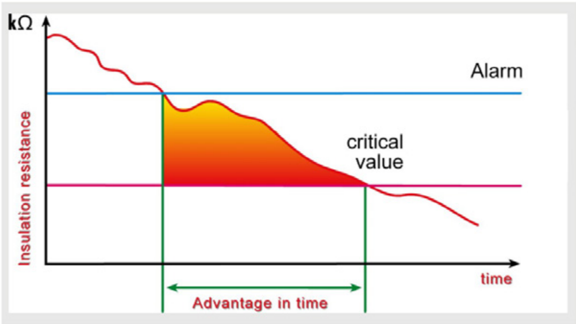

Fig. 2 Insulation decrease over time

IV. The Technology

Isolation Monitoring Interrupters (IMI) or Ground-Fault Detection Systems (GFDS) have been employed to monitor ungrounded power systems for decades. In their simplest form, the common H Bridge has been around since the 1950s. Nowadays, power systems have matured to a degree where a simple measuring circuit is no longer adequately equipped to effectively monitor accurate isolation values. The interfering factors are plenty. For starters, there is power conversion followed by heavy utilization of rectification and high frequency switching involving IGBTs. There are also intended ground connections via Y-caps and filter circuitry. Mix that with voltage variances due to constantly changing load and charge demand, and the need for a sophisticated IMI circuit and the algorithm becomes apparent. Bender IMIs couple onto the HV system via pilot wires. They generate an internal measuring signal that superimposes onto the HV rails from where it penetrates the entire vehicle's electrical system.

1) Figure 3 illustrates such an IMI circuit. Signal generator "G" impresses a voltage on the HV+/- battery system via coupling resistors "R". The signal strength "Um and Im" is constantly evaluated across the measuring portion at "Rm" and triggers "K" will be alerting the operator if insulation fault "RF" causes the isolation to decrease below safe values.

2)

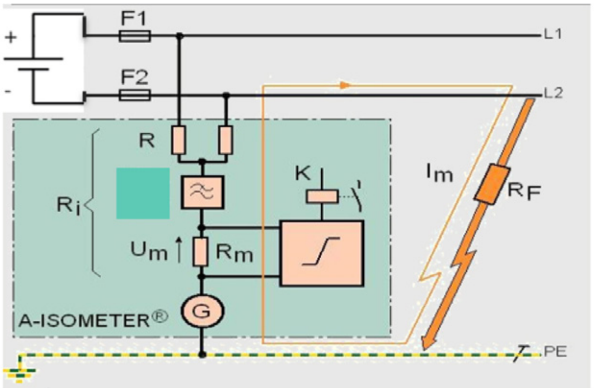

Fig. 3 An IMI signal generator between HV+/- and Chassis (Here: PE)

3) The implementation of the IMI is shown in figure 3 and 6. The measuring signal "Im" can be best described as an alternating square wave with varying amplitude and duty cycle. This is considered to be active measurement. The active component enables the IMI to see through inverter stages, handle AC, DC and eliminate the negative influence of Y-caps on the system. It is these filter caps that often cause an IMI to get false readings or cause serious delay in response time and accuracy.

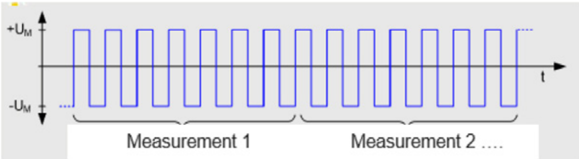

Fig. 4 An IMI signal, the AMP Adaptive Measuring Pulse

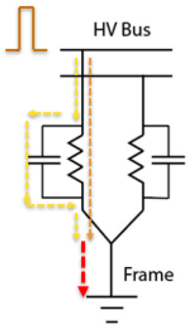

Fig. 5 Y – Cap filter

4) Figure 5 explains the influence of Y-caps on an IMI measurement signal. The IMI's signal is shown as a rectangular square symbol in brown. It follows a potential resistive path to ground as the brown dotted line, however, the Y-cap produces an alternative path and the current splits off (yellow dotted line). The resulting red dotted line represents an AMP signal that carries now capacitive and resistive portions skewing the true ohmic value. Note: For a successful ground-fault reading we are only interested in the resistive value in ohms. The IMI needs to be able to compensate for the capacitance effect.

V. Conclusions

Modern IMIs are an integral part in ensuring continuous uptime and safety of an ungrounded, airborne power system. With advanced measurement algorithms and techniques, they enable electric powerplants in airborne applications to pursue safe and reliable operation.

VI. References

[1] ASTM International F2840-14 Standard practice for design and manufacture of electric propulsion units for light sport aircraft.

[2] UL2231-1,2 Standard for Personnel Protection in Electrical vehicle systems. Electrical vehicle supply systems.

[3] Walther Bender Fault current monitoring in electrical installations in acc. to IEC62020 and other international standards.

[4] FMVSS305 Electric powered vehicles: Electrolyte spillage and electrical shock protection

VII. Vitae

Torsten Gruhn began his career as a certified electrical motor rewinder in Germany. He graduated from trade school and worked on everything electrical that can turn, produce or transform power. He obtained a Bachelor of Science degree in electrical engineering from the University GH in Paderborn, Germany with the emphasis on power generation, transmission and distribution. Torsten's main focus in his current position is new business development, sales and the support of ground-fault protection equipment.

VIII. Appendix

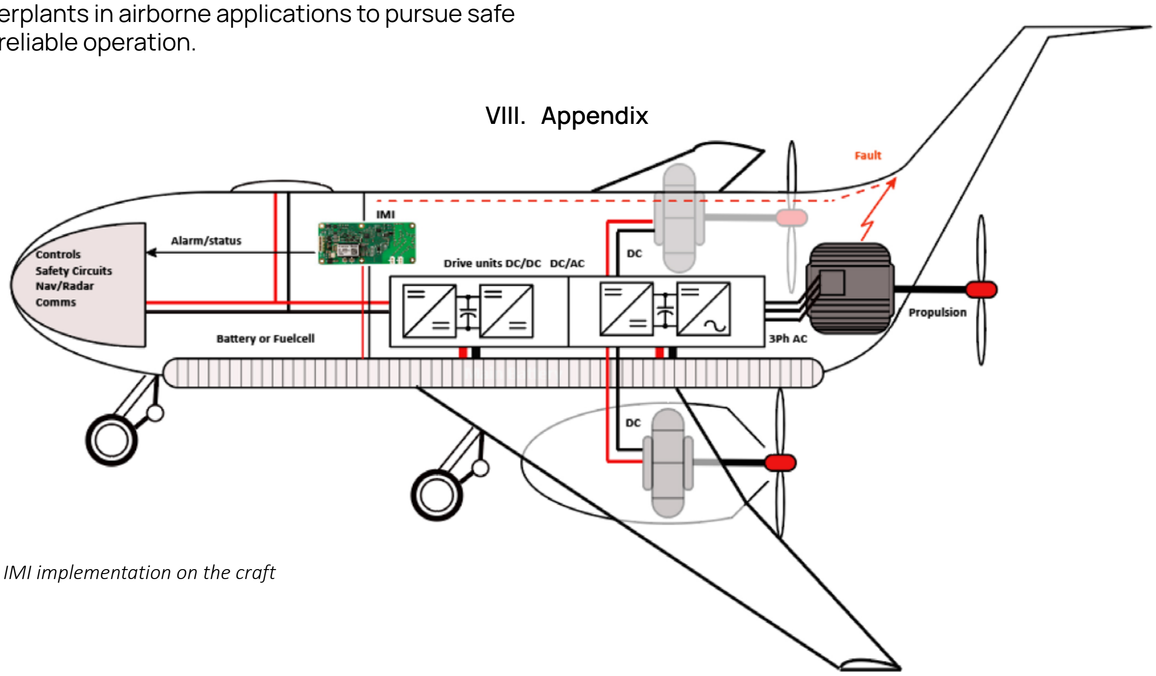

Fig. 6 IMI implementation on the craft

Torsten Gruhn
Bender Inc.
torsten.gruhn@bender-us.com