# A Modelling Design Framework for Integrated Electrical Power and Non-Electrical Systems Design on Electrical Propulsion Aircraft

Catherine. E. Jones, Kieran Millar, Kenny Fong, Rafael Peña Alzola, Patrick Norman, Graeme Burt
University of Strathclyde, Glasgow, UK
catherine.e.jones@strath.ac.uk

*Abstract-* **The electrification of power and propulsion systems on aircraft is a key enabler for the decarbonisation of aviation. A significant challenge for the design of these electrical power systems is that electrical propulsion is a disruptive technology, with neither the associated electrical power system (EPS) architectures nor industry standards established. Compared to conventional, state-of-the-art aircraft, these next-generation aircraft necessitate much more interdependent design of different systems and sub-systems. As such, the efficient design and down-selection of an EPS which meets both performance (e.g. weight) and dynamic functionality requirements is challenging. This paper builds on a pre-existing, hierarchical-based EPS modelling framework developed by the authors to present a new design methodology which also incorporates bi-directional interfaces between EPS performance and dynamic functionality, and EPS and non-electrical systems design. The methodology is demonstrated for interdependent electrical power and non-electrical power systems design, through a case study focussing on the development of a fault management strategy for an EPS integrated with a carbon fibre reinforced polymer structure on a concept electrical vertical take-off and land aircraft.**

## I. INTRODUCTION

Electrification of propulsive systems for aircraft is a key enabler for the decarbonisation of future aviation [1]. A dual trend, also driven by aviation decarbonisation, is the light-weighting of aircraft structures via the use of carbon fibre reinforced polymer (CFRP) structures [2]. The closer integration of the electrical power systems (EPS) with the CFRP structure offers an opportunity for lighter-weight, more compact systems. A major challenge to the design of these integrated systems is the low electrical conductivity of the CFRP, and the need to design both the structure and EPS in parallel. The low technology readiness level (TRL), disruptive nature of the technology, and the lack of pre-existing EPS architectures industry standards combine to present as a significant challenge for both the design of the EPS for electrical propulsion aircraft (EPA), and integrated electrical power-CFRP structural systems. However, this also presents as an opportunity by enabling both flexibility in the design space for viable solutions, and the opportunity for the creation of new industry standards specific to these new technologies and systems.

For an EPA, it is obvious that the EPS a flight critical system. The high-level interdependencies between the EPS, the propulsor fans, the prime-mover for generators, the aerodynamic and structural design, and the thermal systems are outlined in [3]. These interdependencies have been investigated at a steady state modelling level for optimization of performance of aircraft propulsion systems [4]. The interdependencies between different aircraft systems have been considered at a dynamic modelling level, e.g. [5](systems level) and [6] (subsystems level). However, these studies have been carried out in isolation from other levels of modeling complexity, without a methodology to utilise the results to refine wider systems design.

From the literature, several authors have proposed approaches to the analysis of the performance of candidate EPS for EPA, in terms of weight and efficiency, reliability [7-11]. The modelling standard, SAE AIR 6326 [12], provides a mechanism for achieving computationally efficient modelling of the full aircraft EPS, and associated sub-systems and technologies. This enables design decisions to take place, but alone does not provide a methodology for EPS design. The EPS modelling framework [13] has 8 Levels, which map to the levels of modelling complexity described in SAE AIR 6326 [12]. Within Level 1, which focusses on steady state performance (*e.g.* weight, cost, reliability), a series of system design levers (SDLs) are worked through methodically to generate a baseline EPS architecture. These SDLs are defined (in order) as: define baseline power requirements, determine fault management strategy, consideration of availability of power, choice of power distribution method, power quality considerations and approach to thermal management. With the baseline architecture generated, design corner cases (power flow under normal and abnormal operation) can be defined. Performance analysis of this EPS architecture for these design corner cases takes place to determine if it meets performance requirements, or if further revisions (via adjustment of the SDLs) are needed, prior to dynamic functionality analysis.

However the original EPS Modelling Framework [13] only considered the system parameters of voltage, frequency and power to be passed between the different levels of the framework. The range of these parameters was refined as the system design narrowed from a generic to specific choice of technologies and topologies. A methodology for incorporation of results from modelling at Levels 2, 3 and 7 into the SDLs at Level 1, and thus actively updating approaches to system and sub-system design, was not included. This uni-directional design process is limiting, as it prevents the efficient downselection of system design options based on dynamic functionality analysis. Further, while the influence of non-EPS factors on the EPS architecture design to meet performance requirements was considered in the original version of the

Modeling Framework, no consideration was given to inter-system interdependencies at the dynamic transient levels, and

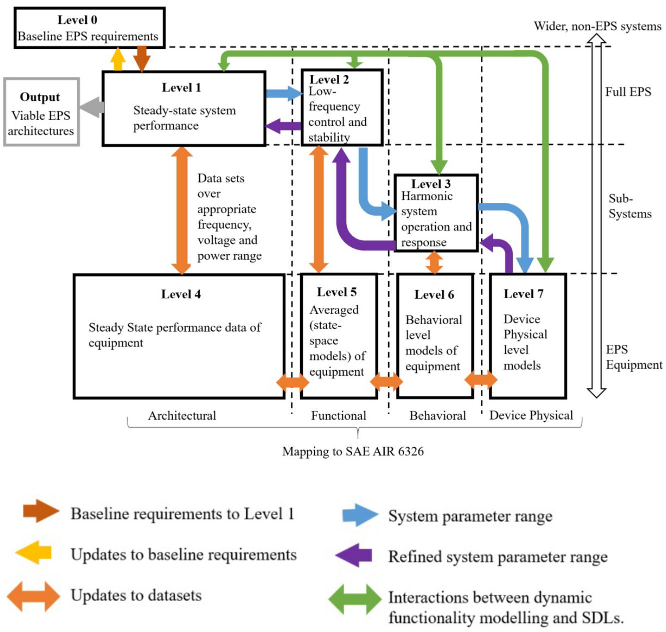



Fig. 1: Revised EPS Modelling Framework with interactions between the SDLs at Level 1 and the dynamic functionality analysis at Levels 2, 3 and 7.

incorporation of these findings back to the EPS system design at Level 1. This paper describes the updated framework which addresses these challenges. The processes involved are demonstrated via a case study focussed on establishing a fault mangement strategy for an integrated electrical power and CFRP structural sytem for a conceptual electric vertical take-off and land aircraft (eVTOL).

## II. The Revised EPS Modelling Framework

### *A. Revised Interactions between Level 1 and other levels of the Modelling Framework.*

Fig. 2 outlines the updated design process for the revised EPS Modelling Framework in Fig.1. This process takes place once an initial baseline EPS architecture has been derived from Level 1. During the Level 1 design process, areas where further analysis is needed to investigate the dynamic functionality are flagged. Analysis does not take place at Levels 2, 3 or 7 until an initial baseline EPS architecture has been defined at Level 1: first, to inform what the topology and equipment of systems or sub-systems to be modelled is; second, to enable an initial appraisal of system performance, so that the system under investigation can realistically be expected to meet performance targets, thus supporting an efficient design process.

First, a set of studies is defined to enable the capture of the dynamic response of the system, and the response is assessed against pre-defined criteria ("1" in Fig.2). Ideally, these criteria align with industry standards and critical design space thresholds. However, a challenge for disruptive technologies is a lack of industry standards, so an informed decision must be made either based on the extrapolation of existing standards, or knowledge of the feasible solution space. If the system meets appropriate criteria, then system parameters and the choice of equipment (e.g. specific converter topology) are refined ("2" in Fig. 2) and updated parameters and selections of equipment (for datasets) are passed to the wider Modelling Framework.

If the system does not pass the assessment criteria, the system design process returns to Level 1. The appropriate SDL is identified, and the tuneable parameters in both the EPS and any interdependent non-EPS systems are defined ("3" in Fig.2). Methods to adapt these tuneable parameters are identified ("4" in Fig.2). The ranking process ("5" in Fig.2) may require assessment of dynamic functionality at Levels 2, 3 or 7. Hence there is a closed, interactive feedback loop between the deeper dive (compared to the first iteration) into design decisions made for a particular SDL at Level 1, and the appropriate level of dynamic functionality modelling.

Once solutions which meet dynamic functionality requirements are downselected, this is fed back to the relevant SDL at Level 1. The SDLs at Level 1 are revised, and the performance of the revised architecture is assessed. Revisions to SDLs for non-electrical systems are passed to the non-electrical systems design process.

### *B. Selection of Tuneable Parameters*

Tuneable parameters are defined as elements of the EPS, and of any systems interdependent with the EPS, which influence system behaviours. For example, this may include the choice of grounding or converter topology, a particular load or a thermal managemnt system, while the exact choice of tuneable parameters may vary on a case by case basis. Depending on the system design, the flexibility to adapt a tuneable parameter will vary. For example, if a particular converter topology is required to enable limiting of fault current as part of the Fault Management (FM) SDL, then there is limited change that can be made to that converter topology when considering the Power Quality SDL.

With tuneable parameters selected, the criteria to assess the tuneable parameters against are determined. The flexibility of how easy it is for a tuneable parameter to be adapted will be ranked and will be common across all SDLs. However, additional criteria need to be identified on a case by case basis for each SDL. For example for the FM SDL, this may include the influence of tuneable parameters on fault diagnostic methods and protection technology choices.

Each of the criteria is assessed against each of the tuneable parameters, and ranked accordingly. Ranking may be based on expert knowledge or results from dynamic functionality assessment at Levels 2, 3 or 7 of the Modelling Framework. A ranking of 9 indicates a highly favourable option, 3 a medium option and 1 for a low ranking.

## III. Case Study: Resilent Integrated Systems Design for an eVTOL Aircraft

### *A. Derivation of intial EPS architecture*

A conceptual eVTOL aircraft with the mission profile shown in Table 1 has been selected to demonstrate the design methodology of the EPS Modelling Framework. The 4 passenger eVTOL has 4 batteries powering 8 pairs of electrically driven propulsor fans. The system requires 600 kW

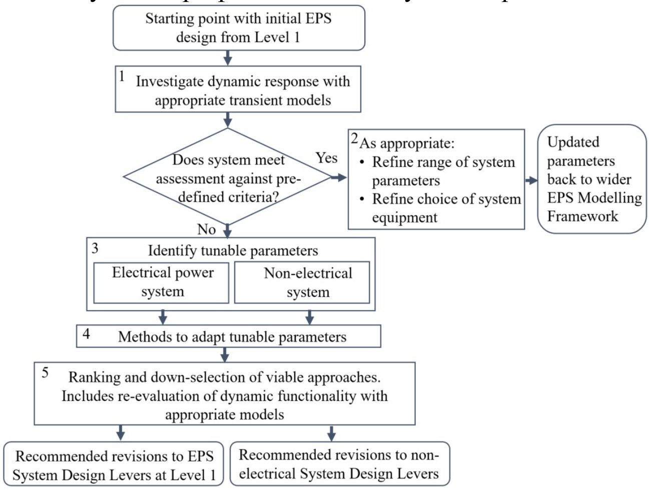



Fig. 2: Flow chart detailing the design interface between the EPS and non-EPS design at dynamic functionality level, and the methodology for determining updates to the SDLs, for both EPS and non-EPS.

to take-off or land, and 300 kW for cruise. The mission profile is described in Table 1. It is expected that emergency cruise and land can be carried out with only 2 out of 4 batteries and 6 out of 8 propulsor motors operational. The maximum take-off weight is estimated to be ~2,300 kg [14].

The focus of this case study is to demonstrate the process of developing an EPS architecture design with a fault management strategy appropriate for a system where the EPS is closely integrated with a CFRP structure. This integrated system design reduces the volume and weight of additional infrastructure needed to keep cables and CFRP separate. This additional infrastructure can add 30 % to the weight of the cables [15]. However, the fault management strategy must respond appropriately to a rail to ground fault through CFRP. This is a challenge due to the variability of the fault resistance that CFRP can add to the fault path [6].

A single line diagram of the initial architecture from the first iteration through the SDLs is shown in Fig. 3. The decisions made at SDL 1 – 4 are captured in Table 2. At this stage decisions around power quality (SDL 5) and thermal management (SDL 6) are not considered. The design corner case is the loss of 2 batteries, 2 motors and the failure of a bus tie, such that the system is purely radial. It is assumed that for symmetry in electrical propulsion, if one motor is lost, a second must also be turned off. Under normal and off-nominal operation, it is assumed that thrust is split evenly between operational motors, and power drawn is split equally between batteries. Under normal operation, the contactors between busbars are open, such that the system is a 4 channel architecture. The focus of this paper is to demonstrate the EPS system design methodology using the Modelling Framework, hence for brevity, only the weight of the EPS has been considered.

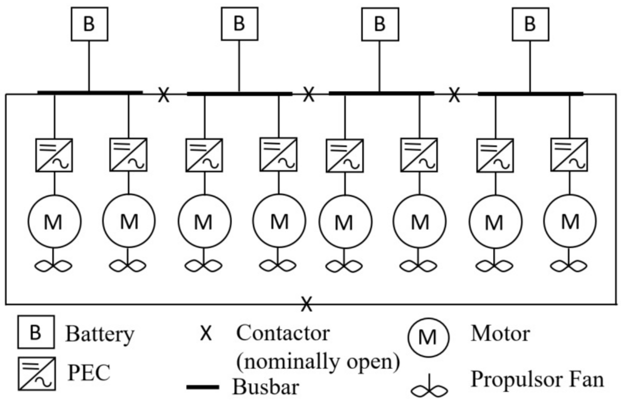
### B. *Initial system sizing*

During the first pass of the system design, protection technologies are not included in the EPS. A better understanding of fault response is needed to select an

TABLE I
MISSION PROFILE OF THE EVTOL

| Mission Segment | Total motor power required (kW) | Duration (minutes) |
|---|---|---|
| Take- off | 600 | 1.5 |
| Cruise | 300 | 10 |
| Land | 600 | 1.5 |
| Emergency Cruise | 300 | 5 |
| Emergency Land | 600 | 1.5 |

TABLE II
DECISIONS AT LEVEL 1 SDLS TO DETERMINE AN INIITIAL EPS ARCHITECTURE.




| System Design Lever | Decisions made |
|---|---|
| 1. Capture Baseline Power Reqirements | Normal operation:<br>• 4 batteries, 8 motors.<br>Off-nominal operation:<br>• Loss of 2 batteries, loss of 2 motors |
| 2. Fault Management strategy | Must always be able to supply 600 kW to motors to enable safe landing. |
| 3. Availability of Power | Any battery can supply any load.<br>4 channel, ring-radial system. |
| 4. Power Distribution | DC, to interface batteries to DC distribution without power electronics. |

Fig. 3: Initial proposed EPS architecture for the concept eVTOL aircraft.

appropriate approach to fault management. At this first pass of the perfomance assessment of the architecture, the weight of the power electronic converters (PEC) and electrical machines is based on power density values. These are 10 kW/kg for the PEC [16] and 5.9 kW/kg [17] for the propulsor motors. The power ratings of individual components are based on the maximum power that will flow through a component under normal, or off-nominal ("emergency land", "emergency cruise") conditions.

The cables are sized based on the current rating of the cable, which determines the cross-sectional area of the cable, and the appropriate cable is selected from a database of options from the publicly available literature. The busbar current is calculated from the power rating to estimate the area and volume of copper required. The busbars are all assumed to be 250 mm long.

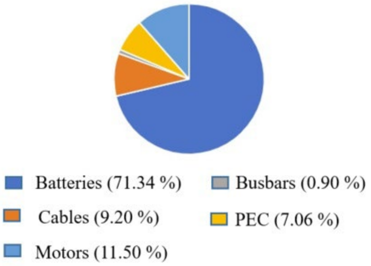



Fig. 4: Breakdown of the mass of the initial EPS design by type of equipment

The battery sizing accomodates the normal mission and the emergency mission. Additional energy associated with system efficiency and useful state of charge were applied as a multiplication factor to increase the required energy reserves. The energy requirements of the battery were estimated by

$$E_{batt} = \frac{1}{(1-SOC_{end})\cdot\eta_{system}} \int_0^T P_{demand}(t)dt \qquad (1)\ [18],$$

where $E_{batt}$ *(WH)* is the energy rating of the battery, $SOC_{end}$ is the minimum useful state of charge, $\eta_{system}$ is the system efficiency (set to 85.76%) and $P_{demand}$ *(W)* is the required power over a period of time, *T* (s). The battery was set to run to a minimum state of charge of 10%, hence $SOC_{end}$ was set to 0.9. Setting this low minimum state of charge trades weight against battery lifespan. Using an off the shelf lithium ion battery pack with a specific energy valuse of 231WH/kg at pack level [19], the mass was estimated to be 203 kg per battery pack, giving a total mass of 813.26 kg. From this, the total weight of the system, without protection equipment, was estimated to be 1140 kg. A breakdown of the system weight by component is given in Fig. 4.

### *C. Detailed Fault Management Design Linking Between Levels 1 and 3 of the Modelling Framework.*

For the eVTOL, it is proposed that the electrical power system is integrated closely with the CFRP structure (electrical cables are run over, or through, sections of CFRP). Therefore the approach to fault management must consider the influence the CFRP on the fault response (undertaking "1" in the process shown in Fig. 2). An example location of a DC link rail to ground fault scenario through CFRP is shown in Fig. 5. As a first pass, the system is considered to be solidly grounded at the mid-point of the DC link. Transient analysis at Level 3 can be used to investigate the fault response. The range of fault resistance added by the CFRP is estimated to be between 1-60 Ω [6]. For a load of 75 kW, if the fault resistance is higher than 10 Ω, then the fault current is less than 20% of the DC link current under normal operation, which is insufficient for conventional overcurrent to detect the fault.

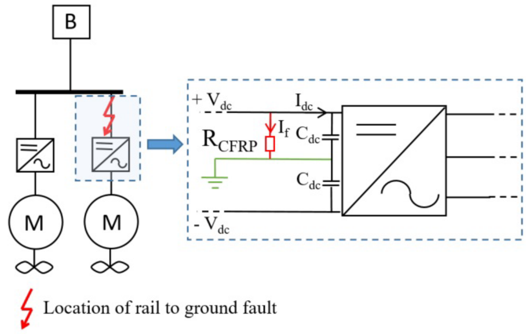



Fig. 5: Example scenario of a rail to ground fault through CFRP, with the fault on the positive rail of the DC feeder to a propulsor motor. The location of the fault in a channel of the proposed architecture, is indicated on the left. The right hand side diagram details the fault scenario.

#### *1. Assessment of influence of tuneable parameters*

Hence the approach to fault management in Level 1 of the modelling framework must be updated to accommodate the influence of CFRP on fault response. Following the process outlined in "3" in Fig. 2, the tuneable parameters of the system are identified for this case study, as the electrical sources, electrical loads, grounding topology, location of electrical bonding to ground and the PEC topology. The non-electrical tuneable parameter is the CFRP impedance.

To further explore options for fault detection and location, each of the tuneable parameters was ranked in terms of influence on different fault diagnostic methods identified from the literature. These methods are: methods reliant on high fault current, such as over current or differential current methods; adaptive protection methods; methods measuring the common mode voltage or current; frequency analysis methods, *e.g.* [20][21]; and superposition methods which inject a signal at non-system frequency, *e.g.*[22]. As is indicated from the ranking in Fig. 6, grounding and converter topologies were ranked as having the most influence on almost all fault diagnostic methods.

Superposition methods are the exception, as these have been demonstrated in the literature for ungrounded, high resistance grounded and solidly grounded systems. The location of electrical bonding of an EPS to ground will impact on pathways to ground, thus influencing strongly on common-mode fault diagnostics and frequency analysis methods. Adaptive methods are very sensitive to system transients, hence load and source transients have high interdependency on those methods. The influence of CFRP is high for approaches where fault diagnostics are coupled to fault current.

This ranking is captured in Fig. 7, where each of the tuneable parameters is ranked for impact on fault diagnostics, alongside

Tuneable System Parameters

| | Grounding topology | Converter topology | Electrical bonding to ground | Electrical load transients | Electrical sources | CFRP Impedance |
|---|---|---|---|---|---|---|
| Over current methods | 9 | 9 | 3 | 1 | 9 | 9 |
| Adaptive methods | 9 | 9 | 3 | 9 | 9 | 3 |
| CM current or voltage | 9 | 9 | 9 | 1 | 1 | 1 |
| Frequency analysis | 9 | 9 | 9 | 1 | 1 | 1 |
| superposition | 1 | 9 | 3 | 3 | 3 | 1 |

Fig. 6: Ranking of influence of tuneable system parameters on approaches to fault diagnostics

Tuneable System Parameters

| | Grounding topology | Converter topology | Electrical bonding to ground | Electrical load transients | Electrical sources | CFRP Impedance |
|---|---|---|---|---|---|---|
| Flexibility in adaption | 9 | 9 | 3 | 1 | 1 | 1 |
| Impact on fault diagnostics | 9 | 9 | 9 | 3 | 3 | 9 |
| Impact on protection technology | 3 | 9 | 3 | 1 | 1 | 3 |

Fig. 7: Ranking of impact of tuneable parameters against criteria for enabling downselection and design of an appropriate fault management strategy.

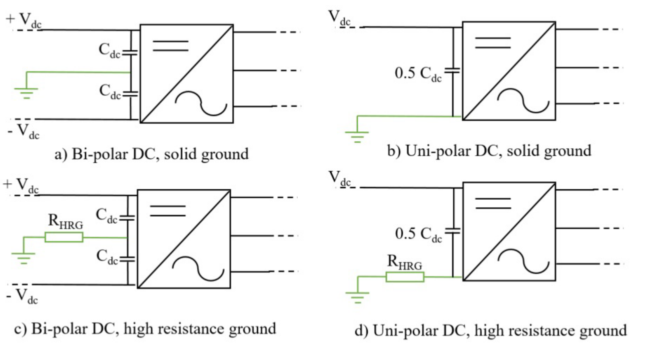



Fig. 8: Different grounding topologies investigated.

impact on choice of protection technology and flexibility in adaption. The system elements which are ranked as offering the highest flexibility in adaption are the grounding and converter topologies, with electrical bonding to ground also an option. While current grounding standards would need to be adapted, the disruptive nature of increased electrification of aircraft, both next generation more-electric and hybrid electric, offers an opportunity to make significant changes to system architectures. Unipolar configurations would also requre higher insulation requirements compared to bipolar topologies.

Electrical loads and sources are less flexible. It may be possible to adapt system architecture to change the location or rating of loads and sources and in turn impact on fault response, but ultimately these elements may be much more challenging to adapt than grounding or converter topology. Hence both of these elements have been rated as a 1. Controlling the electrical impedance of CFRP requires further fundamental research on electrical characteristics of CFRP, including methods of electrically bonding CFRP panels to ground. Therefore, for near term research, this has been rated as a 1.

However, CFRP has a significant impact on fault diagnostics, as it impacts on fault impedance. Similarly, grounding topology, choice of converter and the approach to electrically bonding the EPS to ground all impact significantly on fault response and fault diagnostics. Electrical sources and load transients will have some impact on fault diagnostics, but to a lesser extent when compared to the other system elements.

The choice of protection technology is strongly influenced by the converter topology, as this can be chosen to perform fault current limiting functionality. Due to their impact on fault response, the grounding topology, bonding to ground and CFRP will also impact on protection technology choice, with loads and sources having a relatively low impact.

*2. Selection of grounding topology to support FM approach.*

From the ranking, the adaption of grounding topology is chosen as the first option to investigate at Level 3 in order to investigate the fault response. Fig. 8 shows the different grounding topologies considered.

At this stage, the methodology moves from Level 1 to Level 3 of the modelling framework to investigate the influence of grounding topology on fault response. A single motor feeder was modelled. The rail to rail voltage of the DC link is 540 Vdc. The motor is a 2 pole pair, 24 krpm permanent magnet synchronous motor, nominally rated at 80 kVA. The 3 phase full bridge converter operates at a switching frequency of 4.8 kHz, and converts the DC voltage to 3 phase, 230 Vph rms at 400 Hz. The DC link capacitance was set to be 2.2 mF rail to rail and the rail impedance is 70 µH and 1.7 mΩ per rail. The internal resistance of the batteries was set to 0.001 Ω.

For the solid grounding topologies in Fig. 8, while the fault current will be too low to detect the fault based on conventional over-current based protection (20 % change in current) if the fault resistance is more than 9.75 Ω (for topology (a)) or 19.5 Ω (for topology (b)), the power dissipated through the CFRP will be ~ 7.5 kW for topology (a) and ~ 14.5 kW for topology (b). More than 18 W of power dissipation through CFRP will lead to thermal degradation of the resin matrix, as the glass transition temperature (Tg) will be reached [23].

High resistance grounding topologies ((c) and (d) in Fig. 8) offer a route to control the level of fault current through the CFRP, and decouple the electrical fault response from the fault resistance [21]. The grounding resistance has been sized in the first instance to limit the current through the CFRP to prevent the dissipation of heat in the CFRP resulting in localised Joule heating. This is given by

$$I_{f\_lim} = \sqrt{\frac{P_{lim}}{R_{CFRP}}} \qquad (2),$$

where $I_{f\_lim}$ (A) is the maximum fault current, $P_{lim}$ *(W)* is the upper limit of power dissipated in the CFRP, $R_{CFRP}$ *(Ω),* to prevent glass transition temperature ($T_g$) of the resin matrix of the CFRP being reached. $P_{lim}$ was set to 10 W, to be well below the 18 W threshold for thermal degradation. $R_{CFRP}$ was set to the maximum value of 60 Ω, to give a limit on the fault current of 0.408 A. At a later stage in design, this value of resistance must be re-assessed, based on the charging current to ground due to distributed common mode capacitances, and to select the larger value of grounding resistance which is calculated.

Using (2), the grounding resistance was set to be 661.36 Ω for grounding topology (c), and 1322.72 Ω, for grounding topology (d). The fault current through the CFRP for grounding topologies (c) and (d) is shown in Fig. 9. The current is slightly lower than the calculated value of 0.408 A due to the small amount of line resistance and internal resistance of the batteries. The power dissipated in the CFRP is kept below 10 W. Although fault current is limited, the neutral point of the system shifts by the value of the DC link rail which has faulted to ground. Hence it is desirable to isolate in response to a fault, in order to minimse operation at these higher voltages, which would degrade the insulation and reduce its lifespan, and to prevent a second rail to ground fault occuring when operating in this faulted condition.

### D. *Impact on Level 1 SDL*

The results of the investigations in part "5" of the process descibed in Fig.2, must be fed back to the Fault Management SDL at Level 1. Based on the fault response, the bi-polar, HRG topology ((c) in Fig. 8) is selected. The approach to isolate in response to an electrical fault is also made. The reason for this response is two fold: first, after the first rail to ground fault, the system would need to be rated to operate at this higher votlage for the remainder of the mission. Second, if a second rail to ground fault should occur, this would result in a double rail to ground fault scenario, which must be responded to in a timely manner. Hence to avoid this second, much more serious fault condition, the response to the first fault is to isolate.

This architecture, along with the strategy of isolating in response to a fault is passed back to the Fault Management SDL at L1. The revised single line diagram is shown in Fig. 10, and the updated performance analysis of this system shown in Fig. 11. The protection technology selected at this point is an arc-chute circuit breaker [24]. The weight of the protection system is 10% of the total EPS weight (1289.8 kg).

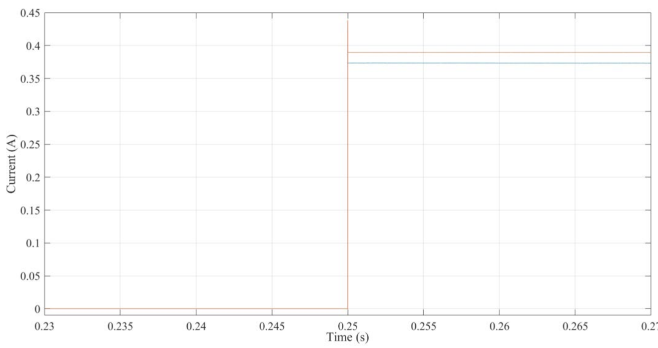



Fig. 9: Fault current through CFRP in response to a DC rail to ground fault for grounding topology (c) (blue) and (d) (orange) in Fig. 6.

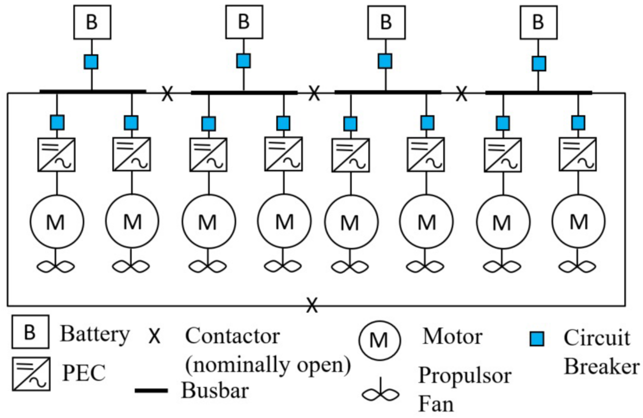



Fig. 10: Updated EPS architecture, with inclusion of approach to fault management.

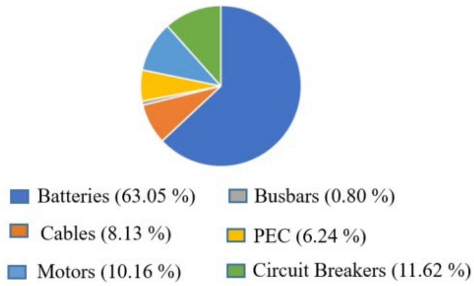



Fig. 11: Updated analysis of system weight at Level 1.

If this weight is acceptable, the next stage for this design process would be an indepth investigation of possible diagnostic methods. This will require further analysis at Level 3, with impact on SDLs fed back to Level 1, and reassessment of the EPS performance.

If the weight of the protection system is not acceptable, alternative approaches to the FM strategy identified in the design process must be investigated. If the performance of the system is still unacceptable, then the original baseline architecture must be reconsidered, by working through the SDLs at Level 1.

## IV. Conclusions and Future Work

The efficient design of an EPS for a disruptive technology, requires a structured, interactive design process between the performance and dynamic functionality design. The outcome of modelling at dynamic functionality levels directly influences the SDLs at Level 1. It is too simplistic to use dynamic functionality modelling to narrow system parameters (as was the case in the first iteration of the Modelling Framework[13]).

The EPS design cannot be considered in isolation from non-electrical systems. By the identification of tuneable system parameters which influence the design decisions around a particular SDL, the parameters which are attributable to non-electrical systems are incorporated alongside EPS system parameters. In the case shown, this was the influence of the CFRP structure on electrical fault response.

The case study showed two iterations of the system design to demonstrate the interdependencies between the performance and dynamic functionality elements of the Modelling Framework. In practice there would be multiple interations. For example, having established an approach to fault management, the stability of the system in response to the sudden loss of electrical sources or propulsor loads must be investigated. It may be necessary to have a DC-DC converter interfacing each battery to the system for control purposes, as this would allow the battery and DC distribution voltages to differ. In addition, this would also offer an option to use the battery interfacing converters to limit fault current. To fully consider the design of the EPS with these battery interfacing converters requires a similar process which was followed around fault management SDL to be carried out for the power distribution SDL. Investigating the response of the system to such load changes would require the electrical – mechanical interface with the propulsion fans to be included in that reassessment of the SDL.

Further work is needed to streamline the design process. This includes more refinement of the interactions between Levels 1, and Levels 2,3 and 7, and non-electrical power systems. The Modelling Framework is a mix of quantitative and qualitative methodologies. Understanding where the boundary between these two approaches to system design lies, would offer further opportunity to make the design process more efficient.

Due to the disruptive nature of the systems that the Framework aims to aid the design of, there is a need to incorporate timeframes for entry into service, TRL and technology road maps into the Level 1 proceses. This would also support the use of the Modelling Framework for identifying challenges around certification and standards for next-generation aircraft.

## ACKNOWLEDGMENT

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