ANKARA YILDIRIM BEYAZIT UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DESIGN OF HELICOPTER DC POWER DISTRIBUTION UNIT

M.Sc. Thesis by

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May, 2022

ANKARA

DESIGN OF HELICOPTER DC POWER DISTRIBUTION UNIT

A Thesis Submitted to

The Graduate School of Natural and Applied Sciences of

Ankara Yıldırım Beyazıt University

In Partial Fulfillment of the Requirements for the Degree of Master of Defense Technology, Department of Electric & Electronic Engineering

by

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May, 2022

ANKARA

M. Sc. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **“DESIGN OF HELICOPTER DC POWER DISTRIBUTION UNIT”** completed by **Ali Seçkin ŞAHİN** under the supervision of **Prof. Dr. Hüseyin CANBOLAT** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ACKNOWLEDGMENTS

Firstly, I would like to express my sincere gratitude to my supervisor, Prof. Dr. Hüseyin CANBOLAT for his tremendous support and motivation during my study. I could not complete this thesis without his helpful attitude and precious recommendations. I also thank to my dearest mother Rabia ŞAHİN who is the reason of the start this master's degree and my wife Ece my daughter Ela and my brother Ali Yiğit UZUNGİL to support me always to complete my degree especially during thesis period. Also thanks to my respectful colleague Onur DAĞ to teach me electrical and avionics systems on an aircraft and for their endless support both on the job and life.

2022, May **Ali Seçkin ŞAHİN**

DESIGN OF HELICOPTER DC POWER DISTRIBUTION UNIT

ABSTRACT

In our modern time, all helicopters have the electrical power to supply the equipment for several systems both flight critical and operational. Helicopter may be used for SAR (Search and Rescue), combat, military tactical, cargo transportation, health (ambulance), farming and commercial, military or VIP transportation. For all usages of modern helicopters have to use electrical power for systems that are used for several missions.

The Electrical Power Generation and Distribution System (EPGDS) generate and distribute electrical power to not only the aircraft electrical power utilization equipment but also enable the engine starting.

There are two types for electrical power as AC and DC. AC system is mainly used for systems, which has high power consumption (generally supplied from 115VAC, 400 Hz power source) such as ice protection, window-cabin heating, main-tail rotor heating or weapon systems.

DC power is used especially on the avionics equipment that are generally supplied by 28VDC and 28VDC power source.

This thesis is about the design principles of a helicopter's DC power distribution unit by considering not only the electrical standards but also all the subjects that are necessary to design the power distribution unit (PDU) beginning with requirements till the end of design by using systems engineering principles. There are some assumptions

PDU shall be capable of deliver DC electrical power from generators to secondary distribution units (circuit breaker panel, relay panel etc.).

Keywords: Helicopter, DC Power, Electrical, Distribution, EPD, PDU

HELİKOPTER DC GÜÇ DAĞITIM ÜNİTESİ TASARIMI

ÖZ

Modern zamanımızda, tüm helikopterler, hem kritik hem de operasyonel çeşitli sistemler için ekipmanı besleyecek elektrik gücüne sahiptir. Helikopter, SAR (Arama Kurtarma), muharebe, askeri taktik, kargo taşımacılığı, sağlık (ambulans), tarım ve ticari, askeri veya VIP taşımacılık için kullanılabilir. Modern helikopterlerin tüm kullanımları için, çeşitli görevler için kullanılan sistemler için elektrik gücü kullanmak zorundadır.

Elektrik Enerjisi Üretim ve Dağıtım Sistemi (EPGDS), elektrik enerjisi üretir ve yalnızca uçağın elektrik gücü kullanım ekipmanına dağıtmaz, aynı zamanda motorun çalışmasını da sağlar.

Elektrik gücü için AC ve DC olmak üzere iki tip vardır. AC sistemi esas olarak buz koruması, pencere-kabin ısıtması, ana kuyruk rotorlu ısıtma veya silah sistemleri gibi yüksek güç tüketimine sahip (genellikle 115VAC, 400 Hz güç kaynağından sağlanan) sistemler için kullanılır.

DC güç, özellikle genellikle 28VDC ve 28VDC güç kaynağından beslenen aviyonik ekipmanlarda kullanılır.

Bu tez, bir helikopterin DC güç dağıtım ünitesinin sadece elektrik standartlarını değil, aynı zamanda güç dağıtım ünitesini (PDU) gereksinimlerden başlayarak tasarımın sonuna kadar sistem mühendisliği kullanarak tasarlamak için gerekli olan tüm konuları dikkate alarak tasarım ilkeleri hakkındadır. prensipler. bazı varsayımlar var

PDU, jeneratörlerden sekonder dağıtım ünitelerine (devre kesici panosu, röle panosu vb.) DC elektrik gücü sağlayabilecektir.

Anahtar Kelimeler: Helikopter, DC Güç, Elektrik, Dağıtım, EPD, PDU

CONTENTS

ABBREVIATIONS

(I)	Information
(R)	Requirement
A	Ampere
AUX	Auxiliary
BAT	Battery
BDB	Battery Distribution Box
CDR	Critical Design Review
COTS	Commercial off the Shelf
DC	Direct Current
EASA	European Union Aviation Safety Agency
EIRD	Equipment Installation Requirements Document
EMC	Electromagnetic Compability
EMI	Electromagnetic Interference
ENG	Engine
ESS	Essential
EXT	External Power Source
FAA	Federal Aviation Administration
GCU	Generator Control Unit
GEN	Generator
HIRF	High-intensity radiated field
ICD	Interface Control Documents
LRU	Line Replaceable Unit
NM*FM	First blade passage main rotor frequency, Hz
PDR	Preliminary Design Review
PDU	Power Distribution Unit
SDR/SFR	System Design Review / System Function Review
SRR	System Requirements Review
TRR	Test Readiness Review
W/C/A	Warning/Caution/Advisory
WOW	Weight on Wheel

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CHAPTER 1

INTRODUCTION

When electrical power distribution was first used, direct current transmission was provided. However, an efficient transmission to long distances could not be realized due to the loss of electrical power due to the increase in the length, material resistance, current and decrease in the cable cross-sectional area of the cables used. Alternatively, in Alternating Current power transmission developed by Nikola Tesla and George Westinghouse, they reduced the power distribution losses over long distances by increasing or decreasing the voltage value with transformers. This situation can be considered as a development that paves the way for the efficient management of electrical power. Power distribution systems established with the development of technology are used in many areas today. Power distribution units are units developed to provide maximum efficiency from the energy produced in power systems. Switching equipment and generator controls, which enable good planning and management of power systems, have made great progress with technology. With the advancement of telecommunications and information technologies, remote control of power systems has also been made possible. Typically, electrical power distribution units consist of electrical elements, cables, enclosed in a shielded enclosure. These equipments are designed to allow easy access and intervention to the internal components when necessary and to protect the internal components from external influences such as exposure to extreme heat, water, dust, dirt and vibration. Today, control and distribution of electrical power systems are the basis of many systems such as computers, refrigerators, air conditioners, industrial machines, airplanes, ships.

To be specific, there are several types of rotorcrafts so there are many different types of DC PDUs because a PDU is most likely unique to the allocated rotorcraft due to the specific requirements. There are multiple reasons for this uniqueness such as architecture of the electrical system, human factors, location of the PDU on the helicopter, humidity, sand-dust, explosive atmosphere, EMI-EMC, etc. All reasons will be covered in this thesis with assumptions related to the subjects.

1.1 Development and Literature Review of PDU

With the fast improvement on technology, electronics is clearly very important in our daily and social lives and also in our jobs and day by day it will be getting more important. On the other hand, electronics for all modern aircrafts cannot be described with “important” word, it should be mentioned as a “critical” issue. There are some papers on the development of PDU and in this section these papers will be mentioned.

In this study, the Hybrid Energy Storage System (HESS) system, which was developed to prolong the life of battery packs, is proposed for the problem of battery capacity deterioration caused by high current magnitudes and current changes that may be encountered in electric vehicles. This system incorporates a multi-port DC-DC converter for the management and control of electrical energy between the battery pack, ultracapacitor and output ports. In the proposed energy management strategy for the HESS system, the ultracapacitor assembly acts as a temporary power source to smooth the battery current and prolong battery life. The performance of the developed Energy management system has been simulated on HWFET (Highway Fuel Economy Test Cycle) and Matlab/Simulink platforms and it has been seen that it is effective in prolonging the life of the battery pack of electric vehicles. [1]

This article describes an Electrical power distribution unit design that enables Remote Control with advanced RF features. It was developed in order to avoid the negative effects of power supply instability encountered in underdeveloped countries. In cases where manual switching between power sources is difficult, it is controlled stably to allow automatic switching. It is aimed to eliminate the instability of the system caused by irregular currents and to obtain a constant and uninterrupted power supply. [2]

The power system used in space vehicles is being developed as radio-electronic and electrical systems with different features and standards than many other power systems. The system is expected to be reliable and noise resistant. A typical and commonly used power distribution system in a spacecraft includes solar panels, batteries, and controllers used to distribute power between payloads. Different approaches and software are designed for the coordination of the power network, as the protective filters placed in order to prevent malfunctions that may occur in the spacecraft will increase the load mass and the weight of the spacecraft and reduce the noise immunity and reliability of the system. [3]

Power distribution units in aircraft must have the capability to meet high expectations. It should be able to supply electricity to all systems, especially flight critical systems. It should be able to respond immediately to any change when necessary and its reliability should be high. In this study, the real-time frequency domain of an interconnected power system is defined and stability analysis is made. [4]

In this study, solutions have been proposed to improve power converters, which cause the destabilization of a power electronics-based distribution system on an electric ship. Accordingly, one of the things to be done to ensure system stability is to ensure that the converters in the system adjust their local controller in accordance with the developing changes. To achieve this, it is necessary to add controllers that can define changing transfer functions and impedances to the circuit and can be activated to meet user-specified constraints. In this study, simulated tests were carried out on the Matlab/Simulink platform in order to control the system performance. It has been observed that the developed control adaptation ensures that the system output response is very slightly damped and oscillating. This is an important criterion that shows the effect of the applied controller design on the system. [5]

It is a study to develop the function of controlling the high output power of the new generation NODE type junction box system with high power consumption developed for research activities on the ocean floor. In this study, it is aimed to protect the input power regardless of the state of the output electricity by providing a stable power consumption and equipped with a NODE balanced circuit function. In the designed system, the electrical power distribution function is simplified, its efficiency is increased and it is ensured that it does not affect the constant current supply in case of possible power fluctuations. FET, which is more efficient and sensitive than a Zener diode, is used to consume excess electrical energy. [6]

In this study, the Electric Power Distribution Box (EPDB) designed in accordance with aviation standards for small aircraft in the CS-23 category is explained. With the developed EPDB, many combinations of the Electric Power System used in the entire aircraft are integrated. The main function of EPDB used in the system is intelligent electrical energy distribution. The system is designed as dual channel. There are a total of two sets of EPDB distribution boxes allocated to the power supply system on both sides of the aircraft. In the system, power supplies are connected to the input of EPDB and loads are connected to its output. For the distribution of electrical energy, loads are categorized according to their importance. The system is allowed to automatically start the engine when the appropriate power source is connected, disconnect the power supply when the Ground Power Unit is connected, and disconnect Non-Basic loads when necessary. The system also provides significant loads in terms of power when the necessary conditions are met. Automatic processes in the system have reduced the workload of the pilot and increased the reliability of the system. [7]

Increasing the electrical equipment of aircraft will reduce the operating, maintenance and availability costs of aircraft and the weight of the aircraft. It offers greater reliability than hydraulic systems, as electrical equipment can be easily isolated from subsystems in case of faults and is possible through behavioral modeling of systems combined with fault detection algorithms. This increases the usability of aircraft. However, more electricity planes have brought with them complex network architectures. Various innovative architectures have been put forward for this. This study proposes an integrated optimal approach for power integration by increasing the power densities of the systems and optimizing the aircraft system. [8]

The architecture of electrical power systems is critical to subsystem voltage, current ratings, structural and thermal feasibility, safety, usability, size, weight, power and energy efficiency, reliability, and energy usage cost. In this article, an alternative method to the existing complex designs for electrical power systems is proposed, thus simplifying the design problems by dividing the system into smaller, well-defined and optimized subsystems. Several large-signal averages, small-signal simulations, and an experimental result are included in the study. [9]

In this study, hydraulic–electric power units (HEPU) design, which is developed to provide constant pressure hydraulic power and constant voltage electrical power to hydraulic-based mobile robots, is explained. The hydraulic system is used for the movement of the robot, while the electrical power controller is used for system sensors and other peripherals. In the developed HEPU design, it has been seen that gasoline is the fuel with the most suitable specific energy in order to meet the high electrical and mechanical requirements of mobile robotic devices for a long time. Ragone graphics were used to determine the design to be used to provide the desired uptime. [10]

In this study, a DC distribution system is simulated for a small-scale ship from industrial power systems that need reliable power supply. The focus is on the interaction between "AC to DC" and "DC to AC" converters. System performance has been tested under Generator Dropout, Ground Fault and Short Circuit on DC Bus occurrence conditions. In the study, it has been shown that the systems to be developed specific to the failure that may occur are more efficient. [11]

1.2 Characteristics of PDU

As it was mentioned above on the abstract, PDU is critical for modern helicopters on their missions. PDU shall be designed specifically to a helicopter and “One solution for all” idea cannot be applicable for PDU because of specific needs for helicopter himself and subsystems. These specific needs, which are basis of defining characteristics of PDU, are defined, controlled and managed by systems engineering with requirements.

To design a PDU, first, electrical scheme shall be clearly defined otherwise PDU will not be integrated efficiently. Even in worst case, PDU may not be integrated because of the mechanical and electrical connections and interfaces. PDU shall be designed by taking these steps into consideration;

i) Type of the helicopter (SAR, combat, sea platform, utility, training etc.)
ii) Engine Count
iii) Systems that will be used on helicopter
iv) Electrical System Architecture
v) Electrical Power Source
vi) Location on the Helicopter
vii) Expected Performance
viii) Physical Shape

ix) Mechanical Connections and Interfaces

x) Human Factors

xi) Materials and Processes

xii) Accessibility

xiii) Service Life

xiv) Environmental Usage of Helicopter

xv) Safety

xvi) Testability

xvii) Maintainability

xviii) Certification

xix) Logistic Support

xx) Possible Future Needs (Assumption)

1.2.1 Types of PDU

PDU on an aircraft can be used for AC and DC systems. In this thesis, 28 VDC PDU will be mentioned.

- AC PDU: Due to MIL-HDBK-704, there are different types of AC voltage regulations that are listed below.
  - Single Phase, 400 Hz, 115 V (MIL-HDBK-704-2)
  - Three Phase, 400 Hz, 115 V (MIL-HDBK-704-3)
  - Single Phase, Variable Frequency, 115 V (MIL-HDBK-704-4)
  - Three Phase, Variable Frequency, 115 V (MIL-HDBK-704-5)
  - Single Phase, 60 Hz, 115 V (MIL-HDBK-704-6)
- DC PDU: Due to MIL-HDBK-704, there are two different types of AC voltage regulations that are 270 VDC (MIL-HDBK-704-7) and 28 VDC (MIL-HDBK-704-8). For helicopters, most common usage is 28 VDC.

1.2.2 Working Principle of the System

It is a fact that PDU is not the power source of the helicopter. PDU is distributing the electrical power that is created by generator and controlled (and rectified) by generator control unit (GCU). After taking the electricity from GCU, PDU transfers the power to secondary distribution units which are most likely Circuit Breakers or Fuses with respect to the BUS connection. After secondary distribution units, equipments and/or systems will be energized.

1.2.3 Operational Concept of Helicopter

Helicopter may be used for several purposes;

- Combat
- SAR (Search and Rescue)
- Military Tactical
- Cargo Transportation
- Health (Ambulance)
- Farming
- Transportation (Commercial, Military or VIP)

All of these different concepts, some systems may remain the same if a concept change is needed but some systems must be changed, removed or added on the helicopter. According to the size of the change, most likely, electrical system is changed. Especially if a new system is needed, electrical power system must be changed. That is why a PDU must have been designed with extra capacity for estimated possible future needs.

CHAPTER 2

SYSTEMS ENGINEERING ROLE ON DESIGN OF HELICOPTER ELECTRICAL POWER DISTRIBUTION UNIT

System engineering is “An interdisciplinary approach and means to enable the realization of a successful system…considering both the business and technical needs of all customers with the goal of providing a high quality product that meets user needs.” – INCOSE (International Council on Systems Engineering)

The proper way to manage the design process of a PDU for a rotorcraft is to define requirements correctly. While deciding and creating the requirements, verification methods, location, criteria, procedure and environment must be determined.

To be successful from the beginning of the design phase to the end of the production of PDU, also a Systems Engineering Milestone Path, which is given below, must be followed:

- System Requirements Review (SRR)
- System Design Review / System Function Review (SDR/SFR)
- Preliminary Design Review (PDR)
- Critical Design Review (CDR)
- Test Readiness Review (TRR)

Additional path level may be considered due to the Contract Statement of Work with the corresponding sub-contractor.

Also there will be some baseline process from beginning to end of the production. This baseline is given with Figure 2.1.

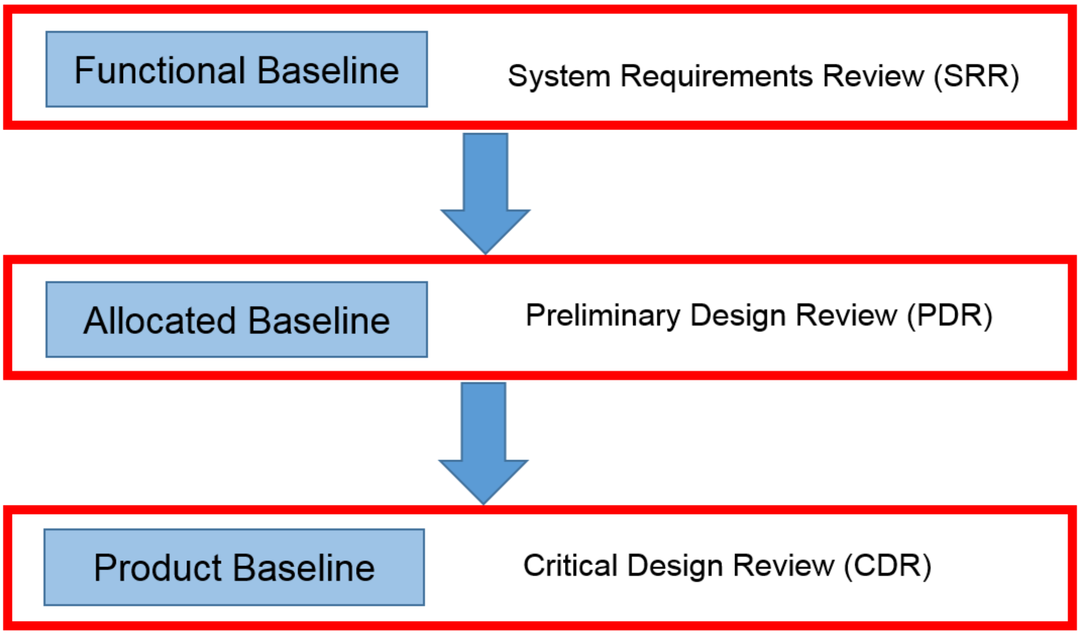

Figure 2.1 Baseline Path

From the beginning of all design process, documentation and configuration must be strictly controlled.

2.1 Requirement

Requirement is "A statement that identifies a product or process operational, functional, or design characteristic or constraint, which is unambiguous, testable or measurable, and necessary for product or process acceptability. (ISO 26702)". Requirements are very important because many projects fail due to the;

- Inattentive requirements
- Missing requirements
- Underestimated needs
- Requirements that are impossible to do
- Continually changed requirements
- Incorrect requirements

- Inconsistent requirements

- Non-verifiable requirements

- Incomplete requirements

Requirements must be prepared with a direct statement. For example, in such a specific requirement of “The PDU shall supply the aircraft’s 28 VDC Power from -40 to +70 degree Celsius”;

- System is defined with “The PDU”

- Verb selection is done with “shall” which means a mandatory need

- Specific function is mentioned with “supply the aircraft’s 28VDC Power”

- Measurable criteria is added to the requirement with “rom -40 to +70 degree Celsius”

Verbs are very important for requirements. “Shall” means “mandatory”, “should” or “may” means preference/depends, “will” means declaration. While writing requirements, instead of “shall not”, “shall inhibit” or “shall prohibited” verbs must be used.

For a perfect requirement set, there must not be any “TBD” (to be defined) word. However, in some cases especially due to uncertain systems or physical installation, TBD is used in requirement set. In these conditions, the best way is to make assumptions.

Every requirement should have a unique “ID” and also “Object Type” should be indicated. In this thesis, ID numbers will be like “CUH_28DCPDU_ATA24_XX”. With this ID;

- CUH means Created Utility Helicopter

- 28DCPDU means 28 VDC Power Distribution Unit

- ATA24 means the ATA 24 Chapter (Air Transport Association chapter 24 is Electrical Power chapter)

- XX means the unique number for the requirement

There are two different “Object Type”;

- “Information” describes the general information about the system that can be used to design the PDU

- “Requirement” is the needed feature or function of the PDU

To make a specific PDU for a specific helicopter, requirements must be prepared with this point of view.

Requirements are driven by

- Regulations

- All Other Systems

- Constrains and Non-Technical (Program/Project Management) Needs

- Standards

- Specific Customer Needs and Expectations

2.1.1 Regulations

Regulations are only effective if the certification is needed for aircraft. FAA, EASA or Transport Canada are the well-known authorities for certification. These authorities have their own regulations. Most of their regulations are exactly or almost the same.

2.1.2 All Other Systems

To make a proper PDU, preferably all systems but at least majority of the systems must be determined. Without selecting other equipments, estimation is the only chance to start building PDU. For helicopters, especially flight critical equipments or systems must be determined from the beginning of the helicopter design process or at least estimated power needs must be precise.

2.1.3 Constrains and Non-Technical (Program/Project Management) Needs

Program/project management activities are basically consisting of three important sections. The first one is the budget/cost/profit, the second one is the schedule/time and the third one is regulations/laws. After these important issues, organizational needs also must be considered.

2.1.4 Standards

All aircrafts and their related equipments must fulfill some standards. These standards may change due to aircraft's;

- Type
- Weight
- Operational Concept
- Usage

These standards must be chosen wisely because due to standards, equipment's tests, cost, analysis and even possibility to be built will be changed.

2.1.5 Customer/User Needs and Expectations

Customer/User Needs and Expectations generally is about the equipment's working principle, cost and maintainability. If customer has his own operational concept of the helicopter, customer most probably will need;

- How will the system or equipment work
- What functions will the system have?
- Which environmental conditions will effect and how will the system respond during operation?

- How much is the system or equipment cost?
- When will the system be ready?
- How will the customer be trained about the system or equipment?
- How will the customer get related documents? (e.g. ICD, EIRD)

2.1.6 Technical Requirements

Technical requirements gives technical expectations for the related system such as;

- Operational
- Functional
- Performance
- Information
- Installation

Product Integration and System Integration are also two important terms which are critical for the perfection of the PDU. Product Integration for PDU means combining all the components to build the functionally working PDU as a complete product when assemble phase is completed.

System Integration for PDU means after installation of all equipments on the helicopter, all systems and subsystems get their power from PDU properly. As a natural fact, integration happens throughout the design process, not just at the end. Design of any product including PDU cannot be completed without following these two important issue.

2.2 Configuration Control and Documentation

2.2.1 Interface and Configuration Control

During the design of PDU, Interface Control and Configuration subject must be followed because;

- Control and configuration of interfaces is essential
- Coordination and communication about interfaces between the various design teams is crucial for integration and the design process
- Generally controlled through ICDs (Interface Control Documents)

2.2.2 Documentation

ICD document cannot be obtained without Interface Control and Configuration method. ICD document;

- Describes the interface(s) between systems or subsystems
- Describes all inputs and outputs for a system and also potential inputs and outputs
- Defines interfaces and interface design in detail

Without ICD document, not only the production of PDU is failed, also the troubleshooting and fault isolation cannot be done because the traceability of a fault cannot be completed as it was written as “some documents (schematics, wiring diagrams, aircraft fault isolation book, system description document, data module) must be supplied for fault detection and isolation.” [12]

2.3 Verification and Validation

2.3.1 Verification Method

Verification method is for the evaluation and proof of the requirements.

- Similarity can only be done if there is another equipment that already passed the same tests with the same material, size or production type.

- Analysis is a common and trusted method and can be used for many purposes especially life cycle, fracture or electrical load.

- Demonstration is a method which can show the system's or equipment's performance with a prototype or mass production.

- Test method may be the most expensive and time taking method but its results and data are certain.

2.3.2 Verification Location

Verification location is where verification of a requirement occurs. Verification can be done on the aircraft, in a laboratory or with technical analysis.

2.3.3 Verification Criteria

Verification criteria is the specific observed values which provide proof of clear evidence that the requirement has been met.

2.3.4 Verification Procedures

For each verification method, ATP (Acceptance Test Procedure) must be prepared. In these ATPs, listed below subjects must be clearly identified;

- Purpose

- Prerequisites

- Before-During-After test actions

- Pass-Fail status

CHAPTER 3

PDU REQUIREMENTS

3.1 PDU General Characteristics

3.1.1 General Description

In this section, electrical system is generally described with its components.

DC System will have three different power sources. (I)

- One external power supply
- One engine driven generator
- One battery

One and only PDU will provide 28VDC to the system (I)

3.1.2 System Architecture

Electrical power distribution system is described in this part. Also type and number of electrical buses, component requirements are stated in this section.

Electrical Distribution Architecture will be “Generator>GCU>PDU”. (I)

PDU shall have three Bus (Main Bus, Essential Bus and BAT Bus) (R)

Main Bus: The main bus supplies the systems necessary in normal operation described in MIL-STD-704F. (R)

Essential Bus: The essential bus supplies the power to selected systems necessary for safe flight, landing and some selected mission equipment in case of generator or GCU partial failure (because of power drop). (R)

BAT Bus: The battery bus supplies the power to selected systems necessary for safe flight landing in case of generator or GCU complete failure (R)

All safety necessary components shall be inside the PDU, no component shall be installed outside of the PDU to make system work. (R)

All components and equipments that are used inside the PDU shall have aerospace certification. (R)

All components that are used inside the PDU shall inhibit require an end-user certification. (R)

All components (circuit breakers, fuses, relays, contactors etc.) shall be automatically working unless the system is controlled manually by the user. (R)

The PDU shall indicate its status with analog or digital signals. (R)

The electrical ratings all contacts of contactors shall be suitable with the load ratings of the system. (R)

None of any single failure (fire, cable cut, one component failure, Bus failure etc.) shall affect all system. (R)

Electrical Load Needs are given below on Table 3.1 (I)

Table 3.1 Electrical Load Needs

PDU BUS NAME	ELECTRICAL LOAD NEED
Main Bus	120A
Essential Bus	22A
Battery Bus	4A

Main Bus shall supply power to Main CB Panel (30A), Search Light (5A), ECS System (35A) and Targeting System (30A). And except these equipments/systems, 20A shall be in capability for possible future usage. (R)

Essential Bus shall supply power to Essential CB Panel (19A). And except Essential CB Panel, 3A shall be in capability for possible future usage. (R)

BAT Bus shall have the capability to power the BAT CB Panel and Essential CB Panel with total load of 26A. (R)

BAT Bus shall be connected directly to main BAT over a BAT contactor. (R)

BAT Contactor may be located outside of PDU. (R)

Main BAT shall supply power to only BAT Bus during GEN and/or GCU failure. (R)

External Power shall be connected on ground. (R)

ECS and heater systems shall inhibit be operational at the same time. (R)

Busbars shall have transfer capability of %20 higher than given ampere values. (R)

Busbars shall stand in at least 280°C. (R)

All materials shall be designed in accordance with ASTM-B-152. (R)

Harness shall be installed with respect to SAE AS 50881 (R)

Insulation on electrical wire, cable or busbars shall be self-extinguishing during the 60-degree test. The average burn length may not exceed 3 inches and when the flame source removed, the flame time shall inhibit exceed 30 seconds due to SAEAS50881. (R)

3.1.3 Location on helicopter

The location of the PDU is crucial because it will affect environmental and E3 requirements. Furthermore, electrical wiring/harness design will also be affected by the location of the PDU because the more PDU is located far from GCU, the more cable diameter shall be used for power cables, which will cause the increase of the weight of the harnesses.

PDU will be located in the AFT Section close to GEN and GCU. (I)

BAT will be located in the AFT Section avionics bay door and as close as possible to the PDU. (I)

BAT contactor will be located as close as possible to the BAT. (I)

3.2 Functional and Performance Requirements

In this part, detailed functional and performance requirements are stated such as operational concepts (normal, battery, engine start, and short circuit), interface characteristics, physical and weight requirements, human factors, materials and life target. Each and every title will be explained in detail.

PDU shall distribute all electrical power that comes from GEN and BAT. (R)

PDU shall have the capability to protect the GCU and the GEN while external power or BAT is providing power. (R)

PDU shall provide signals (analog and digital) for external power feedback and monitoring, during external power is providing power. (R)

PDU shall provide signals (analog and digital) for BAT power feedback and monitoring, during external power or BAT or GEN is providing power. (R)

PDU shall provide signals (analog and digital) for GEN power feedback and monitoring, during GEN is providing power. (R)

PDU shall provide signals (analog and digital) for BAT power feedback and monitoring, during external power is providing power and GEN is working during ground start or ground tests. (R)

PDU shall provide all busbar voltages and amperes signals (digital). (R)

Electrical characteristics of PDU and BAT contactor shall be compatible with MIL-STD-704F. (R)

PDU shall have the capability to receive 28,7 VDC electrical power with a continuous rating of 200A, a two-minute rating of 300A and a five second rating of 380A from GCU. (R)

PDU shall have the capability to receive 24 VDC electrical power from BAT. (R)

PDU shall have the capability to receive 28, 7 VDC electrical power with a continuous rating of 240A from EXT whether GCU is operational or not. (R)

PDU shall inhibit the power source change (between BAT, GEN and EXT power sources) more than 50 milliseconds as pointed in MIL-STD-704F. (R)

3.2.1 Normal Operation

Normal operation means aircraft is energized by the main power source which is GEN. GCU will transfer the electrical power from GEN to PDU. In this case, there is no W/C/A expected from electrical system.

GCU and GEN, or EXT are working properly as expected in Normal Operation mode described in MIL-STD-704F. (I)

Main Bus, Essential Bus and Battery Bus shall be energized from GCU during normal operation. (R)

PDU shall provide power from GCU to the BAT in normal operation to charge the BAT. (R)

PDU shall provide power from EXT to the BAT in normal operation to charge the BAT. (R)

3.2.2 Battery Operation

In battery operation, there is a failure in at least one of the equipments of GCU, GEN or partially PDU so battery takes the responsibility to energize the selected equipments (equipments on the battery and essential bus).

GCU and EXT are inoperative and the only power source will be BAT in Battery Operation mode. (I)

In BAT mode, PDU shall provide the power that is received from BAT to BAT bus and ESS bus. (R)

During flight (when helicopter is not in WOW mode), PDU shall switch to battery operation after GCU failure. (R)

On ground (when helicopter is in WOW mode), PDU shall inhibit to switch to battery operation after EXT failure. (R)

On ground (when helicopter is in WOW mode), PDU shall provide power to ESS Bus and BAT Bus when the only power source is BAT (EXT is not connected and GCU is not operational). (R)

PDU shall inhibit to provide power to Main Bus. (R)

3.2.3 Engine Start Operations

Aircrafts shall start their engines before takeoff by using via external power or with battery. Some aircrafts may not have both operations but shall have at least one of them. Generally, engine start with external power is not common because for this feature, aircraft's weight has to increase with the components that are needed for the external power operation such as contactors, cables, external power connectors.

3.2.3.1 External Power Operation

In our aircraft, external power source can be used to start engine. During external power operation, no other source is needed as an electrical power source.

On ground (when helicopter is in WOW mode), PDU shall stop using the BAT as the power source automatically when EXT is connected and operational. (R)

EXT shall be controlled manually with a switch in normal operation mode. (R)

EXT shall be controlled automatically with respect to under and over voltage operation limits. (R)

EXT shall provide under and over voltage and reverse polarity protections with respect to MIL-STD-704F. (R)

EXT shall provide under and over voltage and reverse polarity protections with respect to MIL-STD-704F. (R)

Engine shall be started with EXT. (R)

3.2.3.2 Battery Start Operation

In this condition, without external electrical power source, engine can be started with the battery.

Engine shall be started with BAT. (R)

During the engine start with BAT, ESS Bus shall be supplied from BAT. (R)

PDU shall control the electrical power during battery start operation for main, essential and battery buses to avoid unwanted voltages. (R)

PDU shall control the electrical power during battery start operation for main, essential and battery buses to avoid unwanted voltages. (R)

3.2.4 Short Circuit Operation

In this section, details are given for the short circuit operation. PDU shall have the capability for short circuit analysis and with this analysis bus safety is provided.

PDU shall do short circuit analysis and protection for main, essential and battery bus for all operation modes. (R)

The short circuit analysis shall be provided considering the cable resistance given in Table 3.2. (R)

Table 3.2 Short Circuit Resistance values

Location	Requirement (mΩ)
GEN to GCU	4,27
GCU to PDU	0,52
GCU to Earth Ground	0,27
PDU to Battery Contactor	2,652
Battery Contactor to Earth Ground	0,57

Cable between PDU and Battery Contactor shall be chosen in accordance with MIL-STD-704F and SAEAS50881. (R)

PDU shall isolate a fault occurred on any bus for bus safety. (R)

PDU shall isolate a fault less than 7 seconds in accordance with MIL-STD-704F. (R)

3.2.5 Interface Characteristics

With interface details, observation and control of the PDU is fully obtained. Interfaces shall be detailed as much as possible for comprehensive control and evaluation.

All interfaces will be given as requirement. (I)

PDU shall receive EXT ON/OFF control signal (discrete; GND for active and OPEN for inactive, continuous signal) from helicopter by a switch or software. (R)

PDU shall provide GEN's status signal (discrete; 28 VDC for active and OPEN for inactive, continuous signal) to helicopter. (R)

PDU shall provide GCU's status signal (discrete; 28 VDC for active and OPEN for inactive, continuous signal) to helicopter. (R)

Battery Contactor shall receive battery ON/OFF control signal (discrete; GND for ON and OPEN for OFF, continuous signal) from helicopter. (R)

PDU shall provide GCU's current value (analog; standard 25mV, every 0,2 second period) to helicopter. (R)

PDU shall provide GCU's voltage value (analog; from 0 to 32 VDC, every 0,2 second period) to helicopter. (R)

PDU shall provide BAT's current value (analog; standard 25mV, every 0,2 second period) to helicopter. (R)

PDU shall provide BAT's voltage value (analog; from 0 to 26 VDC, every 0,2 second period) to helicopter. (R)

PDU shall provide EXT’s voltage value (analog; from 0 to 32 VDC, every 0,2 second period) to helicopter. (R)

PDU shall provide main bus voltage value (analog; from 0 to 32 VDC, every 0,2 second period) to helicopter. (R)

PDU shall provide ESS bus voltage value (analog; from 0 to 32 VDC, every 0,2 second period) to helicopter. (R)

PDU shall provide BAT bus voltage value (analog; from 0 to 32 VDC, every 0,2 second period) to helicopter. (R)

PDU shall receive engine start command signal from helicopter’s related panel and transmit the signal to GCU (discrete; 28 VDC for ignition and OPEN for inactive, for 5 seconds) to helicopter while BAT is the power source. (R)

PDU shall receive engine start command signal from helicopter’s related panel and transmit the signal to GCU (discrete; 28 VDC for ignition and OPEN for inactive, for 5 seconds) to helicopter while EXT is the power source. (R)

PDU shall provide voltage from EXT or BAT to GCU. (R)

PDU shall provide voltage from EXT to BAT. (R)

PDU shall provide voltage from GCU to main and ESS bus. (R)

PDU shall provide voltage from BAT to battery bus while BAT is the only power source of the helicopter. (R)

3.2.6 Physical Requirements

Physical requirements and physical interfaces (electrical connectors, fasteners etc.) shall be described at least generally. Giving a specific part number or giving too much detail about these components may result with big problems such as material incompatibility, safety issues or qualification test failures such as vibration.

Center of gravity, mass and inertia values of PDU shall be provided. (R)

Mechanical drawings and interfaces (fastener types, quantities etc.) of PDU shall be provided. (R)

All mechanical screws shall be marked with lock tie at the end of the assembly. (R)

Installation of bonding jumper information shall be provided if it is needed for electrical bonding requirement. (R)

The connector types of PDU shall be compatible with MIL-C-38999 Series III. (R)

Heat dissipation values of PDU and Battery Contactor shall be provided. (R)

3.2.7 Weight Requirements

Weight is one of the most important issue on aircrafts, especially in helicopters because some features are directly depends on useful load. By this reason, weight shall be limited for every equipment. To make a meaningful weight limitation, design background or at least a sample is crucial. Aiming an impossible weight limitation will result with non-complied requirement. Weight requirement may be revised due to the test results.

The weight of PDU shall be less than 9,9 kg including bonding strap (if any) and all installation parts (screws, straps etc.). (R)

The weight of BAT Contactor shall be less than 0,5 kg. (R)

The weight of PDU shall inhibit more than 9,9 kg. (R)

3.2.8 Dimensional Requirements

During the design phase of the helicopter, it is needed to place all the equipments or at least dedicate a space for equipments to complete space allocation. This space allocation may be easy for COTS equipments because their dimensions are certain. However, dimensions of equipments', which are under development phase such as PDU, will be predicted or shall fit into a dedicated space. By this reason, dimension limitations should not be exceeded.

The maximum dimensions of PDU shall be less than or equal to the values given below as 100mm x 150mm x 350mm. (R)

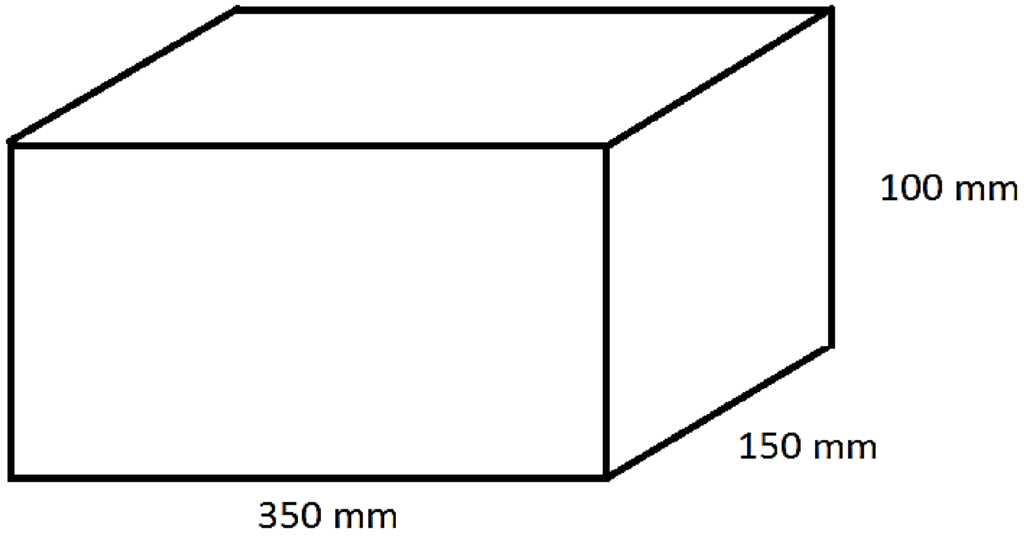

Figure 3.1 PDU Dimensions

3D model of PDU shall be provided. (R)

3.2.9 Human Factors Requirements

This section is especially for maintenance and in service usage.

The label abbreviations on PDU shall be compatible with standards MIL-STD-783, DEF STAN 00-970 Part 7/1 and SAE ARP 4105. (R)

All letters on PDU's labels shall be capital and shall be seen clearly from a safe distance. (R)

3.2.10 Materials and Processes Requirements

To design a PDU regarding location and working conditions, material and process shall be taken into consideration. To complete the qualification period and to have the desired equipment successfully, materials and their manufacturing processes shall be selected correctly. Therefore, to achieve the correct selection, requirements shall be identified carefully.

All materials on PDU shall meet all operational and environmental performance requirements. (R)

All materials on PDU shall be processed and protected to resist corrosion. (R)

Protective coating materials and finishes shall provide abrasion resistance. (R)

Usage of magnesium alloy material shall be inhibited. (R)

If there is no protection for electrolytic corrosion in accordance with MIL-STD-889, then dissimilar metals shall be inhibited to contact each other. (R)

All materials except metals on PDU shall be moisture resistant. (R)

To reduce the both costs of production and life cycle and to increase the possibility of supply of the material, recycled or recovered materials shall mostly be used. (R)

3.2.11 Internal Parameter Accessibility

This section is used to prevent the problems and faults during maintenance and to make the troubleshooting easy.

If any component or part is needed to be visible (current limiter, circuit breaker etc.) shall be physically visible or its status shall be provided. (R)

3.2.12 Life Target for Design

This section is used to prevent the short life time of the equipment.

PDU shall be inhibited to have a life time unless a component failure. (R)

3.3 Environmental Requirements

Environmental requirements are determined due to the working conditions (both for equipment and helicopter) and the location of the equipment on the helicopter. During determination period of environmental requirements, RTCA DO-160 (for civil aircrafts), MIL-STD-810 (for military aircrafts) or DEF STAN 00-35 (for military aircrafts) shall be used. In addition, in some specific cases such as EMI/EMC, some documents (MIL-HDBK-310, STANAG-2895, STANAG-4370, MIL-STD-461 and/or MIL-STD-464) are used as support.

PDU shall function normally and without degradation under any specified environmental conditions. (R)

PDU shall comply with the environmental qualification related paragraphs of CS-27. (R)

3.3.1 Temperature

Materials can be changed due to some conditions such as temperature. To be sure that the equipment is fully operational with respect to the changing temperature, tests written below shall be completed.

PDU and BAT Contactor shall comply with the environmental qualification with DO 160G, Section 4, Category B1 requirements. (R)

Environmental Tests	Cat							
	A				B			
	1	2	3	4	1	2	3	4
Operating Low Temp. Degrees C Paragraph 4.5.2	-15	-15	-15	-15	-20	-45	-45	Note (4)
Operating High Temp. Degrees C Paragraph 4.5.4	+55	+70	+70	Note (3)	+55	+70	Note (3)	Note (4)
Short-Time Operating Low Temp. Degrees C Paragraph 4.5.1	-40	-40	-40	Note (3)	-40	-45	Note (3)	Note (4)
Short-Time Operating High Temp. Degrees C Paragraph 4.53	+70	+70	+85	Note (3)	+70	+70	Note (3)	Note (4)
Loss of Cooling Test Degrees C Paragraph 4.5.5	+30	+40	+45	Note (3)	+30	+40	Note (3)	Note (3)
Ground Survival Low Temperature Degrees C Paragraph 4.5.1	-55	-55	-55	Note (3)	-55	-55	Note (3)	-55
Ground Survival High Temperature Degrees C Paragraph 4.5.3	+85	+85	+85	Note (3)	+85	+85	Note (3)	+85
Altitude Thousands of Feet Thousands of Meters Paragraph 4.6.1	15 4.6	15 4.6	15 4.6	15 4.6	25 7.6	25 7.6	25 7.6	25 7.6
Decompression Test Paragraph 4.6.2	Note (1) (4)	Note (1) (4)	Note (1) (4)	Note (1) (4)	N/A	N/A	N/A	N/A
Overpressure Test Paragraph 4.6.3	Note (2)	Note (2)	Note (2)	Note (2)	N/A	N/A	N/A	N/A

Figure 3.2 Environmental Tests Categories

3.3.2 Altitude

One of the other reasons about the change on the physical conditions of equipments is altitude. PDU shall be tested on the worst case condition which is the highest level of the helicopter's altitude limit.

PDU and BAT Contactor shall work up to 25000ft altitude. (R)

3.3.3 Temperature Variation

This section is connected to at least two different conditions. First one is the helicopter's ascend performance and the second one is the overall temperature change in the current location.

PDU and BAT Contactor shall comply "Category B - For equipment in a non-temperature-controlled or partially temperature controlled internal section of the aircraft: 5 degrees' Celsius minimum per minute" according to DO 160G. (R)

3.3.4 Humidity

Humidity basically causes corrosion and corrosion may change the equipment's case or the components inside the equipment. So humidity tests shall be defined to make sure that PDU is fully operational on helicopter.

PDU and BAT Contactor shall comply "Category B - Severe Humidity Environment" according to DO 160G section 6.3.2. (R)

3.3.5 Operational Shock and Crash Safety

This section is generally about the PDU's strength to helicopter's operational shocks and to be sure that after any crash incident, PDU will not cause any damage to critical systems such as fuel system and also pilots, crew and passengers.

PDU and BAT Contactor shall be tested for standard operational shocks according to DO 160G section 7.1.1. (R)

3.3.6 Vibration

Vibration tests depend on the location of the PDU in the helicopter. Especially in helicopters, there is a standard vibration that comes from rotor blades which shall be taken into consideration.

PDU and BAT Contactor shall be tested for Robust Vibration Test Category R according to DO 160G section 8.2.1.2. (R)

Category	Aircraf t Type	Standard Vibration	High Level - Short Duration Vibration	Robust Vibration
R or U	Helicopter	NA	NA	Sine-On-Random; 2 Hrs at Endurance levels plus dwells (max of 4 dwells, max of 3 hours total test time) and performance test (minimum of 10 minutes) at beginning and end of test period (repeat in all 3 axes). Test repeated 3 times for Category U.

Figure 3.3 Robust Vibration Test Category

Main rotor's first blade passage source frequency (NM*FM) is 22.1 Hz and tail rotor's frequency is 78.6 Hz at %100 RPM. Harmonics are listed below for source frequencies: (I)

Table 3.3 Main and Tail Rotor Vibration Assumptions

	Main Rotor [Hz]	**Tail Rotor [Hz]**
Fundamental	4.8	15.7
NM*FM	22.1	78.6
1st Harmonic	44.2	157.2
2nd Harmonic	66.3	235.8

PDU and BAT Contactor location shall be taken as FUSELAGE. (I)

AIRCRAFT TYPE	TEST CATEGORY	AIRCRAFT ZONE						
		1	2	3	4	5	6	7
		FUSELAGE	INSTRUMENT PANEL, CONSOLE & EQUIPMENT RACK	NACELLE & PYLON	ENGINE & GEAR BOX	WING & WHEEL WELL	LANDING GEAR	EMPENNAGE & Fin Tip
1. Helicopters		VIBRATION TEST CURVES (2)						
(Reciprocating & Turbojet Engines)	R or U (1)	G	G	H	I			J
	U2 (1)	F & Fl	F & Fl					

Helicopter Zone Vibration Test Frequencies						
Zone/Test Curve	la/G	lb / G	2 / G	3 / H	4 / I	7 / J
(1) Test Frequencies fn	Fuselage	Tail boom	Instrument Panel Console & Equipment Rack	Nacelle & Pylon	Engine & Gear Box	Empennage, & Fin Tip
II	NMxFM	NmxFm	NmxFm	NmxFm	NmxFm	NmxFm
12	2xNMxFM	2xNMxFM	2xNMxFM	2xNMxFM	2xNMxFM	2xNMxFM
13		NTxFT		FE	FE	NTxFT
14		2xNTxFT		FG	FG	2xNTxFT

Figure 3.4 Helicopter Zone Vibration Test Frequencies

3.3.7 Explosive Atmosphere

That section is also depends on the PDU location on the helicopter. These explosive atmosphere tests are defined for the possible contact of the PDU and flammable liquid or vapor such as hydraulics oil or fuel.

PDU and BAT Contactor shall be tested for Category E according to DO 160G section 9.3.2. (R)

3.3.8 Waterproofness

This test is for only if PDU is not hermetically sealed.

PDU and BAT Contactor shall be tested for Category R requirements according to DO 160G section 10.2. (R)

3.3.9 Fluids Susceptibility

This test is to observe that there is no corrosion or damage with the contact of fluids that are possibly used on aircrafts.

PDU and BAT Contactor shall be tested for Category F requirements according to DO 160G section 11.3. (R)

3.3.10 Sand and Dust

Specifically for PDU, sand and dust exposure may result corrosion and electrical faults.

PDU and BAT Contactor shall be tested for sand and dust conditions for Category S requirements according to DO 160G section 12.2. (R)

C-Spec (MIL-STD 5007C) may be used as reference for information. (I)

3.3.11 Fungus Resistance

Fungus is a result of humidity, temperature and some other factors. Fungus exposure causes almost the same problems with sand, dust and humidity.

PDU and BAT Contactor shall be tested for fungus resistance for Category F requirements according to DO 160G section 13.3. (R)

3.3.12 Salt Fog

Salt fog is mostly faced on sea, lake or ocean based locations.

PDU and BAT Contactor shall be tested for salt fog for Category T requirements according to DO 160G section 14.2. (R)

3.3.13 Power Input

Power input test is to make sure that PDU is operational and does not affect other equipments after electrical power is applied.

PDU and BAT Contactor shall be compatible with MIL-STD-704F military standard. For all components in PDU and PDU’s overall values for; steady state and in-rush power consumption, maximum transient power consumption and its duration and load characteristics shall be provided. (R)

3.3.14 Icing

Icing can be caused by the relation of humidity-temperature, fluid-temperature or humidity-altitude.

PDU and BAT Contactor shall be tested for icing for category B according to DO 160G section 24.3 (R)

3.3.15 Fire and Flammability

This test is also related to the PDU's location on the helicopter.

PDU and BAT Contactor shall be tested for fire and flammability for Category C requirements according to DO 160G section 26.3.3. (R)

3.3.16 EMI/EMC

For EMI/EMC tests, MIL-STD-461 and MIL-STD-464 can also be used as support documents.

PDU and BAT Contactor shall be tested for magnetic effects for category B according to DO 160G section 15.1 (R)

PDU and BAT Contactor shall be tested for voltage spike for category B according to DO 160G section 17.2 (R)

PDU and BAT Contactor shall be tested for audio frequency conducted susceptibility for category B according to DO 160G section 18.A.2 (R)

PDU and BAT Contactor shall be tested for induced signal susceptibility for category B according to DO 160G section 19.2 (R)

PDU and BAT Contactor shall be tested for emission of radio frequency energy for category P according to DO 160G section 21.2 (R)

3.3.17 HIRF (High-intensity radiated field)

With this test, PDU is checked for the direct exposure of the sunlight.

PDU and BAT Contactor shall be tested for HIRF for category R according to DO 160G section 20.2 (R)

3.3.18 ESD (Electrostatic Discharge)

PDU and BAT Contactor shall be tested for ESD for category A according to DO 160G section 25.4 (R)

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

To sum up, there are many titles that PDU must be tested due to the qualification requirements. For a standard helicopter, these requirements are enough to design a PDU. For safety issues, a backup plan, which is BAT is used for power source, is identified if there is a loss or fault on the GEN or GCU. However, on many single electrical power sourced helicopters there is no backup plan for the loss of the PDU itself. As a result, extra protection can be used as the backup battery distribution.

It can be thought that there are two (2) DC Distribution Boxes. The first is the PDU and the second is Battery Distribution Box (BDB). In normal operation and emergency operation conditions, PDU will be active and operated.

In case of PDU failure or ESS Bus (in PDU) failure, BDB will be automatically activated. So, the redundancy of DC power distribution can be provided via BDB.

Priority between Battery Distribution Box (BDB) and PDU is as follows;

- Whenever PDU is active and operated properly, BDB cannot activate.
- And PDU is not active or is not operated properly, BDB is automatically activated.

That is; PDU > BDB

Some flight critical loads have two power inputs. These are primary and secondary power inputs. The primary power input is connected to ESS Bus and the secondary power input is connected to BAT Bus.

When the primary power inputs voltage is in normal condition (as in set values), primary power input is active. When the primary power inputs voltage is not in normal condition (as in set values), secondary power input is automatically active and primary power input is not active.

BATTTERY DISTRIBUTION BOX (BDB)

Battery Distribution Box (BDB) are consists of one (1) power contactor, one (1) bus bar, circuit protection devices (current limiters, circuit breakers), terminal boards and signal connectors.

- Battery Bus Power Contactor (BBPC) connects or disconnects Battery Bus in BDB and Battery in accordance with availability of PDU.

- BAT Bus consists of a copper bar. BAT Bus has one (1) input connection with BBPC and has adequate outputs. BAT Bus provides distribution of critical electrical loads via power outputs.

- Circuit Protection Devices are used for the protection of power cables and can be circuit breakers or current limiters according to current capacity of flight critical loads. In general, when power cable capacity is less than 35 Amp, load cables are preferably protected with circuit breakers. And, when power cable capacity is higher than 35 Amp, load cables are preferably protected with current limiters. Quick or slow types of circuit protection devices can be used.

- Signal Connector is used for the signal connection of BDB.

BBPC is automatically controlled with the availability of PDU. When Essential Bus Power Contactor (EBPC) in PDU is not energized or is not working properly, BBPC coil is energized and BBPC is activated and BB is energized. On the other hand, When Essential Bus Power Contactor (EBPC) in PDU is energized and is working properly, BBPC coil is not energized and BBPC is not activated and so BB is not energized.

STANDARDS

To design, test and produce a PDU, many specifications and standards must be used or at least should be considered as reference. Some standards are used for both military and commercial helicopters. These standards are;

- A416786 (Requirements for the Design and Airworthiness of Composite Aircraft Structure)
- AC 43.13-1B (Chapter 11 - Aircraft Electrical Systems and Acceptable Methods, Techniques, And Practices – Aircraft Chapter, FAA)
- Certification Specifications (such as CS23 for Small Aeroplanes, CS27 for Small Rotorcraft or other related document)
- DO-160 (Environmental Conditions and Test Procedures for Airborne Equipment)
- DO-178 (Software Considerations in Airborne Systems and Equipment Certification) (especially for software used PDU)
- DO-254 (Design Assurance Guidance For Airborne Electronic Hardware) (especially for software used PDU)
- MIL-DTL-38999 (Connectors)
- MIL-HDBK-704-8 (Guidance For Test Procedures For Demonstration Of Utilization Equipment Compliance To Aircraft Electrical Power Characteristics 28 VDC) (for DC PDU)
- MIL-PRF-680 (Degreasing Solvent)
- MIL-PRF-24021 (Electric Power Monitors, External, Aircraft)
- MIL-PRF-83282 (Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base)
- MIL-PRF-87257 (Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base, Aircraft And Missile)
- MIL-STD-461 (Requirements For The Control Of Electromagnetic Interference Characteristics Of Subsystems And Equipment)

- MIL-STD-464 (Department of Defense Interface Standards: Electromagnetic Environmental Effects Requirements For Systems)
- MIL-STD-704 (Aircraft Electric Power Characteristics)
- MIL-STD-783 (Legends For Use In Aircrew Stations And On Airborne Equipment)
- MIL-STD-810 (Environmental Engineering Considerations And Laboratory Tests)
- MIL-STD-889 (Dissimilar Metals)
- MIL-STD-1629 (Procedures For Performing A Failure Mode, Effects And Criticality Analysis)
- MS20659 (Link, Terminal & Connecting)
- SAE ARP 4105 (Abbreviations, Acronyms, and Terms for Use on the Flight Deck)
- SAE ARP 5580 (Recommended Failure Modes and Effects Analysis (FMEA) Practices for Non-Automobile Applications)
- SAEAS50881 (Wiring Aerospace Vehicle)
- MIL-STD-2165 (Testability Program For Systems & Equipment)
- ASTM-B-152 (Standard Specification For Copper Sheet, Strip, Plate and Rolled Bar)
- DEF STAN 00-970 (Defense Standards: General and Operational Requirements)

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EDUCATION

High School **:** Gaziantep Anatolian High School
Bachelor **:** Bilkent University/Electrical and Electronics Engineering
Master Degree **:** Ankara Yıldırım Beyazıt University/Defense Technologies

WORK EXPERIENCE

- Software Engineer (2011 January – 2011 June) at Turkish Aerospace
- Harness and Electrical Design Engineer (2011 June – 2019 January) at Turkish Aerospace
- Harness Design Chief Engineer (2019 January – 2021 May) at Turkish Aerospace
- T129 ATAK Helicopter Project Engineer (2021 May –) at Turkish Aerospace

TOPICS OF INTEREST

- Aviation
- EWIS
- Avionics
- Troubleshooting
- Fault Isolation
- Harness Design
- Avionics Equipment Integration
- Avionics System Test and Evaluation
- Helicopters
- Defense Technologies