

Modeling and Simulation Enabled UAV Electrical Power System Design

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ABSTRACT

With the diversity of mission capability and the associated requirement for more advanced technologies, designing modern unmanned aerial vehicle (UAV) systems is an especially challenging task. In particular, the increasing reliance on the electrical power system for delivering key aircraft functions, both electrical and mechanical, requires that a systems-approach be employed in their development. A key factor in this process is the use of modeling and simulation to inform upon critical design choices made. However, effective systems-level simulation of complex UAV power systems presents many challenges, which must be addressed to maximize the value of such methods. This paper presents the initial stages of a power system design process for a medium altitude long endurance (MALE) UAV focusing particularly on the development of three full candidate architecture models and associated technologies. The unique challenges faced in developing such a suite of models and their ultimate role in the design process is explored, with case studies presented to reinforce key points. The role of the developed models in supporting the design process is then discussed.

INTRODUCTION

Unmanned Aerial Vehicles (UAVs) are being developed for use in both civil and defense applications to capitalize on the potential of autonomous performance. Modern UAV system designs are likely to employ the More-Electric Aircraft (MEA) concept in order to enhance efficiency and improve the availability and maintainability of aircraft systems [1].

These modern UAV systems are likely to be far less dependent on legacy equipment and as such there are fewer constraints on the electrical system design and architecture [1, 2]. The greater flexibility offered creates the opportunity for more integrated electrical system design and greater system optimization. However by relaxing system design constraints, a number of new variables are introduced (e.g. voltage level, system frequency, energy storage usage, load type etc) which presents additional challenges in achieving the optimal design. Given the complexity of this task, accurate network modeling and simulation is an essential element in de-risking the design process for new systems, by enabling the trialing of new technologies and operational concepts. However, the challenges associated with this process for UAV power systems are not well documented in the research literature.

This paper presents the models developed for three candidate twin generator power system architectures (supplying a common set of loads) for a medium altitude long endurance (MALE) UAV application. These architectures form the basis of an investigation into optimal power distribution method and network design.

The paper addresses a number of key modeling issues faced in the development of high fidelity electrical system models and discusses measures taken to overcome these. This includes capturing both small and large time constants in the simulation, such as interactions between electrical components and between the electrical power system and aircraft propulsion system respectively, in a computationally efficient and yet accurate manner. Furthermore, achieving model validation of system-level behavior of a concept-stage

power system, maintaining modeling consistency between candidate architectures (for fair comparative simulation studies) and implementing a flexible modeling framework to facilitate the simulation based investigation of a wide range of scenarios.

With the modeling capability established, methods of analyzing and evaluating the performance of a UAV electrical system architecture against a number of defined criteria are investigated. In particular, the paper describes the utilization of these models to assess the applicability of an example backup battery before illustrating the response of the network to a variable load profile, and simulation results are shown to demonstrate this capability. Finally conclusions are drawn regarding the use of the developed models in supporting this particular design process and the future work required to maximize their effectiveness.

DESIGN CHANGES WITH ADVANCEMENTS IN TECHNOLOGY

Development of power system component technologies, such as power electronics and electric drives, is enabling improvements in aircraft electrical systems performance and availability [3, 4]. The potential for these system improvements is the driver behind much recent research into the design of novel aircraft electrical system architectures.

This is perhaps most evident from the progressive shift from 115V three-phase AC toward utilizing 270V DC for primary power distribution in modern UAV electrical network designs to capitalize on the many key advantages DC offers [5]. By utilizing DC power distribution, it is often possible to reduce the number of power converters employed in a specific network design, especially where frequency wild generation [1, 6] or novel loads, with unique voltage and frequency requirements, are employed. Elimination of such conversion stages may significantly reduce converter operating losses and the weight/volume of the network. Furthermore, DC distribution readily permits the paralleling of multiple generators onto a single bus, a practice which potentially enables increased whole system efficiency during part load operation, increased design flexibility and redundancy, and reduced through-life costs [7]. This can be particularly beneficial when paralleling Low Pressure (LP) and High Pressure (HP) shaft mounted generators [4], as the operability and performance of the engine can be actively improved [6] by operating the generators at a wider speed range and transferring power between turbine shafts.

However, the lack of lightweight and effective solutions for electrical fault protection of higher voltage DC systems represents a significant barrier to more widespread adoption of DC within aircraft systems [8, 9]. These issues include the potential for high magnitude, rapidly occurring fault currents [10, 11], which result from the discharge of filter capacitors

through limited impedance interconnecting cables. The design of effective protection for DC systems is an area of ongoing research. The overriding challenge in terms of network design is to ensure that the significant benefits attained through the utilization of DC distribution are not negated by the requirement to accommodate additional protection equipment or network redundancy.

Energy storage within aircraft systems are traditionally employed to supply backup power for flight critical loads in the event of primary generation failure, and usually take the form of battery systems. However advanced energy storage devices can play a number of additional roles within electrical power distribution systems. To enable energy storage to become more effective, a combination of both battery and supercapacitor systems are being considered for use on aircraft electrical systems [12, 13]. Each of these storage mediums have distinct dynamic performance [14]. The power density and charge/discharge life cycle of supercapacitors can be considerably greater than that of battery systems, whereas the energy density of batteries can be up to two orders of magnitude than supercapacitors [14]. Thus, employment of both storage mediums can be complementary, providing the capability for both fast transient mitigation (which can benefit both engine and electrical system operation) as well as longer term backup supply, potentially extending the range of possible applications within the aircraft electrical system.

UAV NETWORK ARCHITECTURES

This section presents three modeled UAV power system architectures; a variable frequency AC (VFAC) baseline network, and functionally consistent hybrid AC/DC and full DC variants. These architectures have been selected to cover a range of likely distribution options, capturing both traditional and novel architectures in order to provide a basis for comparison. This approach does not necessarily maximize the potential benefits of each distribution means, however it is anticipated the analysis of the three networks will inform upon the optimal network architecture for future studies.

The network models have been developed as behavioral level models [15], capturing converter switching effects, and load and fault transients. Modeling work has been conducted within the Simulink and SimPowerSystems blocksets of Matlab [16].

VFAC ARCHITECTURE

The modeled VFAC architecture is illustrated in [Figure 1](#).

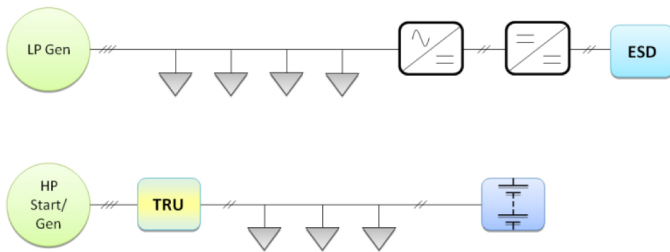


Figure 1. VFAC UAV power system schematic

This network contains two 3-phase, variable-frequency, synchronous generators, which are driven from the low pressure (LP) and high pressure (HP) shafts of an aircraft engine respectively. Generator Control Units (GCUs) are also modeled to regulate the voltages at the primary busses to 115Vrms (line-line). A representative aircraft engine model is employed to provide a rotational speed profile input for the generator and can be adjusted according to the mission status (i.e. take-off, landing and cruise profiles). The engine model is currently represented as a speed-stiff system, whereby changes in electrical loading on the generator do not induce changes in rotor speed. A supercapacitor energy storage device (ESD) has been modeled based on that presented in [17] and is interfaced to the network via a controlled bi-directional DC-AC converter. The applied converter control system is based on a power-balance strategy developed in [17], incorporating tracking of load changes on the network and whilst maintain the charge on the supercapacitor. A Transformer Rectifier Unit (TRU) converts the 115V VFAC supply to 28VDC for distribution to the DC bus. The DC bus also contains an additional battery storage system model to provide an emergency backup supply to the loads on this bus.

HYBRID AC/DC ARCHITECTURE

Figure 2 shows the schematic of the modeled hybrid AC/DC architecture.

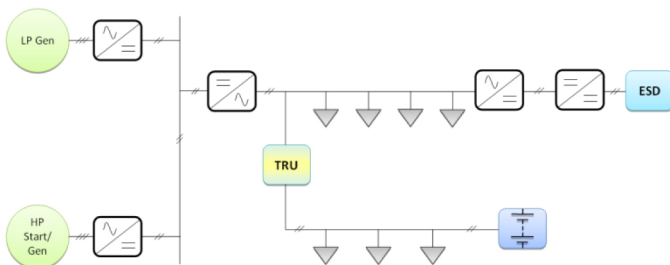


Figure 2. Hybrid DC/AC UAV power system schematic

The hybrid AC/DC network architecture captures key benefits of a DC busbar whilst retaining the more common 115VAC distribution to loads for protection compatibility. In this network, the output of the two generators is now rectified (using voltage source converters and phase angle control [18]), enabling easier paralleling of and power sharing between generators. Tuned droop profiles were employed within the converter interface controllers to ensure optimal power sharing between HP and LP driven generators, as illustrated in Figure 3 below. At present, equal maximum and minimum voltages have been utilized for improved voltage regulation of the rectifier outputs. However as [19] reports, greater machine efficiency can be achieved with a different voltage range on either generator control. There is also potential for the power split between the two generators to be regulated to optimize engine operability throughout different phases of the aircraft flight cycle [20]. Greater knowledge of both the engine's and two machines' efficiency against load characteristics may allow these benefits to be maximized in future. The rectified generator output also provides opportunity for wider generator speed range operation of the aircraft engine and the introduction of power dense generator technologies.

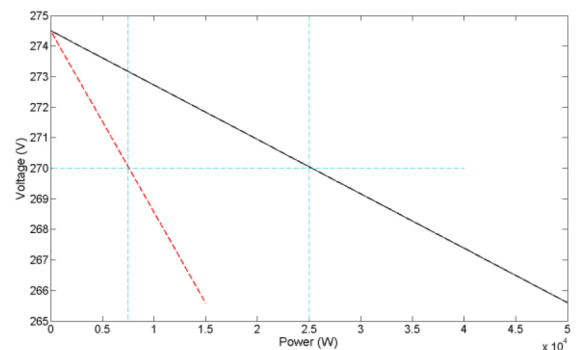


Figure 3. Voltage droop profile for the LP (solid line) and HP (dotted line) rectifier control systems

Other important features for this network include the use of a single inverter interface to supply 115Vac loads with a TRU connected to this supplying the 28VDC bus.

DC ARCHITECTURE

The schematic in Figure 4 represents the third UAV electrical system architecture considered within this paper, where power is now distributed through a 270VDC ring network. Within this network, the DC ring provides the opportunity to reduce the number of power conversion stages between generation, energy storage and loads, potentially increasing overall efficiency. The ring architecture of the 270VDC network section also utilizes parallel supply paths to loads, providing increased security of supply.