International Journal of New Technology and Research (IJNTR)
ISSN:2454-4116, Volume-2, Issue-7, July 2016 Pages 72-75

Auxiliary Power Unit Evaluation for Tethered UAV

Wasantha Samarathunga, Guangwei Wang, Shiqin Wang*

***Abstract*— This paper address a design evaluation problem of a main and auxiliary power unit designed for tethered unmanned aerial vehicles to avoid instantaneous power blackouts during flights. Generally in the absence of a cable power supply, APU must be able to ensure basic functionality for critical systems that should never go off line. The design object is to provide a simple auxiliary battery power source and switch to battery power whenever the primary cable power is unavailable and switch back to cable power when the cable power is available during the UAV flight. This power switching is a technically challenging task when the UAV operates in low altitudes and carry heavy payloads. This requires switching high currents in a high speed logic. We propose a simple and more scalable design to solve the problem. Evaluation tests are carried out on consistency of the proposed APU. The experiments results shows that the outcome of our design is basically positive for further switching speed improvements, thus possible to serve as a priory in flight mission planning over geometrically complex terrains. Further this APU could be useful for hybrid or multi power sourced UAV designs.**

Index Terms*—*Tethered UAV, Auxiliary Power Unit for UAV, Power Supply Switching during Flight, Dual Supply UAV

I. Introduction

This paper address an auxiliary power unit (APU) evaluation problem for tethered unmanned aerial vehicles (UAV). UAV applications are very popular today and expanding toward higher payloads and longer flight missions. In general, tethered UAVs are considered for longer flight missions and heavy payloads, where battery based limitations becomes an issue.

In tethered UAVs less than 400VDC is quite popular. UAV motors normally run on 48VDC or in lighter versions 24VDC. To make DCDC power conversion units as well as UAV itself to be light weighted as possible is a common design requirement to make available payloads higher. This is a reason for using switching regulators for power conversion on aerial vehicle.

Comparing to battery power switching regulators inherit nonlinearities. To obtain higher currents for UAV motors paralleling switching regulators become necessary. Under normal circumstances paralleling switching regulators need to overcome sequencing and synchronization to avoid oscillations. Many attempts have been made to obtain stability while producing high currents. In research [1] illustrated a unidirectional achievement for a typical tethered UAV example. Battery is still the most reliable power source. In [3], [4] and [5] are resent developments on efficient battery power.

To avoid total dependency on just a single power source, it is realistic to have an auxiliary power source to address any instantaneous power failure. Therefore it is necessary to have a battery based auxiliary power supply unit (APU) for tethered UAV till the cable power is back.

The following are common APU unit types,

(1)Online prototypes

Denotes prototypes with simultaneous charging and power supplying capability.

(2) Hybrid prototypes

Denotes prototypes that capable of charging when input power is available and discharge the battery when a power failure is detected.

(3) Off-line prototypes

Denotes prototypes equipped with pre-charged batteries and activate the discharge with detected power failure.

Online and hybrid prototypes are suitable for small to medium payload UAVs whereas for larger payloads offline prototypes can be considered to be better. In this research it is considered that the tethered UAV requires large currents within a very short period of time as the payloads are high and hovering altitudes are low. Hence off-line APU can be considered as the suitable prototype. Figure 1 illustrates tethered UAV system in this research.

The proposed design of this paper will be discussed in details in the next section of this paper

II. Proposed APU Design

The proposed APU in this research is simple and scalable as it does not depend existing power supply topology. Theoretically does not depend on battery type except the basic features as chemical safety and discharge rate.

The following are the technical challenges we have to address. As the UAV operates in low altitude and carries heavy payload, requires high current and high speed logic. At the first development stage we proceed with a solid state relay

Wasantha Samarathunga, Key Laboratory of Agricultural Water Resources, Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, Shijiazhuang, P.R. of China,
Guangwei Wang, Key Laboratory of Agricultural Water Resources, Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, Shijiazhuang, P.R. of China,
Shiqin Wang, Key Laboratory of Agricultural Water Resources, Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, Shijiazhuang, P.R. of China,
*Correspondence: Shiqin Wang

(SSR) as our switching device and TTL logic to control. If the consistency is proved to be positive, then we upgrade the design with faster switching device and faster logic.

Figure1. Tethered UAV System

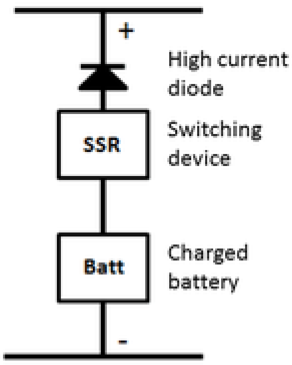

Figure 2: Proposed APU

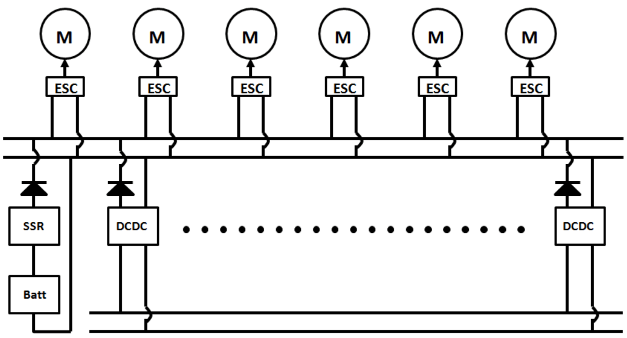

Figure 3: APU with Cable Power Supply

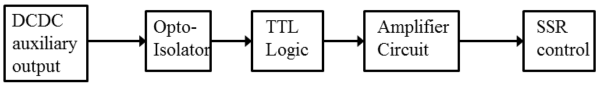

Figure 4: Components of APU Control

Figure 2 illustrates the proposed APU. Figure 4 illustrates the wiring of APU along with main cable power supply. Figure 4 illustrates components of APU control circuit.

The solid state relays (SSR) are considered suitable over electro mechanical relays (EMR) for fast switching, reduced electromagnetic interference (EMI), long lifetime and reliability, no sparking, low electrical or mechanical noise, strong tolerance to mechanical shock and vibration, small size and light weight. Since this approach is an APU consistency problem high current low voltage SSR is used. Next technical problem to consider is coupling technique of SSR.

In SSRs either optical, oscillator-transformer or piezoelectric methods are used for input-output isolation The prototype we used in this design is a photo-coupled SSR for high current DC, which cannot be categorized as typically very fast one, But average. Depending on the evaluation results further improvements on coupling techniques also must be taken. A typically fast transformer coupling is introduced in research [2]. Transformer couplings need additional circuits with high frequency oscillator in primary side and a rectifier on the secondary.

The trigger signal is auxiliary output from DCDC converter module which is logically high when the module is "ready". The trigger signal is logically low when a module is not ready to produce output or in an over current self-protection mode.

The object power switching can be viewed as a dual supply problem. In this very first step we use single device to prevent transitional problem due to imbalances. But since the high currents and finite voltage difference between cable power and APU battery power, we have to block possible reverse currents as in research [1] while achieving enough speed to prevent the UAV from crashing.

When use SSRs in applications, a finite hazard to be avoided is make-before-break possibility. The switching logic must be carefully designed to meet fail safe logic. Paralleling issues also avoided in this stage to get a clear positive or negative evaluation. If the results are proved to be positive, then on a later stage we can get the benefit of paralleling light weighted units for overall UAV payload improvement. Hence the switching device that used in this experiments is quite heavy and bulky for a medium payload UAV, but on contrary gives us the simplicity to evaluate the APU itself one at a time.

With the basics above we set our APU evaluation under two possible situations.

(1). In the event of a random cable power supply failure.

(2). UAV enters over current threshold zone with cable

International Journal of New Technology and Research (IJNTR)
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power.

The above assumptions are fair for normal APU supply conditions. Therefore the outcome of the evaluations are reasonable enough for basic consistency of an APU system.

III. Evaluations under Random Power Failure

Evaluation test for a possible random power failure is carried out with following steps.

(1). Power UAV with cable and increase the throttle up to hovering level (no power drawings from battery).

(2). Turn off the cable power (this state resembles any power fault during flight).

(3). Confirm that UAV shift to battery power and continue the operation.

(4). Turn on the cable power again (this state equals to power recovery).

(5). Confirm that UAV shift back to cable power and continue its operation.

The following figures explain evaluation test results for the proposed APU.

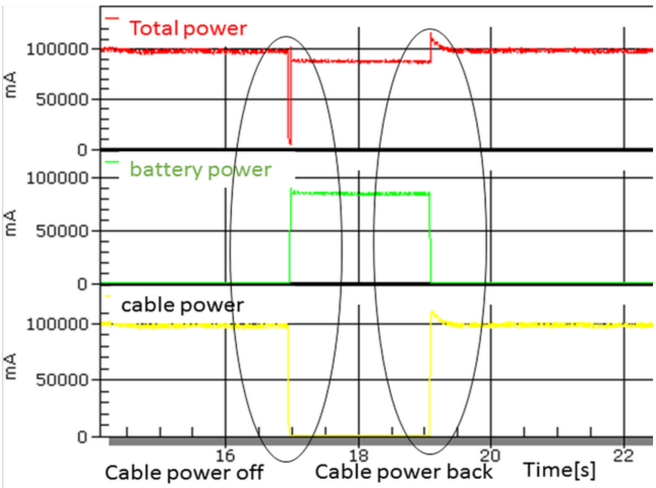

Figure 5: APU Evaluation test (full test)

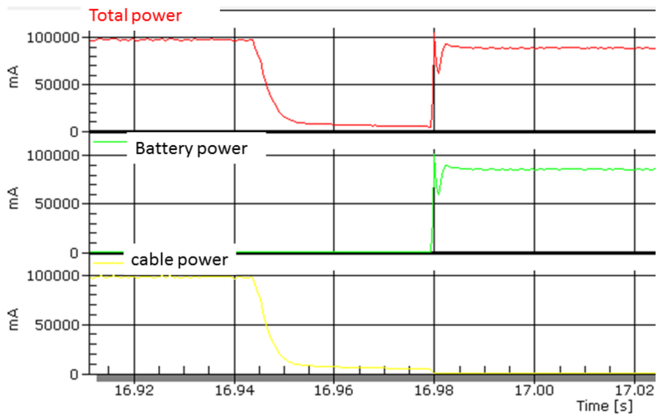

Figure 6: Cable power loss

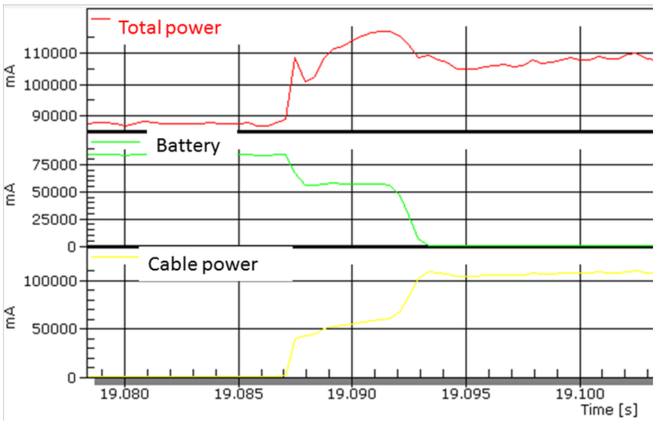

Figure 7: Cable Power Recovery

Test results shows that during black out of cable power short time lag less than 0.02 seconds is presence between the power losses and initialize battery power, i.e. small turbulence (short vertical drop) is presence here. During power recovery the switching shows almost no power loss rather than a simple overshoot of cable power.

IV. Evaluations under Over Current

The following is performance analysis of the proposed APU under over current. The over currents in DCDC conversion is also a definite reason of cable power blackout and APU must be able to respond fast to save UAV.

Evaluation test for a possible over current power failure is carried out with following steps.

(1). Reduce the number of DCDC converters (down scale) to force the over current event may take place in a lower threshold than actual UAV settings.

(2). Power UAV with cable and increase the throttle up to a level that is higher than DCDCs specified current threshold values (no power drawings from battery).

(3). Confirm that UAV shift to battery power and continue the operation.

(4). Reduce the throttle (brings UAV back to non over current or normal operating zone).

(5). Confirm that UAV shift back to cable power and continue its operation.

The following test results illustrates the switching ability of the proposed APU.

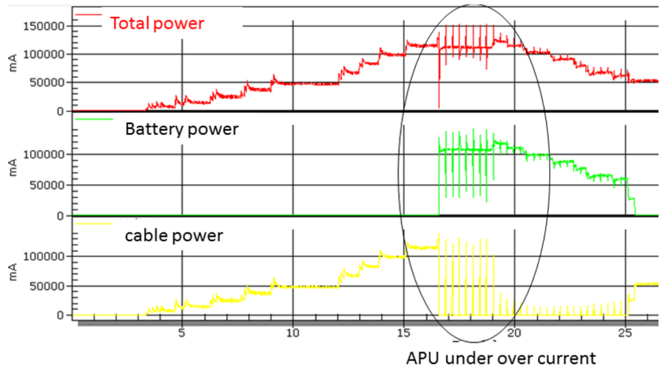

Figure 8: APU under Over Current

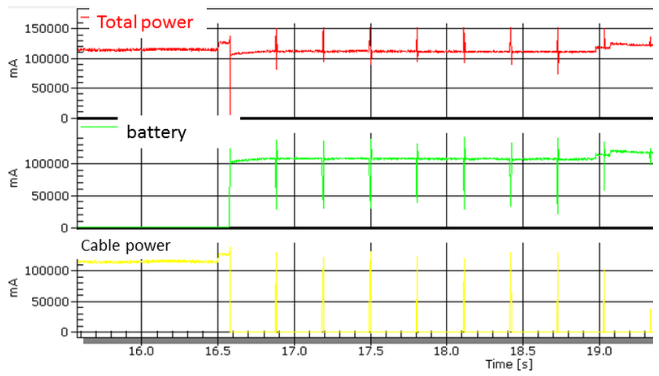

Figure 9: APU Switching in Detail

Since these repetitive power switching occurs in a high frequency, it is impossible to detect with just warning LEDs. Therefore a separate detection and alarm generation circuit should be designed in this case. Over current detection will be a subject in next research. It is necessary to mention that with a priori knowledge based on experiment data, one must avoid reaching this over current threshold which could possibly damage the APU.

CONCLUSION

From the APU evaluation tests results above it can be stated that although the flight may result in a small turbulence during cable power to battery power switching during the UAV mission, the proposed APU unit can prevent possible crashing. Consistency of the proposed APU is proven to be positive and good for further developments. This is quite interesting engineering achievement so far for a DC dual supply problem with inductive loads in other words. Further this power switching logic can be useful in designing hybrid UAVs, i.e. UAVs powered from multiple power sources.

In future designs we can improve the design to minimize this turbulence time and make the power supply management smarter without reducing the switching speed, e.g. try with faster switching devices and faster control logic circuits.

From the UAV operation perspective, ones we can detect this power loss we could shift the software feedback to increase the throttle of the UAV, and if necessary slowly proceed to safety landing.

ACKNOWLEDGMENT

This study was financially supported by the 100-Talent Project of Chinese Academy of Sciences and Key Program of the National Natural Science Foundation of China (No. 41471028).

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