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# Evaluation of Power Conversion on Heavy Payload Tethered Hexarotors: A Strategic Approach

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**ABSTRACT**
This research article addresses the evaluation of power conversion on heavy payload tethered hexarotors where the payloads are high and hovering times are long. Modifications were added to the power conversion unit based on operation reliability perspective. Since the objective power conversion is large comparing to existing tethered UAVs today, a strategic engineering approach was proposed and tested based on partial observations on current spikes and power thresholds of DCDC switching regulators. Research problem is such that, when UAV motors are consuming low currents, the current spikes are not the plausible cause of direct power failure. But at higher currents even small current spikes could cause power failures. Risk increase with time and situations worsen when UAVs operate under high precision flight controls. When the number of parallel converters are small this becomes a mission critical problem. As a solution, fast switching high current diodes are used at the low voltage high current output to block reverse currents, and then apply low voltage bus bar to prevent dependency issues on particular DCDC module. At the cost of a small power dissipations over diodes, the total current thresholds of UAV become higher. Experiment results shows that with the use of proposed method large number of paralleling switching regulators become possible and heavy payload flights become reliable.

***Keywords* -** Tethered Hexarotors, Heavy Payload UAV, Paralleling Switching Regulators, Power Conversion Evaluations, Low Voltage Bus Bar

## I. INTRODUCTION

This paper address the power conversion unit evaluation problem for heavy payload tethered hexarotors for agricultural applications. Using unmanned aerial vehicles (UAV) in agricultural automation and remote sensing missions, long time hovering is a prerequisite. This is the reason of using tethered prototypes. Research [2] introduced a basic design problem for heavy payload tethered hexarotor and in research [1] address in detail the high to low DC power conversion unit design problem for heavy payload tethered hexarotors. Figure 1 (cited as Figure 11 in research [1]) illustrates the tethered hexarotor subject to this research article.

The following figure 2 which cited as figure 3 in research [1] illustrates the contents of total power conversion on UAV. From evaluation tests in the following sections of this paper we made necessary modifications to ensure the reliability of the power conversion unit mounted on aerial vehicle. From the operation reliability perspective. Our main object is 380VDC to 48VDC power conversion for UAV motors as illustrated in figure 3. We isolate this part from the other power conversion units for trouble-free operation.

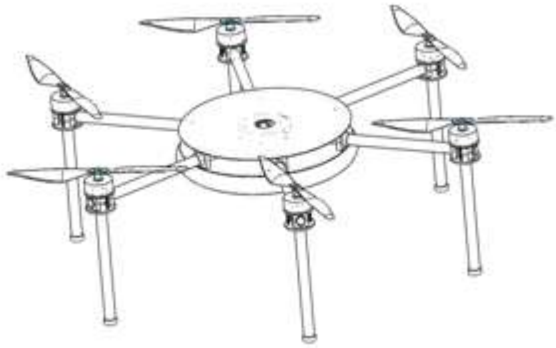

Figure 1: The Tethered Hexarotor Subject for this Research

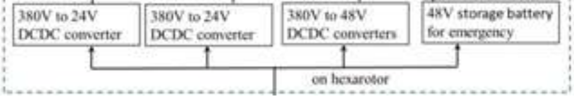

Figure 2: Power Conversion on UAV

In our power conversion unit, inputs are merged and DCDCs are designed for parallel use with theoretically minimum impedance matching. But in reality any delay in powering up or powering down of either regulator would cause a back-feed from a high output DCDC to a low output DCDC, i.e. possible sequencing problem to avoid oscillations. In long term operations better synchronization and sequencing features are necessary.

Make things as lighter as possible is a common practice during UAV designs. This is a reason for using switching regulators for DCDC conversion. When the power is inadequate parallel use of few DCDC converters after impedance matching becomes the next common option denotes as semi-parallel configuration as illustrated in figure 4. Inherent noise is a problem with switching regulators thus requiring additional noise filtering circuits. In research [1] we proposed a full parallel configuration against paralleling few DCDCs as mention above. In this paper we validate the full parallel configuration design as illustrated in figure 5 and add modifications based on semi-parallel and full parallel configurations and relevant hypothetical observations.

In this research operation reliability is addressed in two steps, the former denotes as system based solutions and the latter denotes as module based solutions here. System based solutions are salient than module base for large scale modifications. In our approach we apply system base solutions before module base solutions for better efficiency. This depends on type of the object.

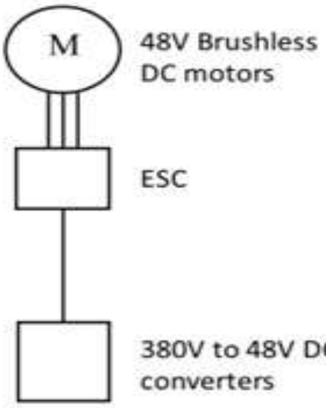

Figure 3: Evaluation Object of This Paper

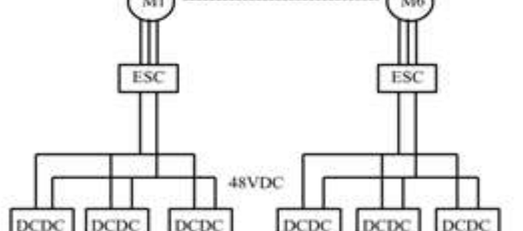

Figure 4: Semi-Parallel Configuration

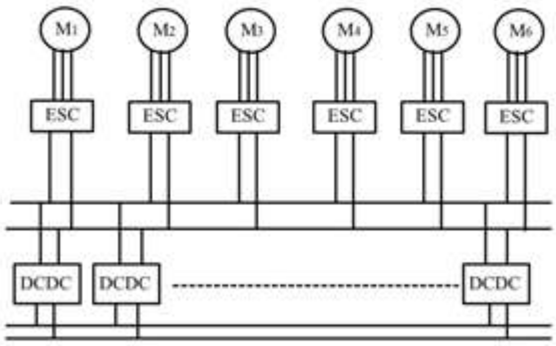

Figure 5: Full Parallel Configuration

The difference between this approach and conventional approach are as follows. In conventional approach identification of problems, analysis the causes, proposed solutions and validation tests on that solutions, i.e. problems and solutions follows a logically linear relationship. Outcome after applying the solutions are relatively easy to quantify. In this research analysis the causes and proposed solutions are complex and nonlinear comparing to the former.

(1) Analysis the causes are based on observations on failures on early prototypes, drawn hypothesis on the possible causes of failure and testing on drawn hypothesis.

(2) Solutions are not strictly related to what caused the problem, rather strategically make their contributions to the whole system. Outcome is quite difficult to quantify.

To serve as a brief survey on existing and ongoing background researches and developments, the followings could be appropriate as references. A good introduction on bi-directional DCDC implementation for UAV is explained in [3]. In [4] and [6] serves as new potential for battery based UAV developments. When higher discharge rates for battery is required [5] explains the long running popularity for lithium. References [8] and [9] serves as basic technical merits of applying high voltages, [7] is a good application. Finally reference [10] can be considered as a good multidisciplinary research achievement.

## II. OBSERVATIONS ON CURRENT SPIKES

The following figures 6 illustrates recorded current data per motor.

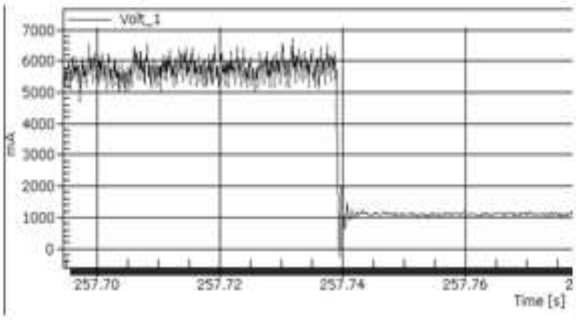

Figure 6: Current data before motor failure

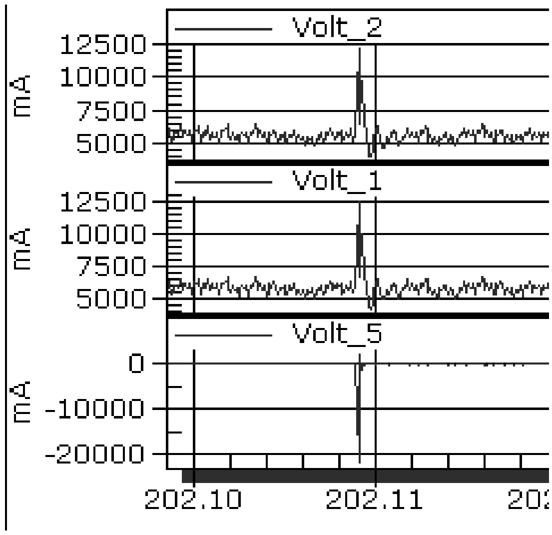

Figure 7: detected reverse currents

## III. CONCLUSIVE POINTS FROM OBSERVATIONS

With increase of operation time in high current ranges number of failures increased.

Increasing the number of parallel modules in one or two module as illustrated in fig. 4 illustrated as semi parallel, no of failures decreases. But occurrences of failure become random, i.e. system is not stable.

From overall system viewpoint this can be considered as a threshold problem. Hence we have to draw a hypothesis, do modifications based on that hypothesis and make validation tests to prove whether the hypothesis is true.

## IV. HYPOTHESIS

Based on previous observations we draw the following possible hypothesis.

“When the motors are running at low current ranges than peak current of each DCDC converter, current spikes and noise is not the plausible reason of power failure. But at high current range small current spike could case the power failure. This risk increase with time.”

## V. MODIFICATIONS

Assuming the above hypothesis is true, the following points could be considered for points for modifications,

1. Revers currents are not desirable even if DCDC tolerates up to a certain level.
2. It is not reliable to depend on module based impedance matching.

Current flow correction measures. In this approach we add fast switching diode to prevent possible negative spikes and also to work as an external shield to protect DCDC modules.

Semi-parallel configurations are no longer reliable for operation perspective and necessity to apply full parallel configuration, i.e. applying low voltage bus bar.

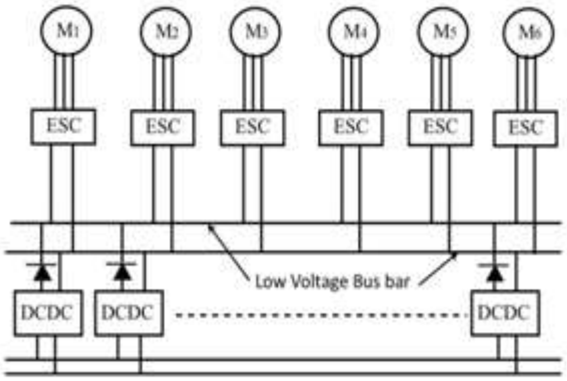

Figure 8: Proposed Modifications

Possible drawbacks considered due to proposed modifications are as follows.

(1). Excessive heat at heat bus bar
(2). Excessive heat due to power dissipation of diodes.
(3). Extra weight due to bus bar

Figure 8 illustrates the proposed modifications under the drawn hypothesis. Argument here is if the merits after modification are higher than these drawbacks, we proceed with new modifications at first and take measures to reduce these drawbacks in a later stage.

If the following validation tests prove performance improvements, then the drawn hypothesis becomes true. That makes the proposed modifications become realistic and applicable.

## VI. VALIDATION TESTS

In order to test the above hypothesis, the validation tests are performed based on necessary power thresholds (denotes threshold test) and to check the ability to response (denotes response test). From the operation point of view the vehicle must has enough thrust to for the target payload and has ability to operate under precision flight controls which need extra power and tolerance.

(1) Threshold test perform with increasing the number of parallel DCDCs and increasing the motor speed

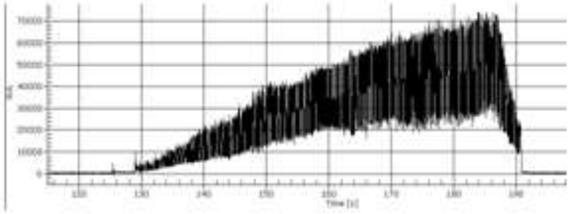

Figure 9: Threshold improvement (per motor)

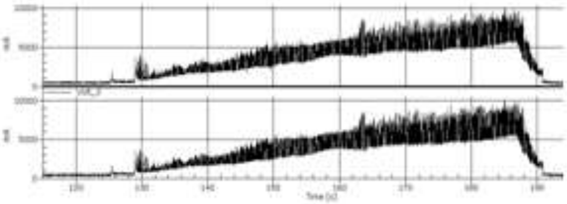

Figure 10: Threshold improvement (each DCDC)

(2) response test performed with sudden increase and decrease of motor speed using control signal frequency

Rapid increase or decrease of motor speed also causes power failures, i.e. weak against turbulences and not suitable for advanced flight controls that need high response.

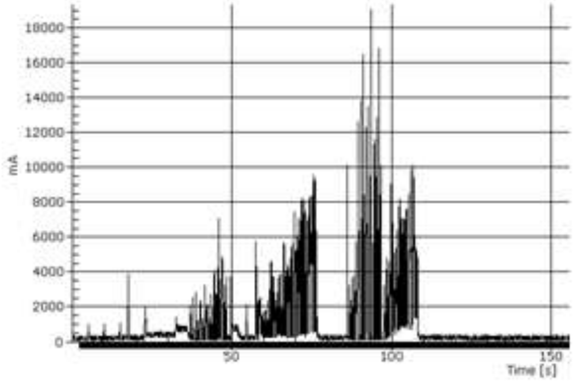

Figure 11: Response improvement

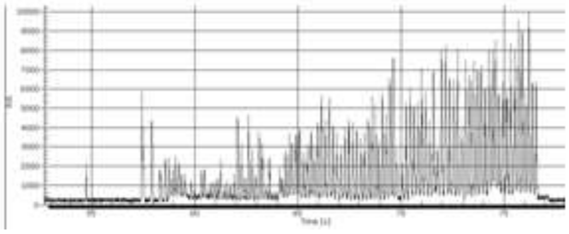

Figure 12: Response improvement (detailed)

Results from above validation tests proves a definite threshold improvement. At a later stage we tested with real flight and verified the results.

(1). No power failure detected. Could continue tests up to ESC current limit.

(2). Increase in response. Could tolerate rapid increase and decrease. This makes the vehicle to be operate under high precision flight controls.

Improvements also could be visible from figure 9 and figure 10. Although each motor's operating current is high, actual contributing current of each DCDC module is way below than module's peak current.

Moreover response tests also did not show any failures. The drawn hypothesis is proved to be true and the proposed modifications are valid. The drawbacks from the previous section become less priority issues to be cleared later.

## VII. CONCLUSION

The large scale power conversion on tethered UAV is very challenging engineering task which restricts developing of new prototypes. Therefore the proposed engineering method can be considered as a positive achievement and a useful strategy for further development on tethered UAV.

As an immediate output of the proposed method large number of paralleling switching regulators become possible and the power conversion unit on UAV become more reliable by making operation threshold become higher than before. In future we plan to add more modifications to the power conversion unit of the proposed hexarotor to make it more robust.

## VIII. Acknowledgements

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