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LONG-RANGE UAV HYBRID PETROL-ELECTRIC POWERTRAIN

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Abstract

Along with increasing UAV both weight load and endurance requirements, there is a need to use alternative propulsion solutions, to satisfy the market as well as various customer applications. Although lithium polymer cells are yet well developed, they are still too heavy for long-endurance UAV missions. Hybrid petrol-electric powertrains are outstanding imitations of hybrid hydrogen-electric propulsion systems, which are currently under intensive development. Not only for their onboard power production and improved overall efficiency but also for simulating a weight load of a future hydrogen-electric system. Therefore, such a system is being tested and aimed to be used in fixed-wing UAVs for long-endurance missions. This paper describes the design and operation of a hybrid petrol-electric propulsion system and further operational optimization based on comprehensive ground testing.

Keywords

hybrid, petrol, electric, powertrain, UAV

1. Introduction

Hybrid powertrain, in its basics, utilizes at least two energy sources or energy conversion agents. By energy conversion is meant chemically stored energy in a fuel or an electrical accumulator to be transformed into mechanical work or kinetic energy of a driven object (Ehsani et al., 2018)

Well-developed hybrid petrol-electric drivetrains, nowadays widely used in the car industry, manifest their capabilities and usability in general.

Mainly, considering VTOL requirements in future applications, as lithium cells are still not energetically dense enough, engine-driven generators are outstanding energy conversion agents, where similarities with the car industry are vastly significant.

As there are many ways of approaching a hybrid UAV powertrain design, the most obvious one is not to use a combustion or jet engine for direct propulsion in combination with another source of energy, but as an onboard powerplant (Bayindir et al., 2010).

The accurate ratio of onboard power production and storage delivers a smart, reliable, and efficient solutions for both fixed-wing and VTOL UAV propulsion, altered respectively (Bongermino et al., 2017).

2. Theoretical approach

As of now, hybrid powertrains are yet applied in UAV usage. Different types of combinations of petrol engines and electric propulsion are designed and built for commercial employment. Divided into two categories, both are considered hybrid powertrains.

2.1. Primarily combustion engine propulsion

The conception of primarily combustion engine propulsion in a UAV utilization fits best for fixed-wing UAVs. Combustion engine mounted with a propeller is being used during forward flight ascend, cruise and descent. Electric propulsion though, typically consisting of three or four smaller electric engines, provides just enough thrust for vertical takeoff and landing, with no other purpose during the flight (Mull & Nix, 2022).

Number of possible vertical takeoffs and landings strictly depends on battery pack size, which is usually limited by maximum takeoff mass restrictions.

Individual propelling systems of such UAV powertrain are mostly not interconnected which could be very beneficial in terms of structural integration and overall simplicity, although instability or failure of one of the systems can cause emergency or an accident.

Such propulsion design is not applicable on multicopter UAVs, which significantly limits general usability and therefore fewer commercially available technologies are offered worldwide.

Operator actions are also required during startup procedure since there is mostly no electric starter present for combustion engine start sequence. Not even starter guarantee successful engine startup since cold starts require choke to be engaged. Multiple attempts are often executed for combustion engine to start. Since these facts are deviating user friendly experience idea, higher level system interoperability is desired.

2.2. Primarily electric propulsion

Primarily electric propulsion provides significantly more satisfying user experience trough well developed electric motors and remote control systems. Generally considered, multicopters are most suitable to be propelled by such propulsion.

Since considering this a hybrid powertrain, electric generator is driven by petrol engine providing enough power to produce required amount of electric energy onboard the UAV. System is always equipped with a small battery pack to store some energy reserve for peak demands and help dampen power fluctuations (Brown, 2017).

These powertrains offer longer endurance compared to pure electric systems however not a much of a range extension which is obvious regarding the design and usage of multicopter type UAVs.

The difference of not using combustion engine for direct propulsion results in mandatory higher-level system interconnection and as a benefit of that, powertrain is adequately integrated as well as redundant.

Although primarily electric hybrid propulsion was previously mentioned to be used mainly in multicopter applications, there is also a great potential in fixed wing UAV utilization.

Not even system interconnection improves operators work load during the startup procedure, unless system control optimizations are made. Similar handling procedures are mandatory as for primarily combustion engine propulsion in terms of operator participation. Complex digital powertrain control and effective involvement of all systems components are crucial for achieving satisfactory results.

3. Hardware and operation design

In this paper, the focus is being kept on designing compact and reliable physical petrol electric hybrid powertrain as well as developing sufficiently intelligent control actions executed by programmable micro computer unit.

Not only energy conversion or multiple energy sources make hybrid, but also the ability of such system to run independently and solely on one of the energy sources at a time.

The idea is closer to primarily combustion engine hybrid powertrain type, however only little improvement possibilities occur. On the other hand, primarily electric hybrid propulsion shown in Figure 1 could possibly be improved in terms of onboard energy conversion and production and general operational autonomy.

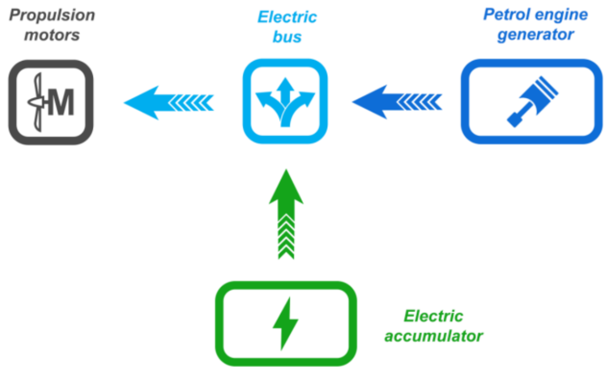

Figure 1: Primarily electric propulsion system scheme.

Various computer executed procedures could reduce operator's startup work load, save fuel and thus increase endurance and range and help manage energy flow within the system.

Powertrain autonomy is a critical factor for efficient operation. Ideally, including self-startup, which is only primarily electric hybrid powertrain type with combustion engine generator eligible for.

Combustion engine is being mechanically solidly linked with the generator, considering RPM identical. Coupler shown in Figure 2 consist of two discs, each of which is customized for individual respective shaft mounting and four flexible shock and oscillation dumping elements.

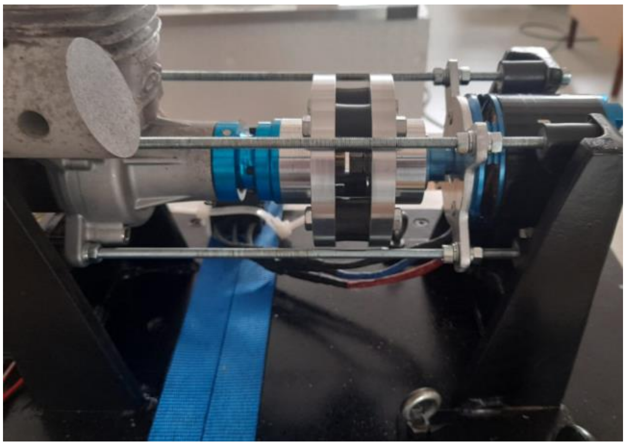

Figure 2: Mounted coupler.

Since generator could also act as a motor, there is no need for additional electric starter to be mounted, whatsoever. Electric energy stored in battery pack is used for combustion engine startup executed by control computer as shown in the Figure 3.

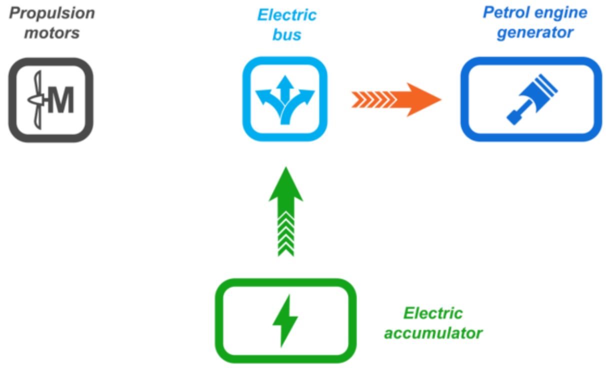

Figure 3: Combustion engine startup - energy flow.

During and after successful startup, electronic servos shown in the Figure 4 control carburetor valves of the combustion engine. Determining factor would be the output voltage as it directly disproportionally changes depending on system load.

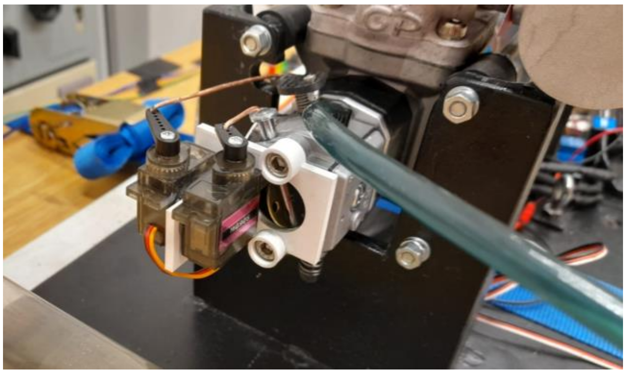

Figure 4: Carburetor control electronic servos.

Generator output voltage value directly relates to generator RPM. Generator under the load though, requires much higher RPM, in order to produce equivalent voltage in comparison with no load applied.

Load as such is reflected by voltage drop even in pure electric powertrains, which is why continuous voltage tracking is essential.

Consequently, generator RPM are controlled by regulating combustion engine power output trough carburetor valve servo.

Voltage measurement should be conducted as close to interconnection between all of the propulsion system components, such as propulsion motors, battery pack and electric generator as possible. Simple yet very efficient solution for both the system main interconnection and voltage reference measurement point is an electric bus bar.

Another key factor is to combine combustion engine and electric motor used as generator with similar nominal power outputs. Based on what, given combination is assumed energetically compatible.

Energetical compatibility could be described as a satisfactory compromise between lost energy and energy converted in a given connection, in this case of using an electric motor as a generator.

4. General operation

As stated before, the system is designed primarily electric, which comes with certain improvement possibilities. One of those, already done, is petrol engine startup performed by the generator. No operator action is needed.

Since bus voltage is main determination factor of petrol generator output control and battery is directly connected to it, battery cell amount sets limitation of operational voltage. Six cell lithium polymer battery of capacity 99 Wh is used. Such battery has nominal voltage of 22.2 volts. Maximum operating voltage is 25.2 volts, while minimum is 19.2 volts.

In the case of an emergency combustion engine shutdown, thus depriving electricity production, battery is expected to cover the demand until safe landing.

This drivetrain was designed and built to actively support maximum of 2 600 W in conditional hybrid operation mode, as shown in Figure 5, which means certain amount of energy is taken from battery pack, while majority is generated.

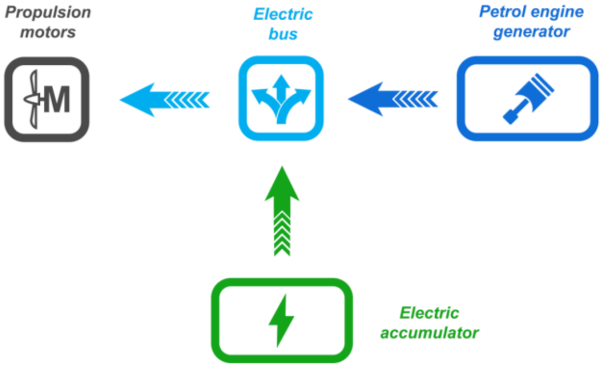

Figure 5: Conditional hybrid operation mode.

For safe operation it is mandatory to keep battery charged within suitable limits, in terms of possible cell damage. Not only after energetically demanding climb flight, but also during relatively slow petrol engine control response to overvoltage caused by ‘sensor to servo’ delay. Therefore, battery pack shouldn’t be charged during cruise flight over 75 percent of its capacity, so it can store overproduced energy for a short time.

As the voltage would be direct indicator of unloaded battery charge level, analogically, 75 percent of its capacity represents voltage of about 23.5 volts. Such voltage provides satisfactory energy backup as well as sufficient overproduction storage.

Drained battery after climb-out acts as a load as propulsion electric motors do, which obviously cause petrol engine with the generator to stay at its maximum power output and recharge battery as shown in the Figure 6.

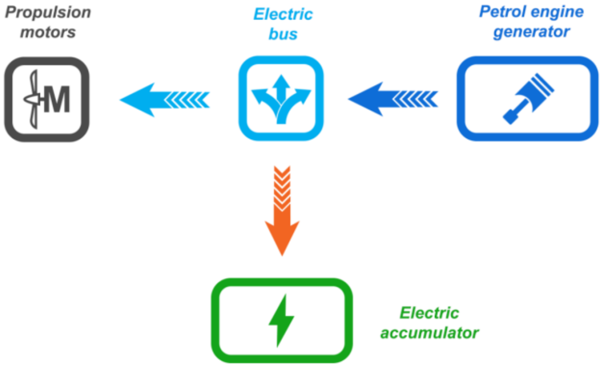

Figure 6: Inflight battery recharge.

After battery recharge to voltage of 23.5 volts is accomplished, system operates in its normal mode, observable in Figure 7, in which demand-production equilibrium is established by control microcomputer. Battery no longer drain or provide energy from and to electric bus. Two stroke, one piston combustion engine is operating near its nominal, 7000 RPM.

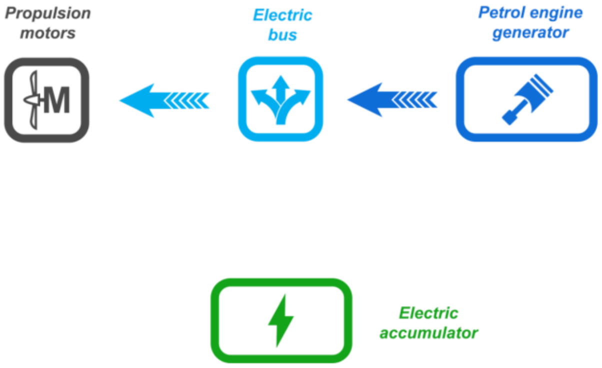

Figure 7: Normal operational mode.

During long endurance cruise flight, with battery recharged up to 23.5 volts and no plan of further climbing, certain amount of stored energy could possibly be used, whereas combustion engine power output lowered, to meet the demand. The process of this specific energy management is described as unconditional hybrid operation mode, manifested in Figure 8.

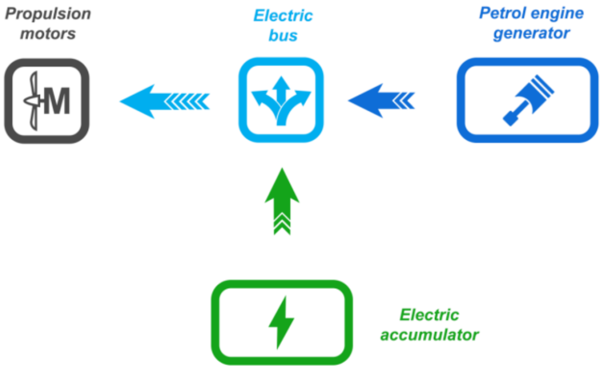

Figure 8: Unconditional hybrid operation mode.

Such operation mode is executed by control microcomputer after certain conditions had been met. Mainly, stable voltage, low absolute battery current and mid-range combustion engine output are required, for the mode to be considered engageable.

Engagement though, depends not only on actual values, but average values of monitored sensors or their time function.

5. Powertrain control

Arduino microcomputer continuously gathers real time data from voltage, current and temperature sensors, based on which subsequently controls startup procedure and combustion engine carburetor valves to adjust power output.

Safety and emergency procedures are involved within the primary code consisting of overheat protection, overvoltage and undervoltage protection.

Simple troubleshooting is available for operator to observe, which consists of three LEDs, determining voltage sufficiency for the startup, safety and emergency protocols engagement and startup pending.

Even complex diagnostics can be received with the laptop connected, shown in Figure 9.

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-> / / / / / / / / / / / / / / / / / / / /
-> FADEC DIAGNOSTICS
->
-> BUS VOLTAGE ACT/AVG           23.04 / 23.57
->                               LOW |  |*|  | HIGH
->
-> BATTERY CURRENT ACT/AVG       23.70 / 12.06
->                               DEMAND | *| |  | CHARGE
->
-> TEMPERATURE AIR/ENG           19.49 / 109.98
->                               LOW |  | |* | HIGH
->
-> CARB SERVO PULSE              1390 // DEMAND //
->
-> FUSE                          OK  0
->
-> ENGINE SWITCH                 ARMED / ATTEMPT DISENGAGED
->
-> PAGE # 423
->
-> / / / / / / / / / / / / / / / / / / / /
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Figure 9: Computer based diagnostics example page.

6. Conclusion

Hybrid UAV powertrains provide not only superior results in endurance and performance, in comparison with pure electric ones, but also limitless opportunities for their improvement in their operation and efficiency.

Highly autonomous systems are often reliable and even deployable in very specific and demanding missions.

Further development and improvements were aspired and successfully conducted, resulted in capable primarily electric hybrid petrol-electric powertrain.

Powertrain control level is adequately strict about outputs as well as inputs, preventing any emergency to become serious incident.

Most importantly though, by imitating weight load and power output of similar hydrogen-electric hybrid powertrain, this research manifests the potential of hydrogen powertrain potential in UAV utilization.

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