IntelliGen Starter Generator System

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I. Introduction

A. The Problem

Unmanned aerial systems (UAS) that are powered by internal combustion engines (ICE) have an ever-growing appetite for electricity. When development of the Aerosonde UAS began in the 1990s the total electrical power needs of the aircraft were less than 20 Watts at 12 Volts. This was all the power needed to run the flight computer, control surfaces, engine systems, and radios. Even with such low power consumption the Aerosonde's 24-hour endurance still needed a generator since a battery of sufficient size would have been too heavy. A simple belt driven three phase motor with six-diode passive rectifier and buck regulator was sufficient to meet the needs of the Aerosonde.

Figure 1. Aerosonde, circa 1998, at the Boeing museum of flight.

Fast forward to today and the electrical power needs of a UAS are vastly greater. Not only are the vehicles more massive, but typical payloads consume hundreds (for stabilized infrared imagers) or thousands (for radar systems) of Watts. In addition, most new UAS systems use electric motors to provide vertical takeoff capability and these motors are fed by enormous high voltage battery packs, which take significant electrical power to recharge after each takeoff or landing. These bigger vehicles have bigger engines, swinging big propellers. Gone are the days when the toy engine could be manually started with an external starter. Modern UAS need integrated engine starting to keep ground personnel out of reach of the propellers. And all of this must still be accomplished using systems that are as light as possible.

Figure 2. L3-Harris FVR-90, circa 2023.

B. IntelliGen Overview

IntelliGen is an intelligent starter/generator controller for use in small engine UAS applications. It has features designed for modern UAS, including sensored boost rectification for a 3-phase motor, variable current limit 28V/30A regulator, high voltage battery charging, low voltage backup battery, and 12V and 6V regulators for avionics and flight control loads.

A. Sensored boost rectification

Rectification is the process of taking the three sinusoidal voltages of the generator phases and commutating them to a single DC voltage. IntelliGen does this using switches configured to push current in or out of the motor depending on the mode of operation. We refer to this as *boost* rectification because the active control of the switches allows software to use the motor inductance to boost the output voltage of the generator to the desired value of our DC rail – even as the generator speed changes with the engine speed. This is key to IntelliGen's ability to charge high voltage batteries. This same process is used by any speed controller that is capable of regeneration.

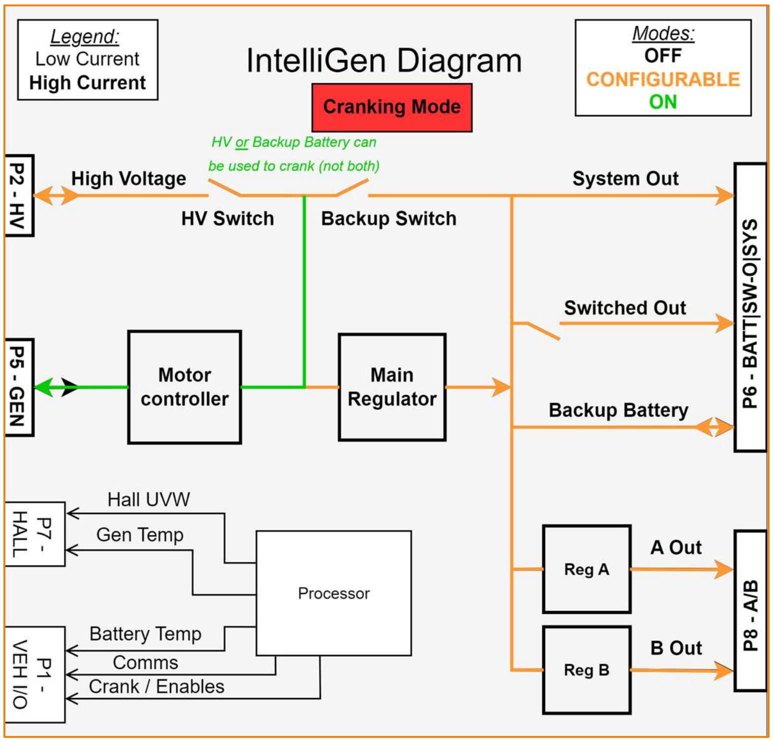

Figure 3 IntelliGen cranking mode diagram.

"Sensored" refers to IntelliGen's ability to use hall sensor signals from the motor. Commutation requires knowing the position of the rotor, which is typically done by observing the electrical signals of the rotating machine. However, such sensorless feedback cannot be used when the machine is not rotating, requiring motor controllers to use small current to get the machine spinning fast enough to enable the feedback. By incorporating sensors IntelliGen can utilize full current at zero speed. Even though IntelliGen only weighs 300g it is capable of cranking large engines*, accelerating the engine from a standstill to 1000 rpm in a single revolution of the crankshaft. This rapid acceleration generates the angular momentum to get the engine through its compression. Without sensors this would require dramatically more current and a larger device.

Once the motor is spinning IntelliGen can switch to classic sensorless techniques for rotor position estimation. This gives redundant rotor commutation sensors, allowing changes to the rotor position source in real time as needed to overcome faults. The sensors also make it possible to commutate significantly more current than sensorless alone can do, because the sensors are not affected by the demagnetization time that corrupts the phase voltage following a commutation state switch.

B. High Voltage Battery Charging and Power augmentation

IntelliGen has a high voltage switch which allows it to connect or disconnect a high voltage (up to 60V†) battery to the rectified DC rail. It also measures voltage and current through that switch. When a high voltage battery is connected IntelliGen will run feedback control from the current to the motor control. Software

* Largest engine to date is over 200cc, the actual maximum engine size depends on generator and engine details.

† The voltage limit will be increased in upcoming revisions of IntelliGen hardware.

uses boost rectification to implement a charge profile for lithium batteries, pulling additional current from the generator when the battery can accept the charge. The charge profile of the battery can be adjusted through software configuration to match the size and chemistry of the battery.

In addition, IntelliGen can run current the other way, consuming power from the high voltage battery and sending it to the motor to augment the shaft power of the engine. This is the same process that is used for engine starting applied to an already spinning engine. The power augmentation can be used during engine warmup to keep a sputtering engine turning or at high engine power settings to increase the available shaft power for the vehicle.

The high voltage battery connection fits naturally with eVTOL UAS, which have large high voltage packs to run their lift motors. IntelliGen makes it possible to use these packs to start the engine, and then recharge the packs in flight.

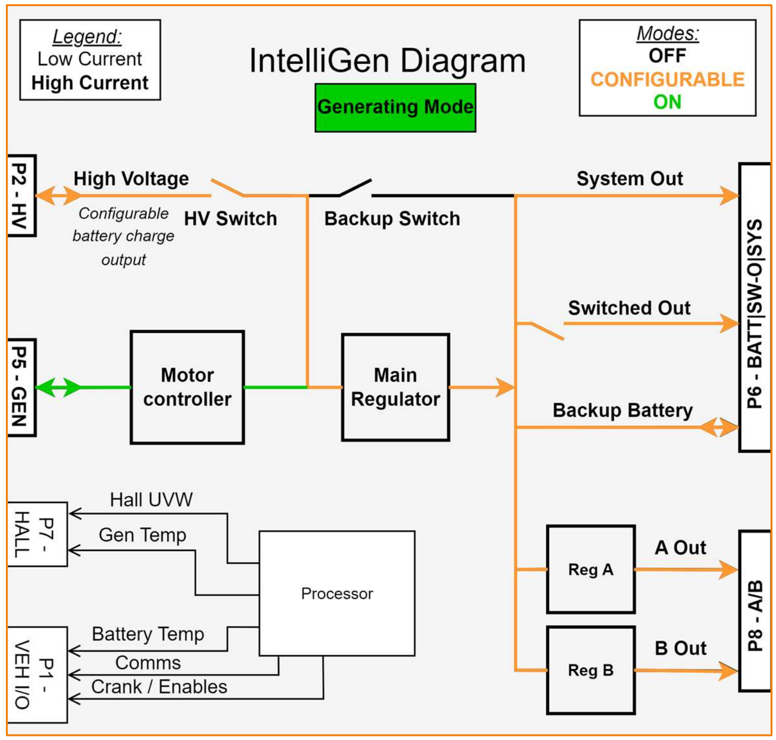

Figure 4 IntelliGen generating mode diagram.

C. Generator and engine load control

The electrical power requirements of the modern UAS can be problematic if the engine is operating at low speed. Consider a 50-kg eVTOL: such a vehicle will typically use an engine capable of around 6kW at 6000 rpm and will cruise at around 4500 rpm and 2.5 kW. At that condition there is an additional 2kW engine shaft power available to send to the generator; so large electrical loads can be easily supported.

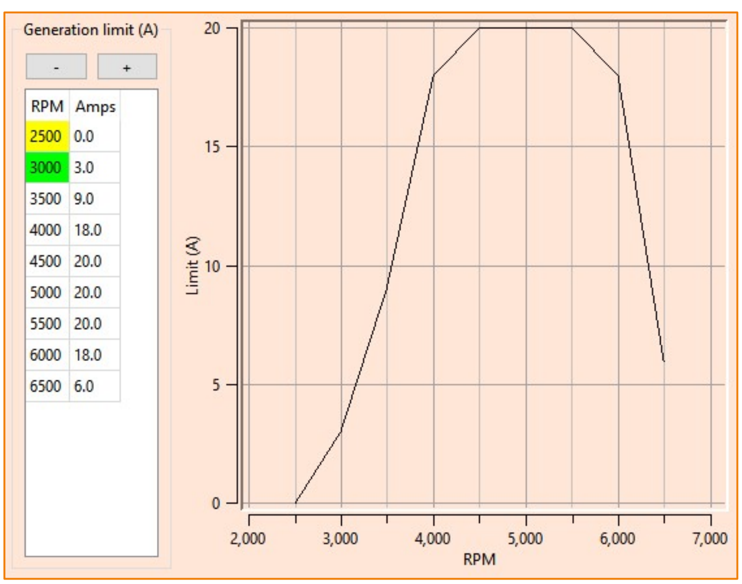

Figure 5. Example generator load profile.

However, the same vehicle will descend at 2500 rpm with nearly zero shaft power. If a large electrical load were to appear at that point the engine would simply be stopped by the generator torque. To prevent this case IntelliGen will shape the load on the generator. Software can be configured to impose a maximum generator current as a function of generator rpm. Hence as the flight controller reduces engine power the IntelliGen can reduce generator current to keep the engine turning. If the electrical load exceeds the available generator current IntelliGen will allow power to flow from the high voltage battery to the regulators to make up the difference.

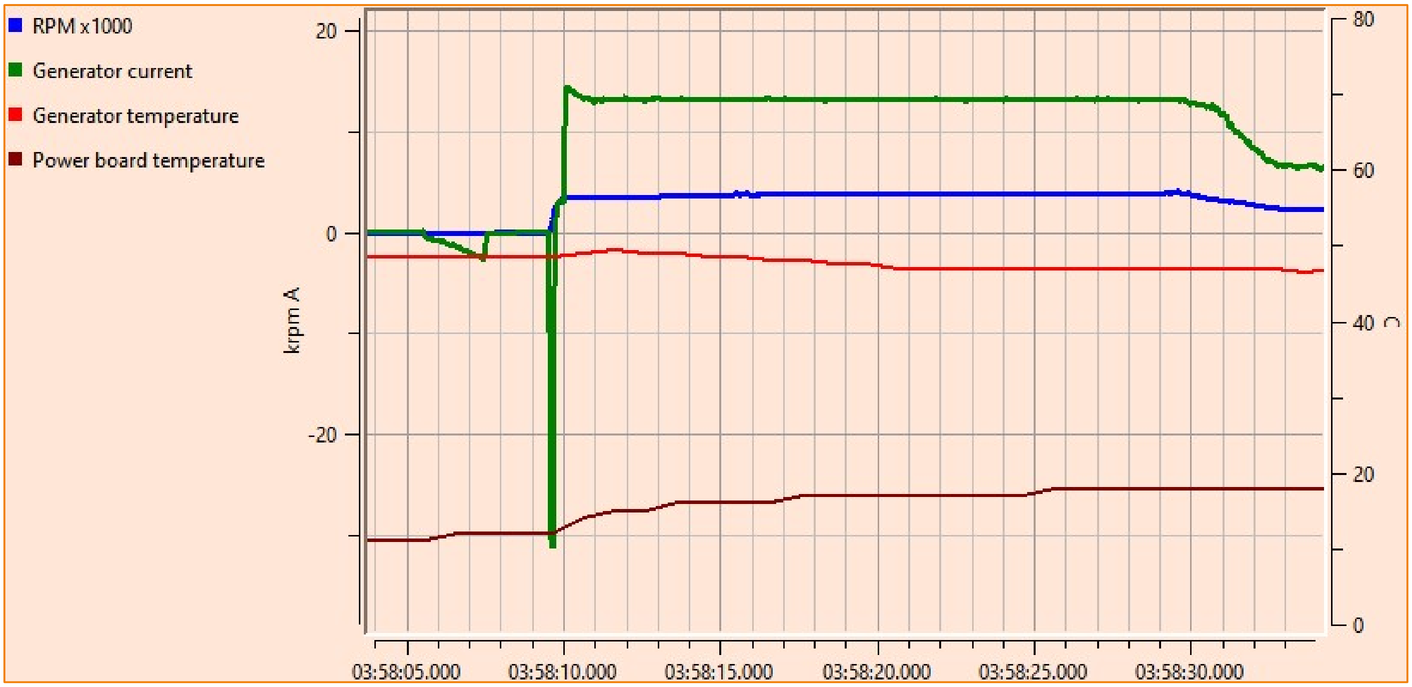

Figure 6. Recorded telemetry from starting a large two stroke engine.

Figure 6 shows some telemetry from starting a large two stroke engine. IntelliGen first reverses the engine to get a running start at compression, and then drives a large amount of current to crank the engine, which starts immediately. The engine runs at 4000 rpm and the IntelliGen pulls a steady 13 Amps to run the downstream regulators and charge the high voltage batteries. At the end of the chart the engine speed is reduced and IntelliGen reduces the generator current draw according to 6 Amps.

D. Real time regulator current limiting

For low voltage outputs IntelliGen includes a battery-backed 28V regulator, capable of 30A

‡. Key to the regulator operation is real time control of the regulator current limit. Anytime the low voltage electrical load exceeds the regulator limit the backup battery supplies the remainder; and when the regulator has excess current it recharges the backup battery. The amount of current that can flow from the generator to the regulator is set by the regulator current limit. Just as with the high voltage battery IntelliGen can limit the load on the generator by adjusting the current the regulator can supply. IntelliGen also measures the current flowing out of the regulator and the current flowing in or out of the backup battery, using the regulator current limit control to make sure the backup battery charges at an appropriate rate.

Software can be configured to operate the IntelliGen with a high voltage battery *and* a backup battery, or just a high voltage battery, or just a backup battery; whichever configuration is appropriate for the UAS in question[§]. Whatever the configuration, the combination of boost rectification and regulator current limit control gives IntelliGen complete control over the flow of the electrical current and the state of charge of the batteries.

‡ Operating with continuous 30A loads requires cooling airflow on the IntelliGen enclosure.

§ Technically IntelliGen can operate with *no* batteries – but this is not recommended as it removes much of the value of IntelliGen.