Family of Lightweight Logistics Fueled Generators

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Abstract

Precision Combustion, Inc. (PCI) has developed 7 variants of battery-hybridized lightweight JP-8 generators by utilizing reliable, low-cost, commercial, off-the-shelf (COTS) 4-stroke engines. The fueling system was modified to operate on JP-8/DF-2 via PCI's novel and patented octane-matching approach. Multiple generators from 300W to 5kW output were matured. AC and DC paralleling of multiple generators was demonstrated. Custom power electronics enable simultaneous DC and AC outputs. Logistics packages and TDPs (Technical Data Packages) were developed for scaling and manufacturing the generators.

The 450 W 28VDC generator had a dry-weight of ~17 lbs. and is ruck-packable. The 300W 28VDC Generator included an on board fuel tank and weighed < 20 lbs. The 1kW 28VDC Generator weighed 25 lbs. The 900W AC version weighed 28 lbs., the 1.65kW AC version was Tactical Microgrid Ready, had electromagnet pulse protective features, weighed 72 lbs. and included an 8 hour onboard fuel tank. The 2kW 28VDC generator weighed 55 pounds, and the 5kW 28VDC generator weighed 112 pounds. All generators include electric start, paralleling/microgrid capability, and external fueling capability.

The family of generators enables a range of solutions that can be used alone or combined together for 0.3kW to 10kW. For comparison, the current power sources in this range are the much heavier and larger i.e., the 2 kW MTG (MEP-531A) weighs 124 lbs. while the 3kW TQG (MEP-831A) weighs 304 lbs.

Stable operation with other liquid and gaseous fuels has also been demonstrated for multi-fuel capability. Any COTS spark ignited engine can be suitably adapted. The particular engines used were chosen for reliability, low noise, and availability.

PCI's proven octane-matching approach is inherently superior to other "fogging" approaches for enabling spark ignited (SI) engine operation on JP-8. SI engines require octane numbers of >80 for stable operation and avoiding knock, yet JP-8 has an octane number of only ~20. PCI uses its in-situ and on-demand JP-8 upgrading reactor (the size of a D-cell battery) and an advanced direct fuel injection approach to upgrade the octane and thereby reliably operate SI engines on JP-8 or other liquid and gaseous fuels. No carburetor, special start fluids or starting procedures are required. This also allows attitude independence during operation. The JP-8 upgrading reactor is tolerant to 3000 ppm sulfur (JP-8 spec) and its performance has been proven over 1000's of hours of testing.

Keywords

Portable; Packable; PPG; STEP; TMS; Reforming; Fuel Processing; Power Generator; JP-8; Diesel; APU.

Introduction

Commercial off-the-shelf gasoline engines are inexpensive and meet the weight, size, and power output requirements for the deployed soldier. These engines however run on gasoline, a high octane fuel (octane number 85-100). As a result, these engines cannot operate with JP-8 heavy fuel, whose octane number is in the range of 15-25. Multiple alternative means have been developed to allow operation on JP-8 however they are inherently flawed due to their reliance upon approaches that do not actually overcome the core octane number problem.

PCI's technical approach: From 2018 to 2022 Precision combustion Inc. (PCI) developed 5 custom generators for the U.S. Army and United States Air Force based on the PCI fuel conditioning technology. These generators built upon prior DoD funded projects in which COTs generators were modified with add-on reformer kits.

The octane number of JP-8 fed to the engine was directly increased to the 80+ range, suitable for operation of SI engines via "Octane Matching". The JP-8 is instantaneously (order of milliseconds) converted to high octane fuel, immediately prior to injection into the combustion chamber via an extremely compact (D-cell battery size), octane-boosting reactor. PCI's underlying CPOX reactor breakthrough has been advanced in collaboration with both automotive and DoD support. Details of each system requirements and specifications are shown below.

Program Goals

PPG: Platoon Power Generation (PPG) is a 28 Volt (V) Direct Current (DC), tactical, quiet, power generation system. The PPG is soldier borne, fitting in a standard ruck sack, with the capability to provide 900 Watts (W) from 2 x (450W) 16.7 pound generators.

The PPG generator was developed to provide up to 72 hours of power for the small unit level, including networked communication devices in austere environments without

requiring resupply. The PPG was designed to be the platoon's primary energy producing source for recharging during missions in austere environments where power resupply is limited or non-existent. The PPG was designed to support the Universal Battery Charger (UBC) and Squad Power Manager (SPM).

Figure 1. Platoon Power Generator. Scale in foreground is 6 inches wide. 28VDC (450W / 500W Peak).

STEP: The Small Tactical Electric Power (STEP) generator was developed to meet the mission requirements currently met by legacy 2 kW Military Tactical Generator (MTG) and 3 kW Tactical Quiet Generator (TQG). With advances in Tactical Network capabilities and technology supporting enhanced situational awareness the need for lightweight, mobile, scalable power generation is growing. The project focused on maturing the technology and reliability of lightweight generator sets. The sets were capable of paralleling and maintaining Ground Fault Circuit Interrupter (GFCI) protection while connected in parallel.

Figure 2. Small Tactical Electric Power Generator 1.65kW / 120VAC / 2kW Peak.

AFRL 1kW, 2kW, 5kW: Existing modified commercial Off-The-Shelf (COTS) 1kW, 2kW and 5kW "flex fuel" generators often require significant user attention. During operation, particularly at part loads, the generator does not run hot enough to completely burn diesel fuel causing the remaining fuel to seep into the oil reservoir, causing it to fill to the point which triggers the generators' safety auto shut

Figure 3. 28VDC Generators Developed for Air Force Research Laboratory. Left to Right - 1kW, 2kW, 5kW.

off. The oil and diesel fuel mixture must be drained to a safe level to allow the generator to continue operation. In some cases the oil may have to be changed frequently, (<1- hour) intervals.

In response to the challenge, PCI developed Lightweight multi-fuel generators based on COTS spark ignited engines that operate without oil dilution and risk of engine damage for HQ AFSOC/SGR and other Special Operations Unit or DoD Units deployed to austere locations.

This family of generators are among, if not the, lightest 1kW, 2kW and 5kW logistics fueled flex fueled generators in existence. The generators weigh 5kW – 112 Pounds, 2kW - 55 pounds, 1kW – 25 pounds. For comparison, the 2kW MEP-501A 28VDC generator weighs more than 138 pounds, 26 pounds more than the 5kW generator developed in this program.

Logistics Packages: Logistics work products were provided based on requirements of each program. Not all programs required every work product. These products included: Electronic Technical Manual (ETM) in accordance with MIL-STD-40051-2. Failure Modes, Effects, and Criticality Analysis (FMECA). Maintenance Analysis in accordance with Army Regulation 750-1 to analyze maintenance support functions necessary for the system, and operator and maintenance tasks. Level of Repair Analysis (LORA) for the system in order to determine repair level decisions. Maintenance Allocation Chart (MAC) in accordance with MIL-STD 400051-2C and DA PAM 750-8. Program of Instruction (POI) including a Training Support Package (TSP) for Operator and Maintainer levels.

Common Principle of Operation

PCI's Fuel conditioning Module (FCM) for each system is based on the concept of converting any spark ignited commercial off the shelf (COTS) gasoline engine or generator to run on low octane, heavy distillate fuels such as JP8 or diesel. Over the course of each program, a solution was developed to meet the power specification by changing a small number of components on the engine and control variables. This makes the technology relatively engine agnostic over a wide range of power levels.

In order to operate the balance of plant components during startup of the FCM a system battery is required. The battery needed to be robust enough to manage operation of these components, while also being lightweight and power dense. In the case of the PPG and STEP generators an Army Standard BB2590 battery was used. For the AFRL generators a commercial $LiFePO_4$ battery was used. Once

Table 1. 450W – 5kW Generator Specifications

	PPG 450W	AFRL 1kW	STEP	AFRL 2kW	AFRL 5kW
Power	450W 28VDC 500W Peak	1kW 28VDC	1.65kW 120VAC 2kW Peak *TMS Ready	2kW 28VDC	4.3kW 28VDC 5kW Peak
Fuel at rated load	9.9 hours/gallon F24/JP8	5.4 hours/gallon F24/JP8	3.8 hours/gallon F24/JP8	3.1 hours/gallon F24/JP8	1.4 hours/gallon F24/JP8
Weight	16.7 Pounds	25 Pounds	73 pounds **	55 pounds	112 pounds
Dimensions	9x11x10 inches	12x13x11 inches	15x24x18 inches	13x16x16 inches	20x19x16 inches
Volume	0.57 ft^3	0.9 ft^3	3.7 ft^3	2.1 ft^3	3.2 ft^3
Status	30 Units completed	Prototype	15 Units completed	Prototype	Prototype
Testing	Independent testing performed by 3rd parties and ATC	PCI Internal Power Quality, Efficiency and Transient Testing	Independent testing performed by 3rd parties and ATC	PCI Internal Power Quality, Efficiency and Transient Testing	PCI Internal Power Quality, Efficiency and Transient Testing
Noise	Max 70.7 dB @ 23 feet	<70 dB @ 23 feet	Maximum 72 dB @ 23 feet	<72 dB @ 23 feet	<72 dB @ 23 feet
Start	Fully Automatic - Electric <5 minutes				
Fuels	F24, JP8, Jet A, Kerosene, Gasoline				
Features	External Tank. With Dry Break Disconnects. HMI with status, and operator prompts. Remote Start. Parallel Operation.		Internal or External Tank, HMI with status, and operator prompts. TMS & Remote Start	External Tank. With Dry Break Disconnects. HMI with status, and operator prompts. Remote Start. Parallel Operation.	
Additional STEP Features	*Tactical Microgrid Gateway developed and evaluated. **includes internal tank, BB2590 Starting Battery, TMG interface, automatic paralleling inverter, HEMP Protective features. Additional capabilities: N+1 operation-up to 15 generators may be connected in single phase 2W configuration. Non-N+1 operation: Generators may be connected in single phase 3W (120v/240V) and 3 phase 4W.				

the system was operating, the control and power electronics recharge the battery and monitor battery state of charge.

The primary requirements with respect to control and power electronics were to provide high fidelity fuel conditioner operation and reliable integration with the engine to properly meter fuel at steady state and transient conditions. The power electronics were implemented to provide reliable AC and DC power as well as providing power management between the balance of plant components and the rechargeable battery.

Figure 4. Complete PPG System including Generator, UBC, and SPM.

Common Generator Features

- Contains a two-button HMI for easy operational interfacing
- Integrated starter generator that allows for push button electric start of the power system
- Contains a hybridized DC/DC converter (both DC & AC generators) designed to regulate voltage and protect from overload and short circuits by automatically interrupting power to the output or inverter. Once the short circuit or overload is removed, output is restored. If the overload condition persists power will be interrupted and restored after the user presses "Reset" on the HMI.
- Simple starting controls. 2-position rocker control switch and a momentary start/reset button enable easy starting, stopping, and resetting the system.
- Contains internal fans that provide fresh air to the fuel conditioner and aid in cooling the electronics, engine, and fuel system during operation and after shutdown
- Contains a fuel conditioner designed to allow for conventional spark ignition engines to operate on low octane fuels such as JP8, F24 and Diesel

External Fuel Source: Each generator connects to an external fuel source of any size using two lines for supply and return. Flexible fuel bladders with fuel capacity of 3 L (0.8 Gallons), 6 L (1.6 Gallons) and 20 L (5.3 Gallons) have been tested.

Conclusions

The feasibility of converting lightweight spark ignited gasoline engines without any internal engine modification, and operating on distillate fuels (i.e. diesel and JP-8), in addition to gasoline has been demonstrated in multiple generators ranging in power from <500W to 5kW. Two designs were produced in low volume initial production and delivered for electrical, environmental and endurance testing. Three additional unique prototypes 1kW, 2kW, 5kW were delivered for evaluation. The generators were capable of starting and operating in varied weather and temperatures, maintaining speed and voltage during load transitions.

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