Natural Gas & LP Fueled Standby Generator Design, Installation and Application Considerations

Abstract

When compared to other backup power systems, such as the (UPS) Uninterruptible Power Supply, photovoltaic battery chargers, or wind generators the engine generator set offers advantages based on extended run times from hours to days and even longer if required. Certain code compliance issues must be addressed for generators operating on natural gas or propane. This paper will discuss issues that must be considered when installing or specifying a dry fueled genset outdoors and the characteristics of these units. This paper will also address the fuel system components of emergency generator systems, enclosure design and alternator information with an emphasis on safety, design, regional operation characteristics and system integration.

Introduction

The future of emergency generator applications will depend on cost-effective reliable emergency generator system design, including the enclosure, engine, generator, safety systems, noise control and aesthetic installations. Customer requirements for a UPS (Uninterruptible Power Supply) that has four – eight hour power outage ride-through duration are expensive and the battery lifetimes may be as short as two to four years. The emergency generator can extend power to the load for hours or perhaps even days.

Engine generator systems with weather enclosures are connected to either natural gas for extended operation, or an on site propane storage system with limited capacity. Natural gas enters the high pressure regulator through a utility meter, or propane enters with no metering. This vapor fuel passes through the high-pressure regulator which reduces the high, but variable, pressure from the input source to a regulated pressure. Regional differences in the natural gas supply can require different high-pressure or primary regulators. Following the high pressure regulator is the fuel solenoid which electrically controls the fuel flow, generally with a 12VDC coil. When the fuel solenoid is energized the fuel flows through the solenoid to the demand regulator which provides the proper amount of vapor fuel proportional to engine demand. This fuel is then routed into the carburetor venturi. The energy in the fuel is now converted into rotational mechanical energy. Mechanically coupled to the engine is the alternator which converts the rotational, mechanical energy to AC (Alternating Current) energy. The AC energy can now be supplied to the customers various loads. If the customer has a primary utility source the generators power output must be connected to the customers loads through a transfer switch.

The described system has the ability to create AC electric power from natural gas or LP fuel, control and ancillary systems are necessary to create a controlled, reliable and safe operating system. One safety system is formed by the engine generator controller which activates the 12VDC engine starter and the 12VDC gas flow solenoid, based on inputs from the engine and alternator. Coordinated with these control function are the alarm and monitoring system which are responsible for the safety and information gathering functions of the system.

System Development

Designing a standby generator into a weather protective enclosure adds a variety of challenges to the system designer including acoustic noise, thermal limitations, airflow dynamics, mechanical enclosure vibration, panel resonance, agency requirements, safety and maintenance. Each of these issues are surmountable individually, the combinations and interactions among these constraints can be overcome to create a cost-effective, reliable standby generator.

Over the last couple decades, engine manufacturers have developed specific features to support natural gas or LP fuel sources. These features include using specialized intake and exhaust valves, computer designed noise abatement, safety sensors and controls to prevent catastrophic damage. The system development and evolution into a product family can consume significant research and development. Much of the effort involves developing the interfaces which work with the emergency generator to form an integrated system. Additional work is required in testing, code compliance and field experience.

Engine Generator Types

There are several types of engine generators on the market.

Consumer / Commercial Grade Portable (500watts to 10kW)

The high volume of sales and manufacturing in the consumer market produces a very cost-competitive product, although unsuitable as a standby power source. A consumer or commercial grade generator set typically has a manual start, direct coupled alternator with rotating field, brushed alternator, operates from unleaded gasoline, is extremely noisy, uses a splash oil lubrication, and exhibits low engine lifecycle. Very basic electronic controls are found on these units.

Contractor Grade Portable (3kW to 15kW)

A contractor grade generator is manufactured in medium to high volumes, but uses robust engines, optional electric start, direct coupled alternator with rotating field alternator, options for brushless versions that more closely approximate a sinusoidal output waveform, optional larger gas tanks, and operates on unleaded gasoline. Improved muffler silencing, pressurized lubrication, medium engine life cycle, robust electronic controls and voltage regulation circuitry complete the features in this category.

Mobile / Towable Generator (20kW to 2MW)

The mobile or towable generator is built in medium volume and uses almost exclusively industrial grade diesel engines, critical grade mufflers, robust mounting features, very rugged electronic controls including electronic governing for precise frequency control, digital or solid state voltage regulation, optional PMG (Permanent Magnet Generator) field excitation, 10 - 12 lead alternators with a voltage reconnection switch to reconfigure the alternator for quick output voltage changes, onboard 24 hour fuel tanks and continuous duty ratings.

Stationary Standby Industrial Grade (20kW – 2MW)

The industrial grade standby is built in medium to low volume and uses industrial grade engines. These units have many of the same features as the Towable units. They are generally built as a custom order for a customer’s specific requirement. Stationary standbys are typically fueled by natural gas, LP or diesel. Because of their potential complexity and demanding installation requirements, engineering and architectural firms typically specify this product and electrical contractors will install the product. When installed outside these units may be found in sound-attenuated enclosure, with failsafe controls, remote monitoring and software packages for control. These units are typically sold as part of a system; the other system parts would include automatic transfer switches or switchgear.

Field Installations

Project managers, site engineers and design engineers work together to place the unit in a strategic location for access to natural gas and electrical service entrance. The group must work together, along with the power system vendor to achieve and demonstrate compliance with local and national requirements regarding installation.

These issues are true for any standby installation, but additional design and layout arise for systems and enclosures containing standby generators where issues regarding fuels and noise include:

- Building and code requirements for local installation, including seismic requirements.
- Unit location
- Installation restrictions with easements, private and public, or public utility easement.
- Permits and surveys.

- NFPA (National Fire Protection Association) technical statements for city councils along with design and compliances for fire marshals and city councils.

- Third party approvals and endorsements, CSA (Canadian Standards Association), UL (Underwrites Laboratories), etc.

Size and noise are key concerns in the installation of the standby generator. The unit must be as small as possible, while maintaining full operational requirements for the site specific fuel and altitude. The emergency generator must also remain a cost-effective solution as compared to UPS systems, wind turbines and photovoltaic battery charging systems.

Engine Details

The design aspect and requirements for engines used in unattended automatic operation will be discussed in this section. The engines used in these applications must be compatible with dry fuel operation, such as natural gas and LP vapor withdrawal. Dry fuel is a vapor form of fuel that does not carry lubricating additives or the cooling effect to the valve seats such as gasoline. Compared to gasoline, the effect of an engine operating on dry fuel is premature piston ring wear, regression of exhaust valve seats and valve damage caused by higher exhaust temperatures. Never the less, overall engine wear is significantly less than the gasoline counterpart because natural gas and LP are cleaner burning fuels. The engine valve train and exhaust ports must be designed to operate on dry fuels.[i ii]

Pressurized and filtered oil is highly recommended. While larger liquid cooled engines have a pressurized oil system, many air cooled engines do not. The engine lifetime is dependent on proper maintenance, engine wear and tear and the overall ability of the engine to maintain lubrication.[iii] With small horsepower engines two methods of lubrication are possible: splash and pressurized. The splash method uses a small internal device geared to the crankshaft. This device splashes oil around the crankshaft and cylinder walls. A pressurized oil system utilizes a gear driven pump which forces oil directly into the main crankshaft bearings, cam shaft and valve train components. The oil forced through the main crankshaft bearings also coats the cylinder walls by centrifugal force.

Altitude impacts carburetion, performance and power output curves. A typical derating for naturally aspirated engines operating on natural gas or propane fuel is 3 percent per 1,000 feet above 500 feet. Thus a generator operating at 4,500 feet will have a output duration of approx. 12 percent less than the same unit operating below 500 feet. System designers must take this into account when choosing the proper size genset for the customers' requirements. As the altitude increases the customer may have to purchase a unit with an oversized engine.

As fuel octane rating vary, the operating characteristics of the engine change too. Low compression engines typically run on 87 octane gasoline with about an 8.3:1 compression.[iv] With natural gas at 130 octane[v] or propane at 97 octane[vi] the compression ration should be increased to 9.5:1 to regain engine efficiency running on the slower burning fuels. Timing also plays a major factor in engine power. Different timing characteristics are needed for propane and gasoline. Typical ignition timing for gasoline engines has a 29º advance which would need to be optimized and adjusted for slower burning dry fuel. Dry fuels operate with a timing advance of approximately 34º. An engine powered by propane or natural gas exhibits about a 10 percent increase in output power when operating with timing appropriate for natural gas and propane.[vii] Another advantage of operating with timing appropriate for propane or natural gas fuels is lower exhaust temperatures. As the timing, compression and carburetion are optimized, the combustion cycle becomes more efficient, power curve is increased, reducing engine exhaust temperatures, the result is a reduction in long term effects on the valve train, muffler components and cabinet thermal dynamics.

Dry Fuel Carburetion

Dry fuel carburetion is very different than carburetion for standard gasoline engines. Dry fuels require a demand regulator that meters the vapor fuel through a spring loaded diaphragm and orifice opening to the carburetor based on engine demand and vacuum signal. This design has been utilized for decades with LP and natural gas supplied engines.

In addition to variations in emergency generator output power from operating at different altitudes, the energy content of the regional natural gas varies.

Audible Noise

The presence of a standby generator in a residential area may cause concern due to nuisance noise. Nuisance noise is a directional noise which can cause discomfort during the generators operation to nearby residents. These concerns are reduced by recent technology advancements in muffler design, flame-resistant sound damping materials and air intake and discharge sound attenuators.

Airflow Dynamics

The enclosure airflow is routed so that the discharge airflow and exhaust are vented on the radiator end of the enclosure, and input airflow for cooling air and engine combustion use the rear or the alternator end of the enclosure. The exhaust air stream is mixed with the engine exhaust to introduce turbulence, this serves to reduce the high frequency audible components without creating excessive back pressure.

Mufflers and Back-Pressure Restriction

Engine muffler design has advanced over the last several years with resonance chambers used in place of glass mat and other restrictive flow-through materials. As a result, back pressure is reduced significantly, increasing engine output horsepower.

Noise Summary

System designers must balance engine power and exhaust back pressure; engine noise and airflow dynamics; enclosure size and thermal dynamics; and mechanical panel resonance and manufacturing and material costs.

Other design techniques such as pointing the output airflow and exhaust, proper site surveys to prevent locating systems near noise abatement areas (hospitals, schools, day care, etc.) and layout of the site to utilize the environmental attenuators such as shrubs, fences or other landscaping can create a very quiet installation. These installations reduce the visual exposure and community impact.

The enclosure should be designed for public access areas, as a result all air intakes, doors screens, access panels, utility appendages (utility boxes or gas regulators) should be designed in such a way that the public cannot get injured if working or playing, on or near the enclosure. Theft can be prevented by eliminating all external hardware such as bolts and screws, except locking devices, thus creating an aesthetically pleasing design. Mechanical strength must be sufficient to survive environmental hazards.

Alternator Considerations

Whenever a wire carries electrical current, its temperature will increase due to the resistance of the wire. One important factor of this temperature rise is the influence it has on the insulation system of an alternator. The higher the wire temperature, the shorter the life expectancy of the insulation, and the alternator itself. The standard for designing alternators relied on by the generator industry is National Electrical Manufacturers Association (NEMA) Standard MG1, which encompasses the entire machine, and includes requirements for alternator temperature rise.

Generator Categories

The MG1 standard defines two duty cycles: continuous, meaning 24 hours a day, 7 days a week under full load conditions, and standby, an emergency power source designed to back up a continuous source. While the standby category doesn’t have any designated hour limits, the accepted standard of operation is much less per year.

Insulation Classes

MG1 recognizes four classes of electrical insulation materials used in alternators – A, B, F, and H. Each of these has different characteristics, but their common feature is that they will have an expected minimum life of 30,000 hours under continuous operating conditions (actual insulation life would need to be determined in the end product). The primary difference is the maximum allowable temperature at which the alternator windings can operate with these types of insulation.

Maximum Operating Temperature – Standby

Since standby duty requires less operating hours than continuous use, MG1 allows the standby windings to operate at a temperature up to 25 °C warmer. The additional operating temperature allows alternators of these types to generate more kilowatts, justifying the higher standby ratings found on most gensets. Most alternator manufacturers typically uses a Class H insulation system while designing its alternators to operate at Class F temperatures, thus reducing thermal stress and building in a temperature margin that prolongs alternator life.

These maximum temperatures are actually made up of two parts – the ambient temperature of the environment and the heat, or temperature rise, created by the alternator windings. MG1 uses 40 °C as its standard for ambient temperature. Subtracting 40 °C from the maximum operating temperature gives us the temperature rise allowed for the heat generated by the resistance of the wire in the windings and other losses in the alternator.

Generator Design

Generator manufacturers have standard designs for alternators based on a number of physical and operating criteria. Some of the physical attributes that control the voltage and kilowatt rating of a design are the size and material of the steel laminations, the length of the lamination stack and the amount of copper wire. The frequency is controlled by the RPM of the rotating magnetic field. DC Current is supplied to create the magnetic field in the rotor through various designs categorized as brush-type, brushless or permanent magnet type. All these items, and the amount of cooling air driven through the alternator, affect the unit's output and temperature behavior.

Derating Conditions

NEMA does not allow any deviation from its maximum temperature constraints. If the ambient temperature is above their 40 °C standard, the temperature rise must be reduced by the same number of degrees. This holds the maximum allowable operating temperature constant. Temperature rise is also influenced by altitude. The thinner air at higher altitudes has a decreased capacity to cool the alternator. NEMA's standard is 1000 meters (3,300 feet) before it requires a duration factor on the temperature rise, which amounts to 1% for every 100 meters above the 1000 meters.

Summary

Reliable power is the backbone on any industry or business. Natural gas and LP fueled generators can provide long-term, reliable backup to distributed or centralized systems. How the unit is engineered, installed and applied to the customer requirement ultimately affect the functionality and success of the project. With proper design and application natural gas and LP fueled standby generators will continue to be the preferred source of power for years to come.

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[iii] "Natural Gas Vehicles Sector Summary, Section NGV Technology, Fuel Characteristics & Safety," Gas Research Institute (GRI), No. GRI-96/0432, Dec, 1996

[iv] "Alternative Fuels The Road Not Taken," Alternative Fuels Data Center, No.3623, Vol. 15, Issue 1, April 1996.

[v] "Natural Gas Vehicles Sector Summary, Section NGV Technology, Fuel Characteristics & Safety," Gas Research Institute (GRI), No. GRI-96/0432, Dec. 1996

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