White Paper

Engine Generators In Outside Plant Applications

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Anthony R. Thorne
Thomas H. Sloane
Alpha Technologies
Bellingham, WA 98225

Abstract

Compared with a battery-only backup power system, engine-generators which are integrated into curbside power nodes, as well as engine generators in standalone cabinets, offer cost savings and extend backup times from hours to days and longer. Issues of code and agency compliance are discussed along with some performance criteria for engine generators operating from natural gas and propane.

1. Introduction

The paper identifies performance characteristics of natural gas and liquid propane (LP) vapor-fueled engine generators (E-Gs) and E-G systems, mainly in the 2-kW to 10-kW power range, with dc output voltages. We specifically discuss the vapor-fuel system components of these E-G systems, focusing on safety, fuel design issues, variations of fuel characteristics by region, quality and flow issues, and system integration requirements as applied to curbside, public-access equipment and the National Fire Protection Association (NFPA). Results and experiences from over 3,000 outside plant (OSP) E-G system installations, some of which have been deployed for over four years, provide examples for these discussions. The future of curbside E-G applications will depend on cost-effective, reliable E-G system design, including enclosure, engine, generator, integrated safety systems, thermal management, and noise control along with minimal or acceptable visual impact.

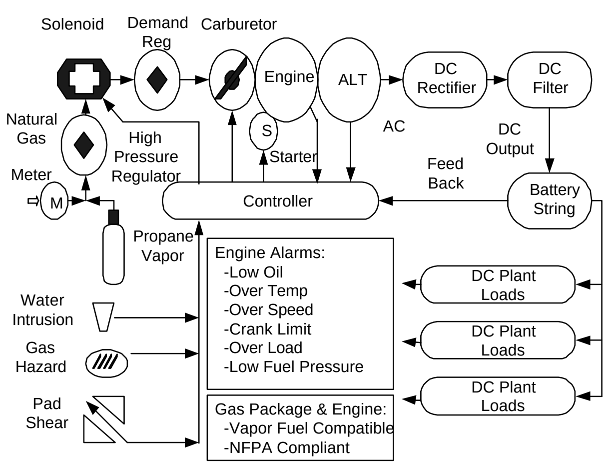

Figure 1. Block diagram of complete E-G system.

As discussed in earlier Intelecs, Bellcore requirements for eight-hour backup periods demand sizable, expensive battery plants with battery lifetimes in the OSP as short as two to four years. A cost-effective solution is a combination of a smaller battery plant, offering one or two hours backup time, and an E-G which extends backup times over days or longer. Zoning restrictions regarding physical size, line of sight, and noise ordinances conspire to require ever-smaller E-Gs with lower and lower noise levels.

Engine-generator systems within power supply enclosures are connected to either a natural gas grid for extended operation, or an on-site propane storage system when natural gas is not available. Other issues regarding installation, maintenance, fuel equipment, thermal issues, along with propane and natural gas, will be discussed in detail. Figure 1 contains a block diagram of many of the system components of a curbside E-G system along with supporting hardware. At the left of this figure, either natural gas enters the high pressure regulator through a meter, or propane enters directly with no metering. This vapor fuel passes through the high-pressure regulator which reduces the relatively high, but variable, pressure from the input source to a regulated pressure. Regional differences in the natural gas supply, even within North America, can require high-pressure regulators specific for each region. Following the high-pressure regulator is a demand regulator which provides a charge of vapor fuel proportional to engine demand routed into the carburetor venturi. At this point in the system, the energy in the fuel is converted to rotational, mechanical energy in the engine. Mechanically coupled to the engine is the alternator which converts the rotational, mechanical energy to ac electrical energy. Finally, rectification takes place to create the necessary dc voltage. The dc voltage is filtered and delivered to a parallel combination of a battery string and dc loads.

The above describes the energy conversion paths of the E-G system in Fig. 1. Although the system described up to now has the ability to create dc electric power from the LP or natural gas input fuels, control and ancillary systems are necessary to create controlled, reliable, safe system operation. Details of the feedback control system responsible for regulation of the dc output voltage are omitted from Fig. 1. One support system is formed by the controller which activates the starter and gas flow solenoid,

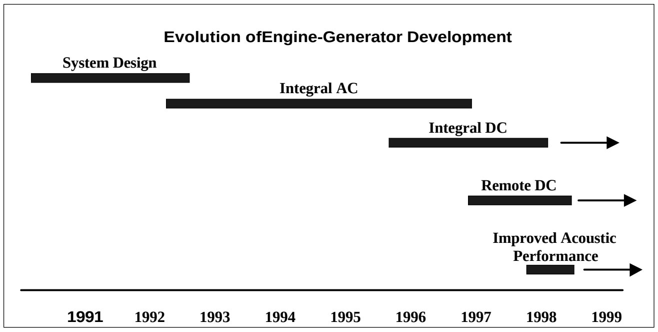

Figure 2. Time line showing industry development of E-G systems. System Design: preliminary research and development, system control and safety standards. Integral AC: hybrid fiber coaxial (HFC) and cable telephony products with 7-kW air cooled ac E-G integration for broadband deployments. Integral dc E-G for broadband and digital loop carrier (DLC) power nodes. Remote DC supports single and multiple broadband power nodes. Improved Acoustic Performance: sound attenuated designs for distributed power.

based on inputs from the engine, alternator, and battery string. Coordinated with this control function are the alarm and monitoring system which are responsible for the safety and information gathering functions of the system. Many of these individual systems and components are discussed throughout the paper.

2. System Historical Development

The development of E-Gs into a system within an enclosure adds a variety of challenges to the system designer including acoustic noise, thermal limitations, airflow dynamics, mechanical enclosure vibration, enclosure panel resonance, safety, compliance with agency requirements, and maintenance. Each of these issues are surmountable individually, and with experience, the combinations and interactions among all these constraints can be overcome to create cost-effective, reliable E-Gs for curbside deployment.

Over the last decade, several manufacturers have developed engines with specific features to support natural gas or LP operation. Features of these engines include using specialized intake and exhaust valves intended for natural gas or LP operation, pressurized lubrication systems, replaceable oil filters, high-efficiency air handling and ducting for cooling, reduced airflow restrictions, computer-designed noise abatement and attenuation systems, and safety sensors and controls to prevent catastrophic damage. As seen in Fig. 2, the system development, and evolution into a product family can consume significant research and development. Much of this effort involves developing the interfaces which interoperate with the E-G to form an integrated, coordinated system. Additional efforts are required in testing, code and agency compliance, along with field experience.

Feature	AC Output	DC Output
Transfer Switch	• Necessary • UL1008 Applies	• Unneeded
Frequency Calibration	• Necessary • 60Hz (±1.5Hz)	• Not Critical
Voltage Calibration	• Yes • AC output voltage	• Yes • DC battery voltage
Frequency Regulation with Load	• Very critical, expensive fast-responding governors	• Not applicable
E-G Oversizing	• E-G 30 to 100 percent oversized	• E-G 10 percent oversize
Parallel E-Gs	• Only with costly, synchronized controller	• Yes, master slave design
E-G System Utilization	• Typical 70%	• Typical 90%
Maintains dc battery plant	• Not directly, must have external rectifiers chargers	• Yes

Table 1. Comparison of ac and dc E-Gs. E-G oversizing may vary; in completely integrated systems, ac oversizing can be reduced to 20 percent through system coordination. Without system integration and coordination, as with ac E-Gs in standalone or remote applications, require a 100 percent oversize ac E-G. System utilization refers to the ratio between usable, load power and rated mechanical horsepower.

Independent of the features or type of fuel used by the E-G, the output voltages can be ac or dc. Although not always true, most E-G systems can be obtained with either an ac or dc output. The following section discusses the advantages and disadvantages of each.

3. Output Comparison: AC or DC

Engine-generator platforms are generally available with either an ac or dc output; each has different advantages and disadvantages. The purpose of this paper is to discuss general curbside E-G deployments, but will be more biased towards the dc version because of market direction, more efficient design, theft deterrence, and the absence of an ac transfer switch. To be sure, the tradeoffs and comparisons between ac and dc output E-Gs are still active topics among system designers, but dc has become the favored choice for deployed curbside applications. Table 1 contains a subset of some of the details which must be considered in any comparison of ac and dc E-Gs. In general, dc E-Gs have much fewer critical adjustments, especially as dynamic loads are considered. Furthermore, variations in the mechanical performance, arising from installation sites at various altitudes with fuels containing different and variable energy content, do not have first-order effects in the reliability and operation of dc E-Gs. With justification for the dominance of dc E-Gs in present deployments, different categories of dc E-Gs are discussed.

4. Engine Generator Categories:

The purpose of this section is to discuss both ac and dc E-G deployments, but since dc deployments are seeing more popularity, dc deployments will be discussed more thoroughly than ac. DC E-Gs are unlikely targets for theft, offer slightly improved operating efficiency, and do not require a transfer switch.

There are several types of E-Gs on the market, some of which can be identified very easily; but the following categories are used for the purposes of explanation.

Consumer Grade

The high volume of sales and manufacturing in the consumer market produces a very cost-effective product, although completely unsuitable as a standby power source for telecommunications. A consumer-grade E-G typically has a manual start, side-shaft direct-coupled engine with rotating field, brushed alternator, operates only from unleaded fuel, is extremely noisy, uses splash oil lubrication, and exhibits low engine lifetime. Standard electronic controls and ignition are also found in these consumer-grade products.

Contractor Grade

A contractor grade E-G is also manufactured in medium to high volumes, but uses more robust engines, optional electric start, side-shaft direct-coupled engine with rotating field alternator, with options for brushless versions that more closely approximate a sinusoidal output waveform, optional larger gas tank, yet still restricted to operation from unleaded fuel. Low tone mufflers, lubrication utilizing both splash oil and options for pressurized oil (optional), medium engine life time, more robust electronic controls and regulation circuitry round out the feature set of E-Gs within this category.

Industrial Mobile Grade

Although similar to the contractor grade, E-Gs in the industrial mobile class utilize engines compatible with liquid propane or diesel fuels, offer quieter mufflers, more robust mounting features, ruggedized electronic controls and regulation circuits, and oversized alternators rated for continuous duty.

Recreational Vehicle Grade

Although a medium-volume market, cost is not the critical factor in determining market share within this grade. More important are the features and reliability of E-Gs within this grade. Also differentiating E-Gs in this grade from other, less-expensive E-Gs are the operational characteristics, startup capabilities, quiet operation, easy access to components, extended operating lifetimes with more sophisticated electronic controls which offer dramatically improved dynamics. Design and integration of this grade of E-Gs into curbside enclosures and power nodes are possible because of the increased air flow, pressurized oil, electric start, RVIA and ANSI safety specifications, NFPA and EPA compliance of E-Gs in this grade.

Critical Grade

Critical grade E-Gs have much of the same features as industrial mobile, contractor, and consumer grades, but are found in expensive sound-attenuated enclosures, with fail-safe controls, remote monitoring and software packages for E-G control, and they meet the NFPA safety standards [7].

For curbside applications, more specialized recreational vehicle grade E-Gs include the necessary equipment and performance for successful operation in unattended, automatically-controlled communication applications. Also, this grade of E-Gs can be successfully integrated into systems enclosures to meet requisite thermal, acoustic, and safety standards.

5. Field Deployments

Deployment managers, site survey engineers, and project managers work together to place cabinets in strategic locations for access to the natural gas grid. This group must work together, along with the power system vendor to achieve and demonstrate compliance with local requirements regarding installation. Among other criteria for site selection, these sites must allow access to easements and orient the enclosure with the exhaust system away from any nearby residences.

These issues are true for any curbside power node or power supply installation, but additional design and layout requirements arise for systems and enclosures containing E-Gs where issues regarding fuels and noise include:

- Buildings and Codes requirements for local deployment, including seismic requirements.
- Traffic patterns and cabinet siting.
- Right of way access compared with private access.
- Installation restrictions with easements, private and public, or public utilities easement (PUE).
- Permits and site surveys.
- NFPA technical compliance statements for city councils (usually supplied by the E-G vendor) along with system design and compliances for local fire marshals and city councils.
- Third-party approvals and endorsements, including as an example, International Approval Services Inc, Intertec Testing Services Inc, Underwriters Laboratories, Canadian Standards Association.

Size and noise are key concerns in deployment of E-G systems enclosures into the OSP. The E-G must be as small as possible, while maintaining full operational requirements for the site-specific fuel and altitude. The E-G system must also remain a cost-effective solution compared to a battery-only backup system, and be as quiet as possible. Most smaller engines are air-cooled devices with internally mounted fan assemblies designed for use on garden tractors or portable generators. These consumer grade engines are not intended for integration into system enclosures where the increased exhaust pressure produces a decrease in cooling air flow. Newer, more aggressive engine-mounted blowers provide more airflow than typical portable generator models and thus offer system designers a solution to thermal issues. Integration and coordination among enclosure and E-G designers are critical to achieving size and noise design goals.

The requirement for increased airflow spawned research and development efforts within the E-G industry which led to improved recreational vehicle and industrial mobile grade E-Gs suitable for residential standby emergency backup systems. These air cooled E-Gs for the recreational vehicle, industrial mobile, and home standby markets are available in 3kW, 5kW, 6kW, 7kW and 8kW sizes with various engine configurations offering electric start, low oil shutdown, and optional controls.

Requirements for E-Gs used in curbside, E-G systems include operation from propane vapor withdrawal or natural gas, compliance with EPA requirements, electric starting capability, safety compliance with NFPA, UL, etc., and the ability to be externally controlled by a network management system or other controller. Unfortunately, only a small subset of E-Gs meet all these requirements. Before this small subset of candidate E-Gs can be used in a curbside E-G system, the system control and coordination interface between the E-G and network controller must be created.

5.1 Engine Details

We will discuss the aspects and design requirements for engines when utilized for unattended, automatic operation. These engines must be compatible with dry fuel operation, such as natural (Methane) 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 liquid gasoline. Compared to gasoline fuels, the effect of an engine operating on dry fuel is premature piston ring wear, regression of exhaust seats, and valve damage caused by the higher exhaust temperatures. Nonetheless, overall engine wear is significantly lower than the gasoline counterpart because natural gas and LP are cleaner-burning fuels. The engine valve train and exhaust port must be designed to operate on dry fuels [3, 4].

Pressurized and filtered oil is highly recommended. The engine lifetime is dependent on proper maintenance, engine wear and tear, and the overall ability of the engine to maintain lubrication [10]. Two methods of lubrication are possible: splash and pressurized. The splash method utilizes 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 crank shaft bearings, cam shaft and valve train components. The oil forced through the main crank shaft bearings also coats the cylinder walls by centrifugal forces.

The selection of a synthetic or standard oil for curbside E-Gs is based on the performance of the lubricant at the elevated operating temperatures found in curbside E-Gs. The integrated, remote and collocated E-Gs used for systems powering in sound-attenuating enclosures are burdened by the higher operating temperatures caused by reduced airflow. Conventional oils are less effective lubricators as their temperature rises above about 330°F. Above this temperature, the conventional oil begins to sludge, lose viscosity, and provide decreased protection to the friction surfaces, thereby accelerating engine wear. Synthetic oils, though more expensive than standard oils, have a much higher breakdown temperature, resist sludge, reduce carbon buildup, and maintain viscosity up through 400°F. The improved performance of the synthetic oil at higher temperatures adds protection, increases engine life, reduces oil changes, and decreases engine maintenance and cost.

Another issue related to lubrication and E-G life and reliability is the proper break-in and maintenance of the newly-installed E-G. Most manufacturers provide maintenance schedules for operation within the first 5 to 25 hours, which is the break-in period. During this initial operation the E-G must be operated with conventional oil to allow the valve train and piston rings to properly seat. After the initial break-in interval, the operator’s manual often recommends use of conventional 10W-30 oil, but systems engineers who utilize these commercial, industrial, or recreational grade E-Gs are placing higher demands on the oils from cooling air restrictions found in these sound-attenuating enclosures. Many E-G system integrators have influenced engine manufacturers to change engine manuals, or create systems level operator’s manuals to ensure proper oils are utilized. Based on extensive contact with all leading engine vendors, the use of synthetic oils will not void any warranties, and engine manufacturers often welcome the use of synthetics because of reduced warranty claims.

Altitude impacts carburetion, performance, and power output curves. A typical derating for small E-Gs with overhead valves, operating on propane fuel, is 3 percent per 1000’ [8]. Thus, an E-G operating at 4000’ can produce a maximum of 12 percent less power than at sea level. Systems designers must take this into account when choosing the engine platform and engine size, and also during qualification testing. In most cases, 90 percent of deployed E-G systems may be at altitudes lower than 4000', but E-Gs at higher altitudes could require the larger, more-expensive E-G platforms. Customer input is necessary to determine if a complete deployment should be burdened by the costs of a larger-size EG, but with a single, standard E-G for the complete deployment; or, if two E-Gs should be used, a smaller one at lower altitude installations and a larger E-G at higher elevations.

As fuel octane ratings vary, the operating characteristics of the engine change too. Low-compression gasoline engines typically run on 87 octane liquid gasoline with about an 8.3:1 compression [8]. With natural gas at 130 octane [8-10] or propane at 97 octane [11], the compression ratio should be increased to 9.5:1 to regain engine efficiency running at the slower burning fuels [4, 6, 8-10]. Timing also plays a major factor in the engine power. Different timing characteristics are needed for propane and gasoline. Since gasoline engines are sold in far greater quantities than propane engines, large-volume manufactures can be reluctant to adjust and provide products with modified timing for propane and natural gas, especially for low quantity engine runs (less than 10,000/year). Typical ignition timing for gasoline engines has a 29° advance which would need to be optimized and adjusted for slower-burning dry fuel. Dry fuels operate with a timing advance of approximately 34°. 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 [9]. Another advantage of operating with timing appropriate for propane or natural gas are the 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 and thereby reducing long-term effects on the valve train, muffler components, and cabinet thermal dynamics.

5.2 Engine Dry Fuel Carburetion

Dry fuel carburetion is quite different than carburetion for standard gasoline engines. Dry fuels require use of 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. Comparatively a liquid fuel device meters fuel with a float and orifice needle seat which sets the level and amount of fuel mixture in a carburetor bowl, controlled by the vacuum signal through the carburetor venturi. This design has been utilized for decades with LP vapor supplied engines for automobiles, but the demand regulator, seen in Fig. 1, must be added to curbside E-Gs, creating an added expense. Storage of gasoline at the curbside has not been allowed due to many safety and operational concerns. Propane and natural gas E-Gs in curbside deployments have been accepted as safe when properly designed and utilized.

Engine Platform and Power Rating	**Rated Horse power On Gasoline**	**Propane 2,520 BTU/ft^3**	**Natural Gas 1,000 BTU/ft^3**
3,000Watt , Air-Cooled 220cc Single Cylinder OHV	7 hp	0.88 Gal/Hr 3.7 Pound/Hr	80 **ft^3**/Hr
3,500 Watt, Air-Cooled 360cc Single Cylinder OHV	9 hp	1.2 Gal/Hr 5.1 Pound/Hr	106 **ft^3**/Hr
4,500–6,000 Watt Air-Cooled 480cc V-Twin OHV	14 hp	1.5 Gal/Hr 6.4 Pound/Hr	120 **ft^3**/Hr
7,000–8,000 Watt Air-Cooled 560cc V-Twin OHV	19 hp	1.85 Gal/Hr 7.8 Pound/Hr	145 **ft^3**/Hr
12,000 Watt Liquid cooled 1.6L, 4-Cyl engine	24 hp	3.5 Gal/Hr 15 Pound/Hr	277 **ft^3**/Hr

Table 2. Laboratory acquired fuel consumption for engines sizes from 3kW to 12kW.

In addition to variations in E-G output power from operation at differing altitudes, the energy content of the regional natural gas varies. Internationally, in countries with warmer climates, butane is added to the propane to increase the boiling level of propane. An undesired side effect of this addition of butane is the lowering of the energy content of the natural gas from a normal, 130 octane to approximately 87 octane, for example as in Malaysia.

Most deployed E-Gs in North America operate from natural gas, with about five percent using stored LP propane vapor withdrawal system. Propane has a specific standard BTU content in North America of 2,516 BTU/ft^3 at 60°F [1], while natural gas in the U.S. has an average energy content of 1,035 BTU/ft^3 [2], but this varies by region. Wisconsin, for example, has an energy content of approximately 850-920 BTU/ ft^3, southern Georgia about 800-850 BTU/ ft^3, and Washington state about 1,000-1,100 BTU/ ft^3. Regional natural gas variances must be accounted for during system design to ensure output power curves are sufficient for engine demand with an EPA-approved fuel calibration device that complies with applicable sections of CARB (California Air Research Board) dependent upon the engine family. Measured fuel consumption rates are contained in Table 2.

6. Audible Noise

The system enclosure may have several sources of noise-generating devices such as exhaust fans, transformers, heat exchanger fans, and pulse-width modulated (PWM) charging. Power system noise levels are typically below 70dBA when measured at distances of 5’ (1.5m) and farther. The presence of a curbside E-G and its placement causes many concerns in the local communities, but nuisance noise is perhaps of most concern to nearby residents. Nuisance noise is a directional noise which can cause discomfort during E-G operation to nearby residential occupants. These concerns with audible impact on neighborhoods are mitigated by recent technology advances in mufflers, flame-resistant sound dampening materials, and intake air sound attenuators. These advances combined with improved cabinet airflow produce systems enclosures with integral E-Gs which produce measured noise levels of 67dBA at a 5’ distance. For comparison, an automobile operating at idle is approximately 72dBA. Other general issues surrounding the mitigation of audible noise are now discussed. Figure 3 contains measured audible levels from an example E-G. Note the asymmetry of these emissions; by design, the noise is intentionally directed towards the street and away from residences located behind the curbside E-G.

6.1 Engine-Generator Speeds

Advances in system controls using variable-speed technologies and permanent magnet generators (PMGs) have allowed system designers to reduce overall system noise using engines and control systems which operate the engine at minimum possible speed (rpm). Typically, loads seen in these OSP applications are not constant, but instead exhibit slow, long-term variations of as much as 30 percent. A PMG has a constant magnetic field, and thus the output of a PMG produces a voltage approximately proportional to rpm: at higher rpm , output voltage increases. Since the maximum output current is determined by the current capacity of the stator windings, changes in output voltage as rpm varies affect the maximum output power too. In a closed-loop voltage control system, as the load increases, the voltage will decrease slightly, and the feedback causes an increase in rpm to maintain a constant, regulated voltage.

AC output E-Gs with field windings must be run at constant speed to maintain an output frequency within the output frequency regulation specifications. DC output E-Gs, on the other hand, can be coupled to a PMG and operate as a variable-speed device. The increased efficiency of a dc E-G is attained because the PMG does not require field current excitation and the associated losses, and also because the variable engine speed offers increased overall fuel efficiency.

Operating the E-G with a load-based speed-control system typically produces quieter operation during times of light

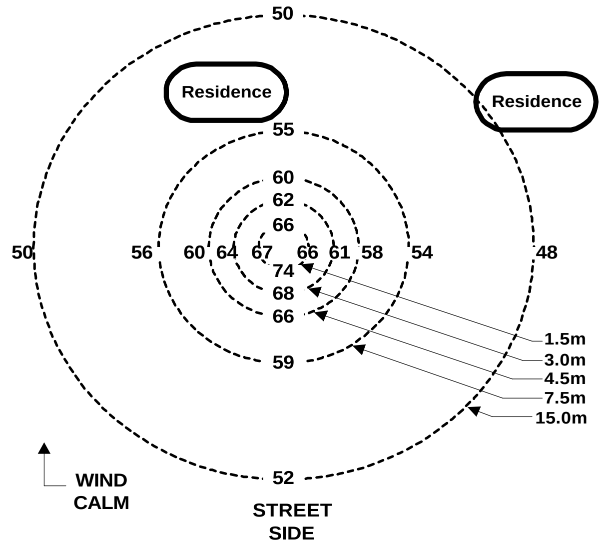

Figure 3. Typical sound diagram of systems location and orientation towards the residence and street regarding noise levels. Ambient noise levels of 43dBA.

loading which can reduce engine wear and friction losses, increasing E-G lifetime, and allows noise control devices to be more effective. Some dc E-Gs use a constant-speed control system and control the output voltage with a variable field generator in place of the PMG alternator, so these systems do not benefit from the variable speed advantages regarding noise, engine life, and fuel efficiency.

Airflow Dynamics Vs Noise

The enclosure airflow is routed such that output airflows and exhaust are vented on the street side of the enclosure, and input airflow for cooling air and engine combustion use the rear of the cabinet. These airflows direct the majority of engine noise away from residences located at the back of the E-G enclosure. The exhaust air stream is mixed with exhaust input cooling air to introduce turbulence which serves to reduce the high-frequency audible components without creating excessive back-pressure. Left unattended, these high-frequency components would be a significant contributor to nuisance noise.

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. Thus, back pressure is reduced significantly, increasing engine power [12].

6.2 Noise Summary

Experienced E-G system designers must create E-G systems by making design decisions which 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. Quieter E-Gs generally add cost.

Through proper noise control design at a system level, 67dba at 5' is acceptable with many city councils when the nuisance noises are eliminated. Source of nuisance noises include engine valve clatter, high-frequency blower noise, crankshaft knocking, expansion bang from the muffler case, expanding exhaust bang out the tail pipe, and panel resonance within the enclosure, all of which must be mitigated.

Other design techniques such as pointing the output airflow and exhaust to the street side of the enclosure, proper site surveys to prevent locating systems near noise abatement areas (hospitals, day care, etc.), and layout of the site to utilize the environmental attenuators such as shrubs and fences, or other noise-absorbent landscaping, can create a very quiet E-G installation. Such installations reduce the visual exposure and community impact, and ultimately reduce the burden to the city council who often are the first to hear community complaints.

The enclosure should be designed for public access areas, thus all air intakes and screens, doors, access panels, external appendages (utility boxes or gas regulators) should be designed in such a way that children cannot get injured if playing on or near the enclosure. External panels cannot be too hot. 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 the environment hazards such as wind-driven rain, snow, wind, or other public hazards such as riots or vandalism.

7. Electrical Considerations

A dc E-G which provides backup to a dc plant, offering a virtually unlimited battery string, must be designed to minimize the ac ripple imposed onto the batteries. Excessive ac ripple can damage the battery string, create regulation issues with the dc plant devices, or cause noise or harmonics to be generated onto the output communications devices. DC generators with ac ripple too large for the loads can use a dc filtering device between the battery string and dc rectifier, as seen in the Fig. 1 block diagram. DC E-Gs require more coordination among load and battery plant than a standard ac E-G because the dc E-G can directly affect the battery current and because the dc E-G can be overloaded during full-load operation while recovering from a deeply-depleted battery string. Also, the battery string can be damaged by extended overcurrent if the dc output of the E-G overcharges a depleted battery string for extended periods. The typical recharge rate for gell cell batteries is C/10, or, with AGM batteries, C/4. For example, a 100 AHr gell cell battery string should have a maximum extended recharge current of nominally 10A. Short duration, less than 3 seconds, recharges as high as C/2 will not damage most battery strings if the occurrence does not heat the batteries, or does not increase the battery voltage above the float voltage level. For this reason, dc E-Gs should incorporate an active current limit feature.

Typical gell-cell or AGM battery float charge voltage is approximately 2.3v/cell. The E-G operates during emergent or emergency conditions, so the E-G dc output voltage is reduced to 2.18v/cell, below the battery string float voltage to prevent overcharging. Through experience gained over thousands of field deployments and years of field experience, battery strings can be maintained indefinitely at this level without reducing battery lifetimes.

Amp Hr of Batteries and Generator Size

The E-G is a mechanic device which produces variable output power and if improperly sized and poorly integrated into a system, the E-G has the ability to damage a battery string. To eliminate the risk of damaging battery strings, the battery string amp hour capacity should exceed the generator power rating by about 25 percent. From years of testing, including battery pack thermal destructive testing, and industry recommendations, battery pack capacities which exceed E-G power by 25 percent provide excellent battery lifetime results.

Maximum Power Overhead for DC Gen-Sets

The designed load range for a dc E-G should be rated for the following:

- Natural gas (lowest thermal BTU content, typically 850BTU/cubic foot)
- High-temperature operation (assuming full load operation until thermally stable)
- Oversized for at-altitude deployments.
- Full rated output load for chosen fuel type.
- Oversized for power consumption of battery cabling, rectifier, filter, and battery losses.

$$P_{E-G} = P_{Full\ Load} + P_{Losses} + P_{Altitude,derate} + P_{Recharge}$$

8. Competing Technologies

- Fuel Cell
- Flywheel
- New battery technologies

Limitations

- Time to market
- Cost
- Risk of components in deployed infrastructure
- Fuel converter (Fuel Cell) reformer

- Spare parts
- Availability of multiple source vendors
- Replacement costs
- Environment variables versus history of design (new designs still may have bugs)
- Peripheral equipment & availability

The advances in piston engine technology, research performed by the Gas Research Institute (www.gri.org), and funding by other commercial and government institutions have provided the telecommunications industry with an interim solution until fuel cells, flywheels, or new battery technologies become deployable. With present-day E-Gs, and the large, worldwide volume of E-Gs in manufacture piston-based E-Gs will remain a viable power solution for deployed OSP for some years to come, possibly for the next several years.

9. Summary

Reliable power is the backbone of the telecommunications industry. New technology must be proven, cost-effective, and provide a systems solution comparable to or better than existing standards of reliability required today for lifeline services, data transfers, etc. Natural gas E-Gs provide long-term, reliable backup to distributed or centralized systems, regardless of the intended application. Engine-generators systems are also deployable for propane fuel when natural gas infrastructure is not available. These E-G systems absolutely must be monitored for alarms, tested for reliability, comply with NFPA and local city emergency response teams and requirements.

[1] American Gas Association (AGA), www.aga.com

[2] Institute of Gas Technology, www.igt.org

[3] Treuhaft, Martin B., Buckingham, Janet P., "Laboratory Evaluation Of Engine Ring Wear Under Natural Gas And Gasoline Operation," Gas Research Institute (GRI), No. GRI-91/0359, Nov. 1991, prepared by Southwest Research Institute, No. SWRI-0750-123 PB# PB93-220903.

[4] Bickerton, R A, Synder , W. E., and Buckingham, Janet P., "Development of Advanced Combustion Technology For Medium and High Speed Natural Gas Engines," Gas Research Institute (GRI), No. GRI-89/0316.3, Feb. 1989, PB # PB92-127117.

[5] Frame, Edwin A., "Natural Gas Lube Oil," Gas Research Institute (GRI), No. GRI-91/0141, June 1991, Natural Gas Engine Technology, Prepared by Southwest Research Institute, No. SWRI-3178-1.4PB# PB92-10 1492.

[6] "Values for Natural Gas, refer to Manual for Determination of Super-Compressibility Factors for Natural Gas," American Gas Association, 1515 Wilson Boulevard, Arlington Virginia 22209, phone 703-841-8400.

[7] National Fire Protection Association, NFPA 37 "Standard for the Installation and Use of Stationary Combustion Engines and Gas Turbines," NFPA 54 "National Fuel Gas Code," NFPA 58 "Standard for the Storage and Handling of Liquefied Petroleum", and NFPA 110 "Standard for Emergency and Standby Power Systems."

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