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BI-FUEL POWER:

A NEW ENERGY ALTERNATIVE

This unique system gives facility engineers the ability to operate their diesel generators in peak-shaving and/or co-generation programs, *while utilizing natural gas as their primary fuel.* In fact, up to 80% of the generator's fuel requirement can be met using pipeline-supplied natural gas. In the event natural gas service is interrupted, the generator will automatically revert to 100% diesel operation, with no loss in generator power output. The Bi-Fuel System has been designed as an affordable and efficient engine technology which gives facility operators additional flexibility in managing their energy needs. By utilizing clean, inexpensive natural gas as their primary fuel, operators can enjoy the benefits of peak shaving and/or co-generation white addressing the concerns normally associated with extended operation of emergency generators such as:

- On-site fuel storage requirements
- Operational fuel costs
- Emissions issues

For many facilities, the emergency power system (EPS) is rarely used, due to the high reliability of utility-provided power in the U.S. Aside from periodic use to check the operational readiness of the EPS as required by code, these systems normally sit dormant waiting for the power to go out. Thus, the EPS represents a significant, albeit necessary investment, which does not provide a return in the conventional sense. However, the Bi-Fuel System will arrow facility engineers to safety utilize their EPS to reduce the energy costs of their facilities, without compromising its readiness, capability or reliability. For those facilities who are already using their EPS for energy management programs, intruding peak-shaving, co-generation, toad-control, etc., the Bi-Fuel System will significantly reduce the operational cost of their generator(s) and increase the savings realized from these programs.

THE BI-FUEL SYSTEM

The Bi-Fuel System operates by blending diesel fuel and natural gas in the combustion chamber. This is achieved using a pilot-ignition, fumigated gas-charge design, whereby natural gas is pre-mixed with engine intake-air and delivered to the combustion chamber via the air-intake valve. The air-gas mixture is ignited when the diesel injector sprays a reduced quantity of diesel fuel into the chamber. This diesel "pilot" acts as the ignition source for the primary air-gas combustible. Because of the high auto-ignition temperature of natural gas, the air-gas mixture will not ignite during the compression stroke, as there is not enough heat present to facilitate combustion.

Because the OEM air-intake and diesel injection systems are utilized by the Bi-Fuel System, no engine modifications are required for installation. The various components of the Bi-fuel System are installed externally of the engine, and at no time is the engine disassembled during installation. All OEM engine specifications for injection timing, valve timing, compression ratio, etc., remain unchanged after installation of the Bi-Fuel System.

The Bi-Fuel System requires a low pressure natural gas supply (approximately 2-5 psi) with a flow rate of approximately 8 scfh/kW (i.e. 500 kW=5,000 scfh).

The primary components of the Bi-Fuel System include:

- Bi-Fuel Control Panel
- Diesel Fuel Control Valve
- Gas Control Valve
- Gas Power Valve
- Manual Gas Valve
- Gas Solenoid Valve
- Air-Gas Mixer
- Gas Pressure Regulator
- Natural Gas Pressure Transducer Manifold Air Pressure Transducer Engine Vacuum Transducer(s) EGT Thermocouples

INSTALLATION

The Bi-Fuel System is applied "in-field" by trained technicians, with the installation normally taking anywhere from a few hours to a few days depending on the size of the generator. During nearly all of the installation process, the generator can be utilized for emergency power with little or no starting delay. Actual downtime of the generator is limited to only a few minutes, and rental back-up power is normally not required during installation of the System.

After installation of the Bi-Fuel System hardware, the generator is then operated under various load settings (normally with the use of a resistive load bank) while the System is checked and calibrated. After this "tune-in" process is completed, the generator is fully tested in Bi-Fuel mode to assure proper operation of the Bi-Fuel System and generator during Light, medium, heavy and transient loads. Finally, the generator is tested in 100% diesel mode to verify that its 100% diesel performance has not been effected by installation of the Bi-Fuel System.

PERFORMANCE

Installation of the Bi-Fuel System in no way compromises the performance of the generator relative to the rated Load of the machine. A generator with a 1000 kW stand-by rating which has been retrofitted to the Bi-Fuel System will still provide 1000 kW of power in both 100% diesel and Bi-Fuel modes. In other words, the generator is not de-rated after installation of the Bi-Fuel System. Similarly, there is no decrease in generator load response or stability white operating in either fuel mode.

The Bi-Fuel System has been designed to allow for transition between fuel modes without the necessity of unloading the generator. In fact, the converted generator can transition from 100% diesel to Bi-Fuel and back again, white at full rated toad. This transition occurs without any significant change in generator stability or power-output.

Engine heat-rejection rates and efficiency during Bi-Fuel operation are nearly identical to 100% diesel performance and as such, peak engine exhaust gas, water jacket and oil temperature values remain within the parameters established by the engine manufacturer. As such, generators utilized in co-generation programs will achieve equivalent heat recovery performance on either 100% diesel fuel or Bi-Fuel. Because engine-operating temperatures are maintained within Limits, engine wear-rates are not increased due to Bi-Fuel operation; in fact, engine wear may actually be reduced during Bi-Fuel operation due to the clean-burning characteristics of natural gas.

SAFETY

The Bi-Fuel System incorporates a sophisticated, electronic control system, which controls both natural gas and diesel fuel during operation. In addition, the Electronic Control System (ECS) acts as an engine safety device, by monitoring up to 24 critical data channels including:

- Exhaust Gas Temperature-Stack
- Exhaust Gas Temperature-Cylinder
- High engine manifold air pressure (turbo-boost)
- Low natural gas supply pressure
- High natural gas supply pressure
- High engine vacuum
- Oil pressure

The various data channels are displayed on the ECS via an LCD display in either text or graphical format. The ECS notifies the user locally (via an LED general fault tight) or remotely via modem, in the event of a fault. If a fault is detected, the ECS will automatically switch the generator to 100% diesel operation and data-Log the fault. The ECS fault set points are field adjustable and allow installation technicians to customize the Bi-Fuel System to the specific requirements of the customer and/or the operational limitations set-forth by the engine manufacturer. Once programmed, the fault settings are protected by a keypad lockout code, which prevents unauthorized personnel from altering the set points.

The ECS guarantees that in the unlikely event of either a Bi-Fuel System malfunction, or a disruption in natural gas supply pressure (either low or high pressure faults), the generator drive engine will be protected from damage. Most of the monitored channels are Latching type faults, i.e. if the Bi-Fuel System is deactivated by the ECS, the generator cannot be returned to Bi-Fuel operation until the ECS panel is manually reset. Lastly, the ECS also incorporates a built-in time delay function, which prevents initiation of Bi-Fuel operation after generator start-up, for a period of up to 300 seconds. This feature is used when the converted generator is used in paralleling operations, and allows the generator to start-up and synchronize on 100% diesel fuel before automatically switching to Bi-Fuel operation.

BI-FUEL SAVINGS

Savings derived from the use of the Bi-Fuel System are the result of the differential between the cost per kWh charged by the utility and the cost per kWh to produce power with a Bi-Fuel generator. Due to the premium prices which utility companies usually charge for on-peak electricity, it is often most viable to operate the Bi-Fuel generator as a peak-shaver, whereby power is produced on-site only during those hours when electricity is at it's highest price from the utility.

In order to determine the cost of producing power with a Bi-Fuel generator, several factors must be considered including:

- Cost of natural gas
- Cost of diesel fuel
- Cost of maintenance program for generator
- Cost of future engine overhauls

A typical example of Bi-Fuel savings for a 500 kW peak-shaving project would look as follows:

Facts and Assumptions	
Fuel consumption @ 500 kW:	35 gph (100% diesel)
Peak hours per year:	1500
Gas ratio:	70%
Diesel cost:	$0.95 per gallon
Natural gas cost:	$0.40 per therm (100 scf)
Maintenance cost:	$.020 per kWh (includes overhauls)
On-peak utility costs per kWh:	$0.12

Bi-Fuel Operations	
Diesel use per hour:	10.5 gallons (35 gph x .30)
Diesel cost per hour:	$9.98 (10.5 gph x $.095)
Gas use per hour:	34.3 therms*
Gas cost per hour:	34.3 therms x $0.40= $13.72
Total fuel cost per hour:	$23.70
Total fuel cost per kWh:	$0.047 ($23.70) 500kW)
Estimated maintenance:	$0.020 (includes overhaul costs)
Total Bi-Fuel cost per kWh:	$0.067

Savings	
Bi-Fuel savings per kWh:	$0.053
Bi-Fuel savings per hour:	$26.50
Bi-Fuel savings per 1500 hours:	$39,750 (750,000 kWh)

* 1 gallon #2 diesel = 140 scf natural gas based on #2 diesel hhv of 140,000 btu/gallon and natural gas hhv of 1,000 btu/scf; 35 gph diesel x .70= 24.5 x 140 scf = 3,430 scf = 34.3 therms

In the case of diesel prime power operations, the Bi-Fuel System will provide savings to the operator relative to the cost differential between the two fuels. In this case, operational costs other than fuel costs are not considered as these costs will be equal to or less than 100% diesel operation during Bi-Fuel operation:

Facts and Assumptions	
Fuel consumption @ 500 kW:	35 gph (100% diesel)
Hours per year:	8000
Gas ratio:	70%
Diesel cost:	$0.95 per gallon
Natural gas cost:	$0.40 per therm (100 scf)

100% Diesel Operation	
Diesel use per hour:	35 gph
Diesel cost per hour:	$33.25
Diesel cost per year	$266,000

Bi-Fuel Operations	
Diesel use per hour:	10.5 gallons (35 gph x .30)
Diesel cost per hour:	$9.98 (10.5 gph x $.095)
Gas use per hour:	34.3 therms*
Gas cost per hour:	34.3 therms x $0.40= $13.72
Total fuel cost per hour:	$23.70

Savings	
Bi-Fuel savings per hour	$9.55
Bi-Fuel savings per 8000 hours	$76,400 (4 million kWh)

* 1 gallon #2 diesel = 140 scf natural gas based on #2 diesel hhv of 140,000 btu/gallon and natural gas hhv of 1,000 btu/scf; 35 gph diesel x .70= 24.5 x 140 scf = 3,430 scf = 34.3 therms

Gas Company Participation

In the example Bi-Fuel energy programs above, the generators will use approximately 50,000 and 270,000 therms of natural gas per year respectively. These figures represent a significant increase in natural gas use for a facility, and will often allow the Local gas company to subsidize all or part of the Bi-Fuel conversion cost. In addition to gas company rebates for the Bi-Fuel System, the increased gas use may also "bump" the total facility gas-load up enough to get a Lower overall gas rate. In one example, a customer had a total savings of $80,000 per year with Bi-Fuel. Approximately 50% of this savings was realized from the lower gas rate that the customer was given by the utility due to the increased gas Load of the facility.

Summary

The Bi-Fuel System enables facility engineers to operate their EPS in a more cost effective manner by replacing a significant portion of the generator's diesel fuel requirement with natural gas. This technology has been designed to allow operation of a converted generator on a high percentage of natural gas, without the requirement to alter or modify the original design of the generator drive-engine.

After conversion to Bi-Fuel, the generator still maintains the ability to operate on 100% diesel fuel. The Electronic Control System insures that the generator drive-engine is thoroughly protected during Bi-Fuel operation by continuously monitoring critical engine parameters and by automatically returning the engine to 100% diesel operation in the event of fault detection. The design of the Bi-Fuel System insures that the generator can seamlessly transition from Bi-Fuel operation to 100% diesel operation and back again with no interruption in power output.

BI-FUEL CONVERSION SYSTEM
TECHNICAL OVERVIEW

The Bi-Fuel Conversion System allows conventional, reciprocating diesel engines to be operated utilizing a mixture of natural gas and diesel fuel. The Bi-Fuel Conversion System (BFCS) has been designed to allow diesel engines to operate on a mixture of natural gas (gas) and diesel fuel, with gas percentages typically ranging from 40% to 90% of total fuel consumed. The BFCS allows users to adjust gas-diesel fuel mixtures according to the specific requirements of the converted engine. The System has been designed to work with all grades of diesel fuel (#1, #2, #3 and heavy/bunker fuel) and with all methane gas types (including natural gas, bio-gas, well-head gas, etc.). Primary to the design of the BFCS is the ability of the engine to be automatically returned to 100% diesel operation in the event of any of the following fault conditions:

High Exhaust Gas Temperature
Low Natural Gas Pressure
High Natural Gas Pressure
Low Engine Oil Pressure
High Engine Manifold Pressure (MAP)

The engine may also be returned to 100% diesel operation manually by the operator. This is accomplished by a master Bi-Fuel on/off switch located on the BFCS main control panel. The BFCS has been designed so that in the event of either automatic or manual switching from Bi-Fuel mode to 100% diesel operation (and vice-versa), engine power output and stability is not interrupted.

The primary components of the BFCS are:

Bi-Fuel Control Panel
Diesel Fuel Control Valve
Gas Control Valve
Gas Power Valve
Manual Gas Valve
Gas Solenoid Valve
Air-Gas Mixer
Gas Regulator
Natural Gas Pressure Transducer
Air Manifold Pressure Transducer
EGT Thermocouples

The BFCS consists of three major sub-systems:

1. *Gas Control Sub-System*
2. *Diesel Control Sub-System*
3. *Electronic Monitoring and Control Sub-System*

Each of these three sub-systems are integrated such that their function relative to each other is seamless. The following is a description of each sub-system's operational details:

Gas Control Sub-System

The gas control sub-system (GCS) has been designed as a means of controlling the amount of gas supplied to the engine while operating in Bi-Fuel mode.

The GCS has been designed to allow the engine to utilize methane gas types with a supply pressure of between 1 and 5 p.s.i. The GCS design is "scaleable" so that it can be adapted to various size engines requiring differing gas flow rates. This includes engines with multiple turbochargers and/or superchargers and multiple air intakes. The GCS consists of a manual shut-off valve connected to supply gas at 1-5 p.s.i. The manual shut-off valve is included in the system for safety purposes as a positive control device which allows all gas flow to the BFCS to be stopped in the case of an emergency (gas leak, fire, etc.).

Downstream of the manual shut-off valve, a gas pressure sensor is installed which allows the BFCS to automatically switch to 100% diesel mode in the event that gas pressure drops below a specified set-point, or alternately, exceeds a maximum pressure value.

Downstream of the pressure sensor is located an electrically operated solenoid valve which provides a means for the BFCS to automatically stop gas flow to the engine in the event of either manual shut-down of the BFCS, automatic shutdown of the BFCS, or in the case of a shut-down of the engine. This design has been adopted in order to insure that positive pressure gas flow is stopped prior to reaching the gas regulating valve, which thus prevents gas flow into the engine at those times when it is not required.

Located downstream of the gas solenoid valve is the gas pressure regulator. The gas pressure regulator is a zero-governor, demand type regulator. The regulator reduces the inlet gas pressure (1-5 p.s.i.) to atmospheric pressure, whereby vacuum is required at the regulator outlet in order for gas to flow downstream from the gas regulator to the engine. This design has been adopted to allow the BFCS to utilize a "demand" gas control scheme whereby engine vacuum and intake airflow is utilized to determine gas flow requirements of the engine. As engine load increases, there is a corresponding increase in engine intake air volume and vacuum, and this vacuum is communicated to the gas pressure regulator which adjusts gas flow according to the strength of the vacuum signal generated by the engine (light load -low vacuum =low gas flow / high load =high vacuum =high gas flow).

Located downstream of the gas regulator is the gas control valve. The gas control valve is a butterfly type valve which is one of the adjustable components of the BFCS, and is set during the tune-in phase of the engine conversion. The gas control valve is an electrically operated valve which can be either fully open (de-energized state) or partially open (energized state). The "partially open" position of the gas control valve is adjustable to allow the BFCS to have a separate gas flow adjustment for light to medium engine load levels, and makes the BFCS more flexible for installation on engines which operate over a wide spectrum of load levels. The gas control valve is scheduled via the BFCS main control panel by monitoring engine MAP levels as determined by a sensor and control module. As engine load level increases to the medium to high level range, the gas control valve is commanded to open fully and no longer restricts gas flow to the engine.

Located downstream of the gas control valve is the gas power valve. The gas power valve is a needle type valve which is one of the adjustable components of the BFCS, and is set during the tune-in phase of the engine conversion. The power valve is used to set the maximum gas flow rate to the engine and once set, remains in a fixed position regardless of engine load. The power valve is the primary adjustment for setting gas flow levels at the medium to high load levels and acts as a safety device by restricting gas flow to a pre-determined maximum flow rate. Once the power valve is set, engine power output in Bi-Fuel mode is limited by this adjustment.

Located downstream of the gas power valve is the air-fuel mixing device. The mixer is of a fixed venturi design and is installed upstream of the engine air-intake, such that all of the incoming air is directed through the mixer. In the case of engines with multiple air-intake systems, one mixer is used for each of the intakes. The BFCS has been designed to utilize mixing devices which do not incorporate any type of air throttle plate in their design. By utilizing a "demand" regulator and a "fixed venturi" type mixer, the BFCS insures that the basic engine operating efficiency will not be negatively impacted by use of the System.

Conventional diesel engines do not utilize an air-throttle device thereby avoiding "pumping losses" which incur significant efficiency penalties. Similarly, the BFCS does not utilize a throttle plate in it's design and thereby maintains an efficiency level during Bi-Fuel operation comparable to 100% diesel operation. After exiting the mixing device, the air-gas mixture is then ingested into the engine air-intake manifold system where it is then distributed to each intake valve as per the normal intake air distribution scheme of the engine. As each intake valve opens as per the valve timing scheme of the engine, the air-gas mixture is delivered to the cylinder for combustion.

Diesel Control Sub-System

The diesel control sub-system (DCS) has been designed as a means of controlling the amount of diesel fuel supplied to the engine while operating in Bi-Fuel mode. The DCS utilizes either a Diesel Fuel Control Valve (DFCV), or alternately, a solenoid operated rack actuator. In either case, the role of the DCS is to limit the total possible diesel fuel flow thereby allowing for the substitution of natural gas.

The primary component of the DCS is the diesel fuel control valve (DFCV) which is installed in the fuel system of the generator. The DFCV is an electrically operated 3-way valve (12VDC or 24VDC) which incorporates an internal needle valve assembly. The DFCV can be manually adjusted such that when in the energized state, the flow of diesel fuel through the valve is significantly restricted, thereby effectively decreasing the quantity of diesel fuel supplied to the engine and allowing for substitution of the above described air-gas mixture during Bi-Fuel operation. For engines with duty cycles that include wide variations in load, an alternative DFCV device may be used which employs a secondary internal needle valve assembly. This allows for fine adjustment of diesel fuel flow in both the light to medium and medium to heavy load ranges. In this case, the DFCV is scheduled via the BFCS main control panel by monitoring engine MAP.

Installation of the DFCV will vary according to the fuel delivery system design of the engine. Typically, two types of fuel delivery systems are employed; (1) rail type systems which supply fuel to rocker-arm activated diesel injectors via a fuel galley under relatively low pressure and (2) positive displacement systems which activate each injector with high pressure diesel fuel from a distributor type pump. In the case of the fuel rail type systems, the DFCV is installed between the pump supplying fuel to the fuel rail and the rail inlet orifice (see figure 2). In the case of distributor pump type fuel systems, the DFCV is installed directly upstream of the injection pump fuel inlet orifice (see figure 3).

When in the de-energized state, the DFCV restores full diesel fuel flow capacity by diverting the fuel path around the internal needle valve cartridge, thereby allowing the engine to operate in 100% diesel fuel mode. Additionally, the DFCV assembly includes a means for relieving fuel back pressure which results on the inlet side of the valve as a result of the needle valve restriction. As fuel pressure increases past approximately 60 p.s.i., a one-way check valve with a cracking pressure of 60 p.s.i, allows diesel fuel to flow to the diesel fuel return system thereby relieving potentially harmful fuel back pressure.

Electronic Control and Monitoring Sub-System

The Electronic Control and Monitoring Sub-System (ECMS) has been designed as a means of controlling various components of the BFCS and also provides a means to monitor critical engine and system parameters and display faults and system status to the user locally and/or remotely. The ECMS has a general fault indicator light and an alpha-numeric LCD display to notify the user of the type of fault and the time which it occurred. All faults except low engine MAP are 'latching" faults which require the operator to reset the ECMS before Bi-Fuel operation will resume. In addition, the ECMS can "call-out" via land line or serial port to notify the user of a fault condition.

The ECMS is powered from the engine panel or starting batteries with 24 VDC. Current flows to the ECMS through the OEM oil pressure safety system. If the engine loses oil pressure, the ECMS will deactivate Bi-Fuel operation. The ECMS provides source power to the various components of the Bi-Fuel System and also monitors the following parameters:

Engine Exhaust Gas Temperature:

The ECMS includes a means for monitoring and displaying engine exhaust gas temperature (EGT). In the case of engines with dual exhaust systems (such as v-configured engines), each exhaust system can be independently monitored. EGT is displayed on the ECMS main panel via digital display. In the event that EGT (for either channel) exceeds a user programmed set-point, the ECMS will automatically shut-down the BFCS, return the generator to 100% diesel operation and notify the user via a panel mount LCD. Additionally, the ECMS will not re-start Bi-Fuel operation until the EGT fault has been reset by the operator.

Natural Gas Pressure:

The ECMS monitors natural gas input pressure to the Bi-Fuel System via a pressure transducer. The ECMS is field programmed to allow for a "window" of acceptable gas pressure. In the event that the gas pressure should drop below or rise above the programmed set-points, the ECMS will automatically shut-down the BFCS, return the generator to 100% diesel operation and notify the user via a panel mount LCD. Additionally, the ECMS will not re-start Bi-Fuel operation until the gas pressure fault has been reset by the operator.

Manifold Air Pressure:

The ECMS monitors engine MAP via a pressure transducer. This pressure data allows the user to set two (2) MAP set-points. The first set-point determines the "light-load" Bi-Fuel cut-off point. At engine loads below this level, the ECMS will deactivate the Bi-Fuel System and return the engine to 100% diesel fuel. The second set-point determines the maximum allowable engine MAP during Bi-Fuel operation. The operator can program the ECMS to limit the maximum allowable engine power in Bi-Fuel mode. If engine load exceeds this programmed limit, the ECMS will automatically shut-down the BFCS, return the generator to 100% diesel operation and notify the user via a panel mount LCD. Again, the ECMS will not re-start Bi-Fuel operation until the MAP fault has been reset by the operator.

The BFCS also incorporates a master "on-delay" time relay which is utilized with engines used as generator drives in paralleling operations. In the event that the generator is required to parallel with either another generator or the electric utility grid, the BFCS will delay initiating Bi-Fuel mode until such time as the generator has completed the paralleling operation on 100% diesel fuel. This "delay-on" function is field-adjustable and gives the user from 1 to 300 seconds to complete the paralleling operation before Bi-Fuel mode is initiated.