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Performance Evaluation of Biodiesel Fuelled Electrical Generation

J. M. Kennedy, R. J. Best, *Member, IEEE*, D. J. Morrow, *Member, IEEE*, and B. Fox

Abstract-- This paper investigates the performance characteristics of rapeseed methyl ester, EN 14214 biodiesel, when used for electrical generation in compression ignition engines. The work was inspired by the need to replace fossil diesel fuel with a sustainable low carbon alternative while maintaining generator performance, power quality and compliance with ISO 8528-5. A 50 kVA Perkins diesel engine generator was used to assess the impact of biodiesel with particular regard to gen-set fuel consumption, load acceptance and associated standards. Tests were performed on the diesel gen-set for islanded and grid-connected modes of operation, hence both steady-state and transient performance were fully explored. Performance comparisons were made with conventional fossil diesel fuel, revealing minimal technical barriers for electrical generation from this sustainable, carbon benign fuel.

Index Terms—Biodiesel, Diesel-Driven Generators, Distributed Generation, Real-Time Control, Sustainability, Transient Response.

I. INTRODUCTION

ELECTRICITY is the fastest growing form of end-use energy globally, representing an increasing share of projected worldwide energy consumption up to 2030 [1]. One reason for the increase is the electrification of the heat and transport sectors, which can subsequently avail of electrical energy generated from renewable sources like wind. In addition, conventional thermal generators are becoming more efficient, so the net effect is a cleaner, more sustainable electric power industry. It is also accepted that the increased electrification of the heat and transport sector will outweigh energy efficiency measures increasingly adopted by domestic and industrial consumers, such that the trend is a steady growth in system demand.

Under the traditional planning approach, significant increases in electrical load would instigate the reinforcement or construction of both new transmission lines and generation capacity to meet this demand. However, in the developed world the lead time for individual transmission reinforcement is typically 7 to 10 years [2]. Indeed, in developed countries, the design and build of new lines, which require new rights-of-way, may in some cases be blocked completely by planning restrictions, due to green belts and conservation areas. Subsequently, delays and restrictions on new transmission capacity,

growth of intermittent renewable generation, and increasing electrical load are all pushing the power system into uncharted territory.

This paper considers the use of fast flexible distributed generation, located near to the load centres, as a means to help balance generation and demand in this new environment. Typically this generation has a diesel fuelled ignition based compression engine as a prime mover and is referred to as a gen-set. Gen-sets have traditionally been used for stand-by power generation in hospitals, offices, telecoms, schools, retail and financial sectors along with many other applications where there is no site supply [3]. In the latter case, with no available site supply, the function of gen-sets is a prime power application. This is frequent in remote locations or third world regions. Diesel gen-sets are also frequently used by large electrical consumers for peak shaving and peak lopping applications, in order to avoid expensive electricity [4]. Peak lopping and peak shaving are, by definition, carried out for the periods of maximum demand in the respective power system. Within the Northern Ireland power system for example, there is 132 MW of distributed diesel generation [5], operating between 4 - 7 pm on weekdays of the winter months (November to February). This capacity could supply over 6.9% of the 1905 MW peak system demand [6].

In addition to peak lopping and peak shaving, there are schemes throughout the world where distributed diesel gen-sets are remotely controlled by network operators to provide emergency system reserve. Wessex water in the UK, for example, own and operate 550 gen-sets, with a total capacity exceeding 100 MW. Out of this capacity, 18 MW is contracted to National Grid for a fast reserve service, available no later than 20 minutes after the tripping of a large thermal unit [7]. Given the growth of variable and uncertain renewable generation, such as wind power, the need for fast flexible generation is apparent, in order to maintain security of supply. The total capacity of distributed diesel plant that could be applied to such a scheme is believed to be over 20 GW for the UK [8], which is very significant in the context of a peak demand of 60 GW, and much larger than the reported 2009 installed wind capacity of 4 GW [9].

These factors suggest that existing flexible generation will be a valuable commodity in the near future and, as such, owners of diesel generation would be well placed to offer additional or ancillary services and thus more fully utilize their capital investment. This is especially true for generation which is located close to load centres and can therefore provide volt-

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age support, reduce power flows on critical transmission lines and hence improve security of the system.

Associated with the use of diesel gen-sets are, however, the emissions of particulate matter, carbon dioxide, carbon monoxide and volatile organic compounds. Such emissions detract from the suitability and public acceptance. Given the need for flexible generation located close to load centres and the capacity of diesel generation already in existence it makes sense to consider how the performance of such generation can be improved. Therefore, this paper considers the performance of gen-sets fuelled on biodiesel, a less carbon dependent fuel, with lower emissions of particulate matter, carbon monoxide and volatile organic compounds.

II. OVERVIEW OF BIODIESEL

Biodiesel is a carbon benign alternative to fossil diesel that is manufactured from vegetable oils, recycled cooking oils, or animal fats. Plants produce oils from sunlight and air, and can do so year after year on cropland, therefore these oils are renewable. Animal fats are, by way of the food chain, derived from photosynthesis, so they too are renewable. Carbon is absorbed from the atmosphere as the fuel crop grows through the process of photosynthesis. This carbon is later released during combustion of the fuel-end product. The net addition of carbon to the atmosphere is therefore smaller than when compared with fossil diesel. On the other hand, combustion of fossil diesel adds carbon to the atmosphere that has been sequestered in the earth's crust over millions of years, and will not be removed in a human lifetime. It is appropriate to remark that Rudolph Diesel famously demonstrated his early diesel engine using peanut oil, and that he himself envisaged a future of biomass derived fuel for his engine. In Europe biodiesel is primarily made from rapeseed oil (canola) producing rapeseed methyl ester (RME), whereas in North America soybean is the dominant feedstock. In some countries, such as France, small quantities of biodiesel are also made from sunflower oil.

Biodiesel is competitive with fossil diesel in most technical aspects and also delivers several distinct advantages compared with fossil diesel [10, 11]:

- Derivation from a renewable domestic resource, thus reducing dependence on and preserving oil reserves.
- Biodegradability (degrades 98% in 21 days, compared with 50% for fossil diesel). Therefore biodiesel is often used in national parks and sensitive conservation areas where the impacts of fuel spillages must be mitigated [12].
- Reduction of most exhaust emissions (with the exception of nitrogen oxides).
- Higher flash point, leading to safer handling and storage.
- Excellent lubricity. A biodiesel additive of 1-2% can completely restore the lubricating properties associated with the use of low sulphur diesel, which is increasingly adopted to meet emission targets.
- A reduction in net carbon life-cycle emissions compared with fossil diesel.

The energy density of fossil diesel [13] is 42.47 MJ/kg and that of biodiesel is 37.417 MJ/kg. The assumed densities of

the fuels are 0.84 kg/l for fossil diesel and 0.89 kg/l for biodiesel. Given this, the mass density (kg/l) ratio of biodiesel to fossil diesel is 1.060, whereas the energy density (MJ/l) ratio is 0.933. Thus, biodiesel contains approximately 7% less energy by volume than typical fossil diesel fuel in the UK and 12% less energy by mass [10]. All biodiesels, regardless of feedstock, have similar energy densities, but noticeable differences in color.

With regard to sustainability and ethical land use, the credentials of biodiesel have been severely scrutinized in recent years. The conclusions from the more authoritative reports are that, with careful land and process management, biodiesel production can displace a small fraction of fossil diesel consumption while providing a net carbon saving, without adverse environmental consequences [14]. The study in [15] finds that replacing gen-set fossil diesel consumption with a 100% blend (B100) of biodiesel mitigates 78% of life-cycle diesel fuel carbon dioxide emissions.

A. Biodiesel and Human Health

The emissions from diesel fuel combustion contain hundreds of different polycyclic aromatic hydrocarbons (PAHs) and mono-aromatic hydrocarbons (MAHs). These emissions are suspected of causing cancer and other life threatening illnesses [16]. The main sources of PAHs and MAHs in diesel exhaust are unburned molecules from fuel, pyro-synthesis and structural modifications during combustion. Biodiesel is free from aromatic compounds and sulphur [17] and therefore has the potential to reduce carcinogenic emissions. Table 1 compares the emissions of biodiesel, made from various sources, with conventional fossil based ultra-low sulphur diesel (ULSD) [18].

Table 1 shows that biodiesel made from waste vegetable oil delivers the greatest reduction in life-cycle emissions of carbon monoxide, volatile organic carbon and particulate matter when compared with ULSD. The nitrogen oxide (NOx) emissions are however seen to increase. Machinery in mines is often switched to use biodiesel blends, as it is believed to reduce the risk of illness and life-threatening diseases. Such factors suggest that replacing fossil diesel with biodiesel in electrical generators, located close to residential areas, would reduce the impact of emissions in the immediate environment and hence the impact on human health would also be reduced.

TABLE I
PERCENTAGE CHANGE IN FULL LIFE-CYCLE AIR POLLUTANT EMISSIONS FOR 100% BIODIESEL COMPARED WITH ULTRA-LOW SULFUR FOSSIL DIESEL [18]

Change in pollutant compared with ULSD	B100 from Rapeseed	B100 from tallow	B100 from waste cooking oil
Carbon monoxide (CO)	-27	-37	-47
Nitrogen oxides (NOx)	+17	+15	+4
Volatile organic carbon (VOC)	-26	-29	-45
Particulate matter (PM)	-15	-16	-23

B. Drawbacks of Biodiesel

Biodiesel has less favorable cold flow properties compared to conventional diesel. Unlike petroleum, fossil diesel and biodiesel can both start to freeze or gel as it gets colder. At

low temperatures the long chain molecules of methyl ester in biodiesel align and eventually bond into a crystalline structure. This happens more readily in biodiesel than in fossil diesel. If biodiesel begins to gel, it can clog filters or may eventually become too thick to be pumped from the fuel tank to the engine.

Analysis of biodiesel samples, from various sources in the UK, highlight considerable variation in B100 pour point ranging from 4°C to -14°C. A pour point of 4°C would present cold weather difficulties in many climates and would need cold weather additives if used neat. For stationary gen-sets operating in a peak lopping or peak shaving role, fuel gelling can be prevented with a simple tank heater and thermostat. This does, however, rely on the availability of a mains supply for energy.

Biodiesel has been shown to increase NO_x emissions in many unmodified engines. NO_x are created when nitrogen in the intake air reacts with oxygen at the higher in-cylinder combustion temperatures. As with fossil-based diesel fuel, the exact composition of the biodiesel will influence NO_x emissions. To reduce NO_x emissions, engine manufacturers are developing new biodiesel fuel additives to combat the problem. For a generator fuelled on B20, [19] demonstrates that a suitable fuel additive can increase power density while reducing exhaust emissions and fuel consumption. Retarding the engine fuel injection timing has also been found to mitigate this problem [20]. More work is, however, required in this area to consider higher concentration blends of biodiesel.

The application of biodiesel in electrical generation is significantly different from transportation due to the requirement for constant gen-set engine speed and highly specified load acceptance. Such tolerances place extreme demands on the technology and fuelling systems. This paper therefore investigates the operation of a diesel gen-set when fuelled on both fossil diesel and B100 (100%) biodiesel, with particular focus on the electrical characteristics of the generator, and hence implications for appropriate generator rating to meet a specific load and load step requirement.

III. EXPERIMENTAL TEST BED

Fig. 1 shows a diagram of the experimental test bed, consisting of a 50 kVA Perkins diesel engine gen-set, with diverter fuel valves to switch between regular fossil diesel and B100 biodiesel. Its standby power rating is 40 kWe and the prime power (continuous) rating is 36 kWe. This gen-set has a 4-stroke, 1500 rpm, 3.99 litre engine with a compression ratio of 16.0:1, and is typical of a unit used by industry for emergency standby generation or peak shaving. The gen-set can operate using the factory fitted governor and automatic voltage regulator (AVR) or can be switched to follow control algorithms implemented in Mathworks xPC Target. In order to accept biodiesel as a fuel source, the gen-set required the retrofit of a biodiesel compatible fuel injection pump.

Both grid-connected and isolated modes of operation are available.

Grid-connection is facilitated by an appropriate control panel, G59 protection relay (as required in the United Kingdom), and use of an AVR with droop current transducer.

Fig. 1. Diagram of test bed configuration

During isolated operation the mains circuit breaker is disconnected and the analogue speed set-point from the control panel to the engine control module (ECM) is overridden by a speed or fuel command provided by the xPC target PC based governor. Communication between the xPC target PC and ECM is performed using controller area network (CAN) messages. A load bank allows various loads to be added to the engine in discrete steps, after which the response of the generator can be monitored.

The xPC target PC interface is also used to measure and record the engine control parameters along with the alternator electrical output. A Canape XL log software module is used to read the appropriate CAN bus register values. This module provides access to fuel consumption, engine speed, fuel temperature, desired fuel injection, final fuel injection, and injection timing angle with respect to engine top-dead-centre.

IV. STEADY-STATE OPERATION

A. Grid-Connected Operation

A grid-connected gen-set will normally be operated near its maximum continuous real power output, as this leads to more efficient use of the gen-set.

The gen-set was connected to the grid and supplies a constant power output of 30 kW, 75% of rated load (50 kVA with a power factor of 0.8). Initially the gen-set is fuelled with fossil diesel, then after 30 minutes the fuel type was switched to 100% biodiesel without stopping the engine. The fuel injection quantity is seen to increase from 76.3% to 81.6% of maximum fuelling rate. This represents a 7% increase, with respect to the fossil diesel fuelling, and is a result of the reduced energy content of biodiesel compared with fossil diesel. Fig. 2 shows the two periods of operation. In this test the electrical power produced is unaffected by the switch from fossil diesel to biodiesel. The engine temperature also remains stable throughout.

Fig. 2. 30 kW operation back-to-back with seamless changeover from fossil diesel to biodiesel

The power reference is increased until the governor reaches its maximum fuel injection quantity. The maximum power that can be extracted from the machine on conventional diesel is 40.8 kW. Repeating the test with biodiesel the governor again reaches its fuel injection quantity limit, but the electrical power is reduced to 37.4 kW.

These steady-state tests show that biodiesel reduces the maximum power capability of the generator by 8% at full load. Although this reduction is noticeable, the efficiency is not adversely affected and it would not prevent feasible operation of diesel gen-sets in a grid supporting role. If such gen-sets were deployed in a grid supporting role the only consequence would be a need for slightly more participating units.

B. Steady-State Fuel Efficiency

The efficiency of the 50 kVA gen-set was calculated at different loads, as the ratio of the mechanical energy of the engine output to the stored energy in the fuel. Energy and mass density of the fuels are assumed to be those from section II. The speed is constant, at 1500 rpm, and the engine is at normal operating temperature. No-load, steady speed losses (friction, windage, engine and alternator auxiliaries) are estimated at 4 kW, and electrical load related losses equivalent to 0.3 Ω /phase at 415 V are used, representing parasitic stator resistance and rotor excitation current.

The efficiency for the two fuels is shown in Fig. 3 and the ratio of biodiesel to fossil diesel fuel consumption at different loads is plotted in Fig. 4. It should be noted that this form of distributed generation has efficiencies which exceed much of the older fast-start open cycle gas turbine plant installed in the UK [21].

From Fig. 3 and Fig. 4 it is immediately obvious that there is not a straightforward relationship between efficiency and electrical load, or between the efficiencies with the two fuels.

Fig. 3. Efficiency of biodiesel and fossil diesel versus electrical load

Fig. 4. Ratio of biodiesel and fossil diesel fuel consumption at different electrical loads

Causes of the efficiency change with increasing electrical load are:

- The steady speed losses become less significant as electrical load increases.
- At very high load, air availability becomes an issue and efficiency tends to drop.
- Variable, or dynamic, injection timing is used. Advanced timing at light load keeps cylinder temperatures high to ensure complete combustion and reduce particulate matter emissions [22]. At higher loads advanced injection timing is also required as a larger volume of fuel is to be injected. These changes in injection timing affect fuel consumption and efficiency.

Differences between the two fuels are caused by:

- Biodiesel's physical properties, such as higher viscosity and mass density, effectively advance the injection timing [23]. This is the main cause of increased NOx emissions from biodiesel. Higher cetane content can cause the fuel to ignite sooner, resulting in further timing advance.
- Biodiesel has a lower energy density, meaning a higher volume of fuel is required for each load. This could affect, for example, power usage by auxiliaries.
- The lower energy density, and thus higher injected fuel quantity, affects the injection timing strategy, which is based upon injected fuel quantity, temperature and speed, rather than engine load.

Referring to Fig. 3 and Fig. 4, efficiency rises sharply with increasing electrical load, then falls slightly as load increases from 5 to 15 kW. In this region, biodiesel's fuel consumption is approximately 17% higher than for fossil diesel at 10 kW load, indicated in Fig. 4. The effects of biodiesel's properties on injection timing appear to be the cause of particularly poor performance at these loads.

Above 15 kW, efficiency of both fuels rises, being characterized by a lower per unit loss and a start-of-injection advancement with load. Intriguingly, biodiesel has a higher efficiency than fossil diesel. Although energy densities reported in literature were used to calculate efficiency and some error is expected, it is observed in Fig. 4 that at 25 kW the fuel consumption with biodiesel was only 4% higher than fossil diesel. This suggests either a higher biodiesel efficiency or an uncharacteristically high energy density. This result must be treated with caution, because although biodiesel's effect on injection timing may cause the engine to run more efficiently,

operation has deviated from the factory calibration, based on fossil diesel, and may affect emissions.

Fuel efficiency drops when operating close to maximum load, and is particularly observable for biodiesel. Using the factory settings, the maximum load achievable with biodiesel was 8% less than fossil diesel. This is caused by the maximum injected fuel quantity limit and the lower energy density of biodiesel. To acquire results for biodiesel at very high load the injected fuel quantity limit was overridden. The drop in fuel efficiency at maximum output is either caused by the fuel being injected outside the optimum efficiency window, due to fuel injector limitations, or by exceeding the stoichiometric limit so that there is not enough air available in the combustion chamber to burn all the fuel.

V. TRANSIENT TESTS: ISOLATED OPERATION

During isolated operation, whether as emergency standby generation or islanding schemes in future distribution networks, adequate gen-set performance is crucial. The gen-set will be required to operate with varying load, and accept or reject significant load while remaining within operating conditions defined in ISO 8528-5 [24] or otherwise.

An investigation into the transient performance of biodiesel in an isolated system is performed. The test bed is modified accordingly; the mains connection is removed and the load bank in Fig. 1 is used to supply load disturbances. The xPC target PC based governor can override the analogue signal to the engine control module (ECM) from the synchronisation capable control panel. Furthermore, the xPC target PC based governor can bypass any fuelling limits normally imposed by the ECM. The governor is fixed gain proportional, integral, derivative (PID), and contains anti-windup functionality.

A. Fuel Comparison

The gen-set transient performance with B100 biodiesel and fossil diesel are compared.

Fig. 5 (a)-(f) show the frequency transients following 76% rated load acceptance and rejection (30.4 kW) along with injected fuel quantity and electric power. Frequency is measured by a magnetic pickup, and the fuel values are returned from the ECM via CAN messages.

Regarding load acceptance, shown in Fig. 5 (a), the fossil diesel performs better than biodiesel with lower maximum frequency deviation and shorter settling time. It may be observed in Fig. 5 (c) that the maximum fuel injection quantity limit (100%) is reached during load acceptance with both fuels. As expected, the steady-state fuel required with biodiesel is higher than for fossil diesel both before and after the disturbance.

During load rejection, in Fig. 5 (b) and (d), the aim is to rapidly reduce the fuel input. In this case the transient response of the two fuels is similar. The varying power at load acceptance in Fig. 5 (e) is due to the transient voltage caused by the AVR's response. Naturally, no such power transient is observed after load rejection in Fig. 5 (f).

It is interesting to compare fossil diesel and biodiesel transients for different magnitudes of load disturbance.

Fig. 6 (a)-(d) show the frequency deviation and $\pm 0.75\%$ frequency settling time for a range of load acceptances and rejections when fuelling with fossil diesel and biodiesel. In general, the performance of fossil diesel is slightly better. There are several subtle performance differences between the fuels, and these can be attributed, either directly or indirectly, to the lower energy density of biodiesel.

Fig. 5. Biodiesel and fossil diesel response to 76% load disturbance. Load acceptance: a) frequency, c) injected fuel quantity, e) electric power; load rejection: b) Frequency, d) injected fuel quantity, f) electric power

Fig. 6. Performance of fossil diesel and biodiesel for different load disturbances: (a) Frequency deviation on load acceptance; (b) Frequency deviation on load rejection; (c) Settling time following load acceptance; (d) Settling time following load rejection

In Fig. 6 (a) and (c) the performance degradation caused by the injected fuel quantity limit during the 93.5% load acceptance is evident. The biggest difference between load acceptance and rejection performance occurs at these large loads.

Regardless of fuel, the gen-set passes ISO 8528-5, G2 performance measures [24] for settling to $\pm 0.75\%$ frequency within 5 seconds of a disturbance, and 100% load rejection within 12% frequency deviation. The -10% frequency limit during load acceptance is passed for 76% load with fossil diesel, but a marginal fail with biodiesel.

When considering the implication of these results, it is worth noting that the engine was designed and the governor tuned for optimum performance with fossil diesel fuel, and not biodiesel. A number of methods could be explored to enhance the transient performance when using biodiesel. These include, retuning the injection timing maps for biodiesel, increasing the governor gains, temporarily increasing the maximum injected fuel quantity limit, and using supplementary governor inputs to improve response, such as real power [25].

VI. PRACTICAL ISSUES WITH B100 FUELLED GEN-SETS

The use of biodiesel has been extensively tested in the automotive industry and hence the implications of using biodiesel to fuel transportation are well documented. The impact of using biodiesel as a fuel for electrical generation is, however, less well documented.

To operate a gen-set on biodiesel fuel, the first consideration must be compatibility of the fuelling system. Biodiesel is not compatible with some fuel pipes and gaskets, as it may soften or degrade certain types of rubber compounds found in the fuelling system (i.e. Buna-N, Nitrile, natural rubber). If such compounds are not replaced the system may eventually fail and potentially leak fuel. However, modern gen-set designs are increasingly adopting biodiesel compatible materials such as Viton.

In addition to material compatibility, biodiesel is a good solvent and may loosen and, or, dissolve sediments in fuel tanks and fuelling systems which have accumulated over time. Fuel tanks and pipes should therefore be cleaned prior to using biodiesel, especially B100, and following the start of biodiesel usage fuel filters should be regularly changed.

As mentioned earlier, gen-sets are often operated close to maximum real power output due to better economics in this region. The steady-state tests in Section IV however confirm that maximum power output is decreased when using B100 by 7~8%. This means that prior to fuelling on B100, the steady-state power output of an unmodified gen-set should be de-rated by 7~8%.

In addition to a reduction in steady-state power output with biodiesel, the ability to accept varying load steps within specific performance limits is also reduced in an unmodified gen-set with the use of B100, as previously described in Section V. If the gen-set steady-state rating is reduced from 40 kW to 37 kW to reflect the use of biodiesel then the acceptable per unit load step can be redefined as shown in Fig. 7.

In Fig. 7 it is observed that the de-rated engine running on biodiesel produces comparable or better results than when fuelled on fossil diesel at the engine's original rating. The largest load acceptance improvement in Fig. 7 (a) is for the 100% load step. This is most likely caused by a small difference in the per unit power output at the maximum injected fuel

quantity, for example, biodiesel is marginally more efficient at 37 kW (100%), than fossil diesel at 40 kW (100%), see Fig. 3.

For load rejection in Fig. 7 (b) the response improves largely due to the inertia constant. Although the moment of inertia is unchanged, the inertia constant which is calculated using the gen-set rating, will increase. This means that for a per unit load disturbance frequency will deviate less, largely accounting for biodiesel's improved response to load rejection.

Fig. 7. (a) Load acceptance and (b) load rejection performance of biodiesel (with modified gen-set rating) relative to fossil diesel

VII. CONCLUSION

With careful land and process management biodiesel is superior to fossil diesel with regard to sustainability and life-cycle carbon emissions. In addition, the emissions of carbon monoxide, volatile organic carbon and particulate are reduced with biodiesel. These properties make biodiesel a suitable alternative to fossil diesel when used in distributed diesel generation close to residential or environmentally sensitive areas. Biodiesel is also compatible with many modern diesel gen-set engines, and can be used in low blends with those that are not fully compatible.

Disadvantages of biodiesel do however include; a higher pour point, which may require pre-heating the stored-fuel in colder climates; higher NO_x emissions, which may require adjustments to engine timing; and lower power density, leading to increased specific fuel consumption and lower maximum power output. However, biodiesel appears to have comparable or indeed higher efficiency, with respect to fossil diesel, in the power range most likely to be used while grid connected.

This paper has shown that biodiesel can indeed fuel gen-sets for grid support and power balancing applications. This can add valuable fast, flexible generation to wind dominant power systems, while minimizing the net carbon release. The only consequence, aside from requiring biodiesel compatibility, is that the gen-sets would be de-rated from their fossil diesel ratings, thus requiring slightly more units to participate in the scheme.

During isolated operation, transient response becomes par-

ticularly important. Biodiesel's physical characteristics affect operation and efficiency at different load levels. Again, it is biodiesel's lower energy density which impacts most upon transient performance in an unmodified engine. Load rejection is only minimally affected by the change of fuel, with a larger degradation being found in load acceptance.

If the engine is de-rated for biodiesel by 7~8%, comparable or better transient performance compared to fossil diesel, with the original rating, is achieved in terms of per unit load step. A number of methods that could improve transient response of a biodiesel fuelled engine were suggested.

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