Resource & Utility Sector

White Paper

Hybrid Power

Technology Brief

VARIABLE SPEED *Retrofit*

Extended Life | Capacity | Reliability

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Problem Statement

- Mining accounts for 10% of Australia’s total energy consumption. This load is primarily supplied by diesel fuel (41%). While diesel generation represents a reliable power solution, the technology can become inefficient and unreliable when subject to large load volatility. The inability of diesel or gas generation to operate flexibly is primarily borne from its reliance on fixed speed, synchronous generation.

- Fixed speed diesel generation is inflexible, and poorly suited to serving a variety of loads.

- Diesel generation is often sized for maximum demand, resulting in assets which run partially loaded for much of their life, reducing engine life and increasing generation costs.

- Fixed speed diesel generation OPEX is high, with the technology poorly suited to renewable pairing (a common approach to reduce OPEX).

Solution

- Variable speed retrofit offers an affordable solution, allowing existing diesel or gas generators to operate as either fixed speed (high load mode) or variable speed (partial load mode). The ability to switch between modes results in a flexible solution able to access an engines full capacity. The improved engine efficiency at low load also serves to extended asset life and reduced emissions.

- Our innovative power converter retrofit, including dc coupled storage and rated transfer switch is unique, offering reducing cost and complexity.

- Variable speed diesel application is suitable for all diesel or hybrid diesel systems. The ability to serve a variety of loads, or loads with high load variability, allows substantial fleet consolidation.

- Our retro-fit solution is easily repurposed across multiple generators, allowing the technology life to decouple from generator lifetime.

- From a mine perspective, the diesel fleet can be consolidated, with fewer units able to serve an expanded mine load. Under variable speed application spares holdings reduce, servicing routines are reduced, and servicing intervals are extended.

Introduction

The Australian mining sector consumes roughly 500 petajoules per year, 10% of Australia's total energy use. Over the past decade both productivity and consumption have risen by 6% per annum, however, energy intensity is also rising [1]. Energy intensity represents the energy required per tonne of product, as determined by ore grade, overburden and distance to market [2]. Current average energy intensity is benchmarked at 50.5kWh/tonne for coal, 10.7kWh/tonne for minerals, and 54.5kWh/tonne for metals. The majority of this load resides in diesel equipment and comminution operations [2].

The prevalence of diesel generation within the sector reflects the reliability, performance, availability, support and servicing of the approach [3]. These traits are essential building blocks from which any viable mining operation is sustained. Unfortunately, fixed speed diesel generation has some notable technical limitations, requiring a stable load profile for efficient operation. Typically this will result in units sized to run at 60%-80% of their rated capacity. Fixed speed diesel generators are accordingly unsuited to serving a variety of load/application [4]. In contrast, mine applications often necessitate units be repurposed from one load to another. Subject to the load, the unit can run inefficiently, resulting in high wear, high emissions and unnecessary cost.

Variable speed diesel technologies address the inflexibility of fixed speed diesel generation, with an ability to operate efficiently across loads [5]. The idea is not new, allowing engine rpm to reduce with load. The results is a dramatic improvement in engine efficiency, unfortunately, most of this efficiency gain is subsequently lost in converter losses, with a power converter required to condition variable output to ensure stable power. Our variable speed retro-fit solves this problem by sizing the converter, and thus the losses, to a fraction of the diesel unit rating. As we only employ the power converter during partial engine loading, the smaller converter offers an elegant, low cost solution. To address ramp rate response, and the ability for the unit to transition seamlessly between partial and full load, a small amount of storage is coupled to the DC bus of the converter, providing a sufficient buffer for the engine to be brought to rated speed and synchronised. As the unit is always operating, sychronisation takes only a fraction of the time taken to conventionally bring a unit online.

In addition to the increased service life and flexibility of variable speed application, the approach also addressed the inability of diesel generation to scale for mine electrification, and pair with renewable technologies. Mine electrification represents a shift in mine load to an increasing share of electrical equipment and battery fed appliances. Electric haulage vehicles are one example, with the technology able to achieve improved haulage efficiency, reduce mine ventilation and facilitate process automation. Renewable pairing is the integration of renewable generation to reduce both the cost and emissions of diesel fired generation under a hybrid diesel arrangement [6]. Despite benefits including reduced emissions (heat, noise, exhaust), higher efficiency and improved safety (process automation for example), uptake of both mine electrification and renewable integration has been slow [2]. One reason is the failure of fixed speed diesel generation to offer suitable hosting capacity.

The solution to unlocking mine potential for improved energy reliability and flexibility lies in transitioning away from fixed speed diesel reliance. Variable speed diesel application offers one such opportunity, providing a hedge to fuel price volatility, geopolitical instability, supply interdependence, and both social and legislative environmental compliance [7].

Variable Speed Diesel Retro-fit

Conventional diesel generators run at a fixed speed, for 50Hz systems this is 1500 rotations per minute (rpm). The engine speed is fixed, because the frequency required of the power system is fixed. Unfortunately, this makes diesel generators unsuited to variable loads [8]. The practice is akin to driving a car using only one gear. Naturally, the efficiency and responsiveness of the unit suffers as the load changes. Variable speed diesel generators exploit this application by allowing the engine to operate at the most efficient rotational speed. The improved control allows the unit to both reduce mechanical stress during load acceptance or rejection, and to operate more quietly, cleanly and efficiently [7].

Variable speed diesel applications remain able to meet the 50Hz system frequency, as a power converter is placed between the generator and the load, Figure 2. The role of the power converter is to ensure the variable frequency output of the generator is conditioned to meet the network frequency. This approach is common across marine electric propulsion, wind, solar and battery technologies, which generate at either variable speed or are direct current technologies. Reliance on a power converter does not reduce the reliability of the approach, however it does improve the power quality and security available to the mine.

The ability of the variable speed generator to select its preferred speed setting is responsible for dramatic performance improvements. The generator is no longer constrained to a very narrow speed reference, and is suitable for dynamic load applications. The approach also acknowledges power converter efficiency, sizing this component to limit losses and allow for the converter to be bypassed under load. [9].

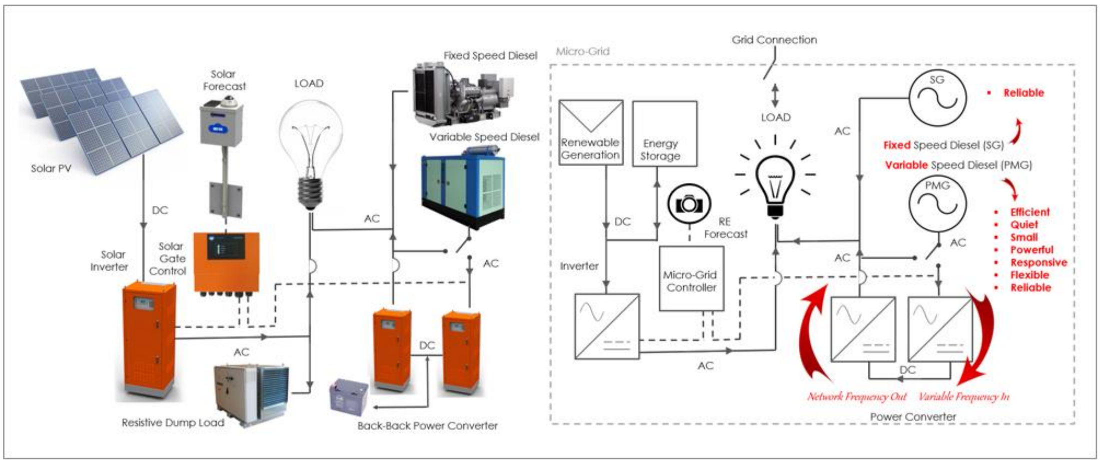


Figure 1 Single Line Diagram for Variable Speed Diesel Application.

Variable Speed Diesel Technologies

Conventional fixed speed diesel generators need to operate heavily loaded to ensure efficient and reliable operation, a scenario which leaves generators inflexible to changing load requirements. Diesel engine mechanical losses are also largely independent of load [10]. Accordingly, as the load decreases within a constant speed application, the losses remain, becoming an ever increasing percentage of the supplied energy. This is one reason why it is typically undesirable to run an engine lightly loaded. At the same time diesel generator sets are sized for maximum demand, regardless of how infrequent this demand might present. By definition these units spend much of their life partially loaded. Variable speed diesel concepts allow the diesel engine to move away from fixed speed operation, typically lowering shaft speed at low loads to capture fuel efficiency and improved responsiveness [11]. With improved partial load range, variable speed diesels are ideal for dynamic load environments, such as hybrid diesel application. Removing the barriers to extended range operability promises to deliver the lowest cost pathway to improved energy efficiency without impact on supply security.

A number of advanced components combine to deliver variable speed diesel capability, including low load diesel engines and power electronics, Figure 3. While modern diesel engines are all essentially able to operate at low load, performance varies significantly across models and suppliers. Common rail injection, supported by electronic governor control is essential to ensure the required injector capability. Complementary engine technologies also include variable geometry turbochargers, cylinder deactivation, turbocharger sequencing, dump load integration and variable load cooling [5, 12].

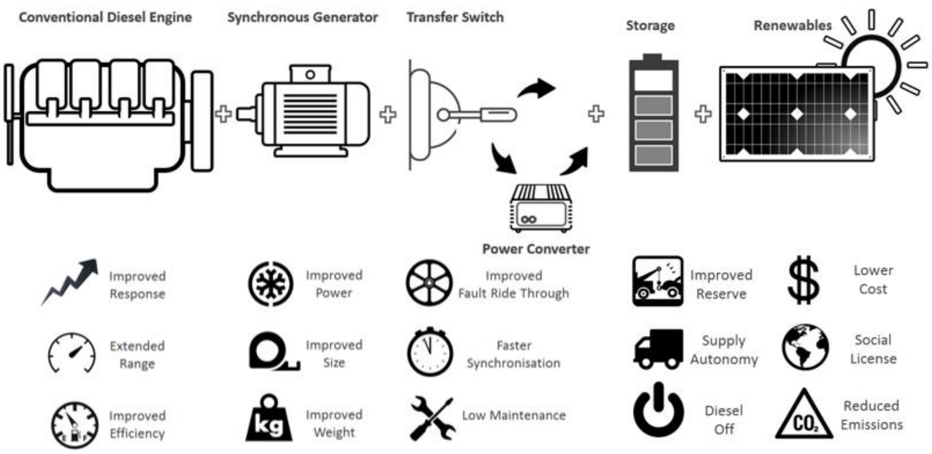


Figure 2 Variable Speed Diesel Benefits as paired with Renewable Generation and Storage

Variable speed application can adopt one of two approaches, with mechanical or electrical solutions possible. The mechanical solution involves the integration of a variable speed coupling. Regardless of the coupling mechanism, mechanical solutions add significant complexity and inefficiency to the drivetrain [5]. For this reason electrical solutions are preferred. Electrical solutions also allow for a partial power converter functionality [13, 14]. A power converter is interfaced to meet the constant frequency requirement of the grid, and while the converter adds to cost and complexity, these are minimised within the proposed approach [11]. Fuel savings resultant from a variable speed application have been measured approaching 40%,

Figure 4. In addition variable speed application is able to extract a higher resultant torque than a conventional fixed speed engine, increasing maximum engine output.

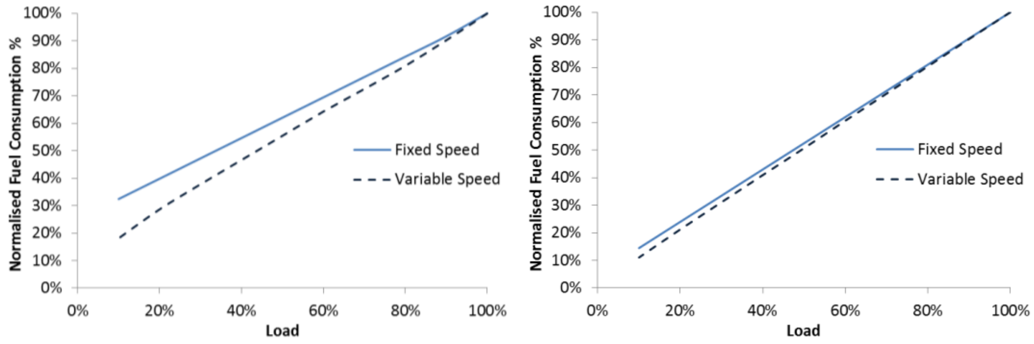


Figure 3 Variable Speed Vs. Fixed Speed Fuel Comparison Small Capacity Engines *(left)*, Large Capacity Engines *(right)* [15]

Technology Maturity

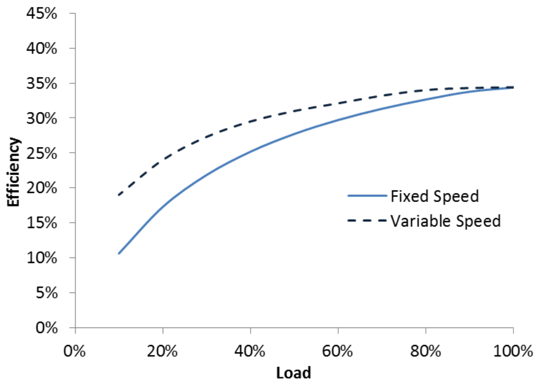
Variable speed diesel technology is applicable to all consumers currently using diesel for electricity generation, including mines, defence facilities, remote communities, research facilities, telecommunications facilities and tourism operations.

The approach has been commercialised by multiple proponents, with a number of demonstration sites in operation. These include:

- Aklavik, Northwest Territories, Canada. Owned and operated by Northwest Territories Power Corporation. Proponent: Innovus Power [8]
- Pulau Ubin Mirco-Grid, Singapore. Owned and operated by Energy Market Authority. Proponent: Regen Power [16]
- Centre for Renewable Energy and Power Systems Laboratory, University of Tasmania, Hobart, Tasmania, Australia. Owned and operated by the University of Tasmania. Proponent: University of Tasmania [17]

Variable Speed Diesel Savings

Variable speed diesel application has been validated within a number of existing off-grid systems. Economic and power system simulation have proven accurate in extending performance to other systems and applications [7, 18]. Observed fuel consumption reductions can be as high as 60%, when deployed in partnership with renewable generation. For applications already benefiting from both renewable generation and energy storage, additional fuel savings of up to 30% are possible under variable speed application. Sites with high renewable energy spill or curtailment stand to benefit most. Fuel savings are allocated equally across low load (improved renewable utilisation) and variable speed (improved engine efficiency) measures, Figure 5. Detailed suitability for mining application requires specific site, load and production consideration, with this paper no indication of site specific suitability.



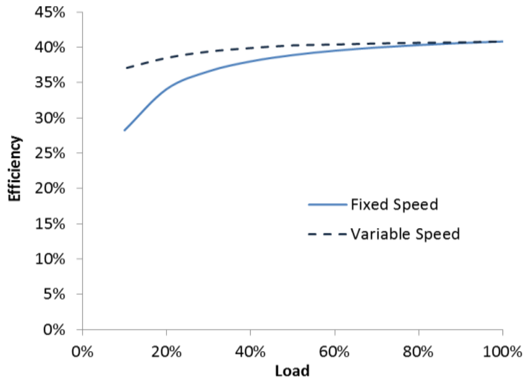


Figure 4 Variable Speed Diesel Fuel Efficiency Curves Small Capacity Engines *(left)*, Large Capacity Engines *(right)*. ***Note the efficiency gains at low load***

Case Study – King island Power System

As for many remote loads, King Island stood to benefit from reduced energy costs under renewable energy integration. King Island is one of several inhabited islands located in Bass Strait, between the north coast of Tasmania and the south coast of Victoria on mainland Australia. It has a population of around 1800 people, and is notable for its mining and agricultural industries. Generators supplying King Island include 4 diesel generator sets (6.0MW), five wind turbines (2.4MW), a 3MW 1.5MWh advanced lead-acid battery, a 1.5MW resistor bank, a dual axis solar array (100kW) and two Hitzinger D-UPS (0.8MW) units. King Island is also host to the University of Tasmania's low load diesel pilot project. The renewable resource on King Island is notable, and currently supplies approximately 65% of the island's power supply. The wind and solar generation used on the island is backed by a single diesel generator power station providing firm capacity and ancillary services. The target of this system is to use all the available solar and wind power to reduce diesel usage. The station has been designed to run unattended and operates with an advanced control system which starts, stops and loads selected equipment, to optimise the available renewable generation whilst maintaining supply security.

King Island has successfully demonstrated fuel savings of approximately 65% annually, while also achieving over 5,000 hours of diesel off operation. Unfortunately the system represents over $20m in technology investment, leaving the approach unsuitable for commercial application. Review of the performance of the King Island system, inclusive of the current low load diesel pilot, does however identify a possible commercialisation pathway via variable speed diesel substitution. Variable speed diesel represents a key enabler for systems looking to emulate the King Island performance. Given the ability to integrate many of the existing King Island technologies into a single low complexity, low cost platform, variable speed diesel has been assessed to halve the capital costs of future system deployments.

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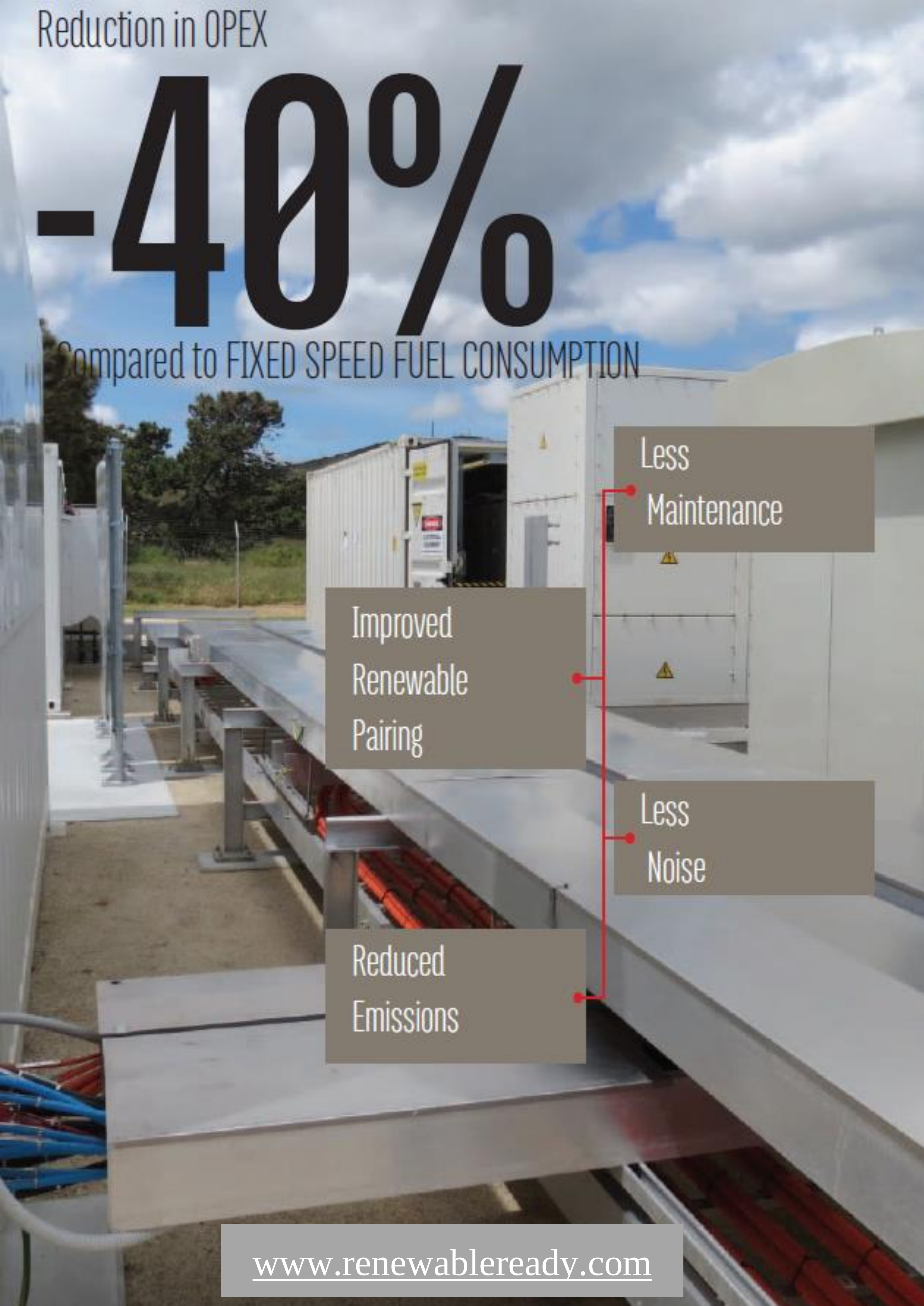
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