



# ***Centre for Renewable Energy & Power Systems***

## **Variable Speed Diesel**

## **Technology Whitepaper**



*Cover Image Supplied Courtesy of Innovus Power*

# Contents

---

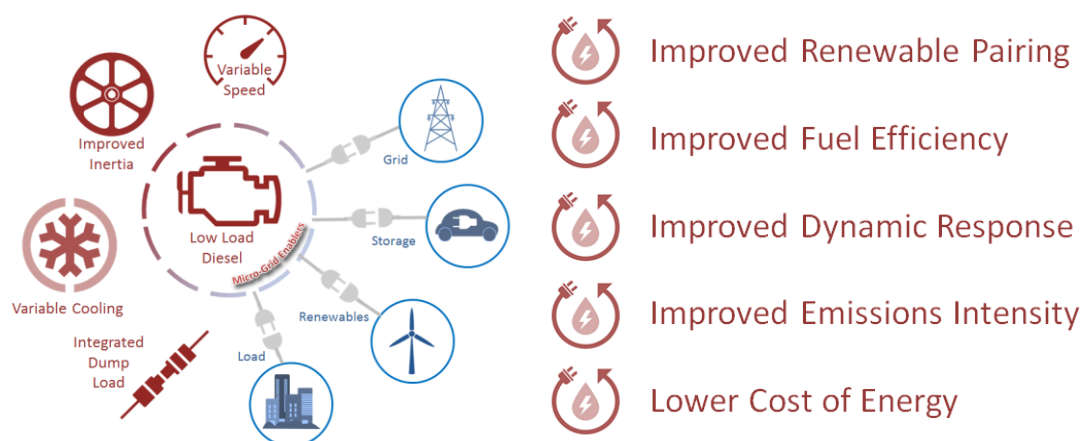
<b>CONTENTS .....</b>	<b>1</b>
PROBLEM STATEMENT .....	2
SOLUTION .....	2
INTRODUCTION.....	3
TECHNOLOGY MATURITY .....	4
VARIABLE SPEED DIESEL SAVINGS .....	4
VARIABLE SPEED DIESEL TECHNOLOGIES.....	5
CASE STUDY – KING ISLAND POWER SYSTEM .....	7
<b>REFERENCES .....</b>	<b>9</b>

## ***Problem Statement***

- Globally diesel accounts for the majority of existing generation within off-grid power systems.
- Renewable technologies offer cost competitive and clean supply alternatives, yet the performance of such hybrid systems is limited by fixed speed diesel generation.
- Fixed speed diesel generation fails to meet the flexibility required of modern hybrid off-grid power systems.

## ***Solution***

- Variable speed diesel offers an affordable solution, allowing diesel generators to operate flexibly, across an expanded range. Fuel savings realized at low load are between 30-40%.
- Variable speed diesel technology enables high renewable energy penetrations into off-grid power systems, without a requirement for battery storage. Renewable utilization is typically increased by 20-30% via improved low load operability and engine flexibility.
- Variable speed diesel delivers improved exhaust emission intensity via improved combustion efficiency.



## ***Introduction***

Off-grid system operators are increasingly turning to wind and solar generation to lower their diesel fuel consumption. Unfortunately, they quickly hit a technical barrier, with the operability of conventional diesel generation constraining the possible renewable energy penetration. In response, system owners and operators have driven renewed interest in the operation of diesel generators below operational load limits, a practice known as low load diesel [1]. Low load application has historically been ill advised, with fixed speed engines poorly configured to meet any sustained load variability [2]. One solution has been developed in variable speed diesel technology. Variable speed diesel application allows a diesel engine to operate at its most efficient speed reference, providing for improved engine flexibility and response [3].

## ***Do off-grid communities need diesel at all?***

Diesel generation remains the most trusted and cost competitive form of energy storage available to off-grid and remote communities [4]. How well we transition from diesel to emerging renewable and enabling technologies such as storage, relies on our ability to maximise the renewable utilization of such systems. Variable speed diesel application will significantly reduce the cost of high penetrations of renewable energy into remote and off-grid power systems, without substantially changing the technology footprint [3]. Accordingly diesel based technologies have a pivotal role in transitioning off-grid power systems to a reduced reliance on diesel fuel [5].

## ***What is variable speed diesel?***

Conventional diesel generators run at a fixed speed, for 50Hz or 60Hz systems this is 1500 or 1800 rotations per minute (rpm), respectively. Variable speed diesel generators can run at any rotational speed, as determined by which speed provides the greatest efficiency for any load setting.

The generator is still able to meet the 50Hz system frequency, as a power converter is placed between the generator and the load, Figure 1. 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 wind, solar PV 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 which can be offered to support the network.

The ability of the variable speed generator to select its preferred speed setting is responsible for the dramatic performance improvements. The generator is no longer constrained to a very narrow speed reference (akin to driving your car without ever changing gear). Of note, mechanical gearbox concepts also exist to achieve variable speed operation, however these increase, rather than decrease the complexity and cost of the approach.

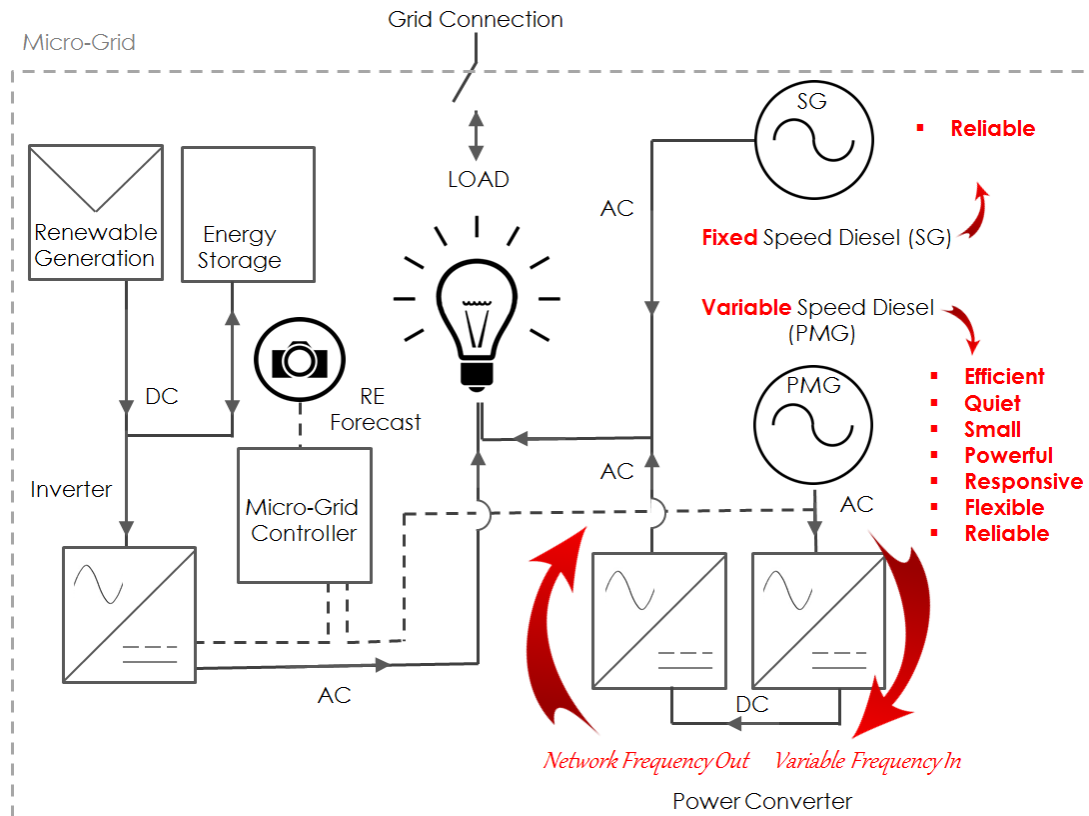


Figure 1 Single line diagram for a typical variable speed diesel architecture.

### 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 commercialized 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 [6]
- Pulau Ubin Mirco-Grid, Singapore. Owned and operated by Energy Market Authority. Proponent: Regen Power [7]
- Centre for Renewable Energy and Power Systems Laboratory, University of Tasmania, Hobart, Tasmania, Australia. Owned and operated by the University of Tasmania. Proponent: Renewable Ready [8]

### Variable Speed Diesel Savings

Variable speed diesel application has been demonstrated within a number of existing off-grid systems utilizing both economic and power system simulation to explore system performance [5, 9]. 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 a 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 utilization) and variable speed (improved engine efficiency) measures, Figure 2.

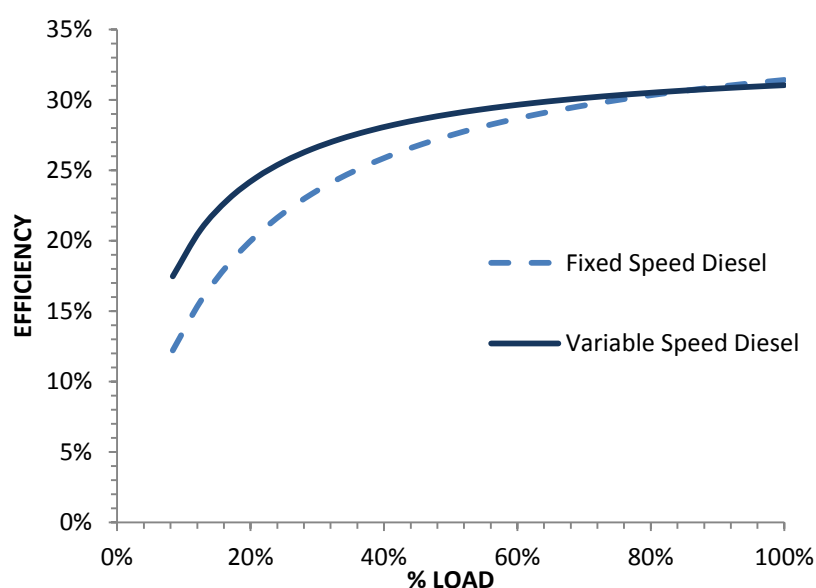


Figure 2 Variable Speed Diesel Fuel Efficiency Curves. *Note the efficiency gains at low load*

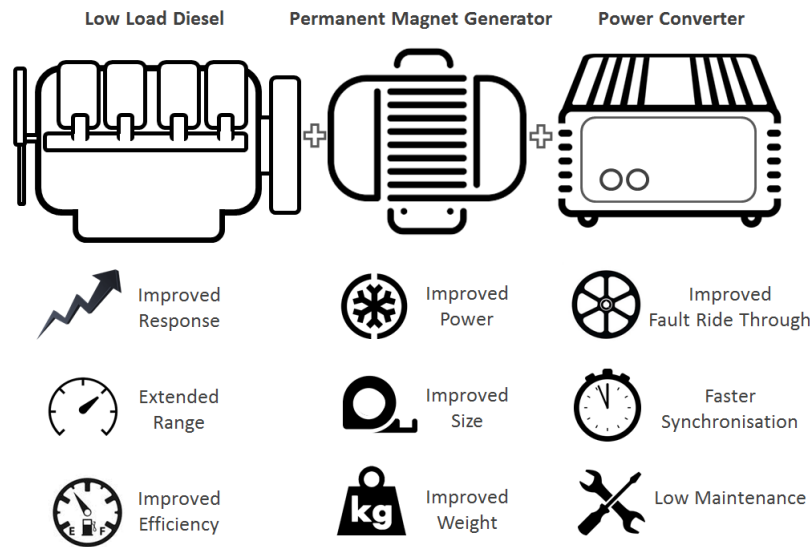
### ***Variable Speed Diesel Technologies***

Conventional fixed speed diesel generators need to operate heavily loaded to ensure efficient and reliable operation, a scenario which leaves limited scope for meaningful renewable contribution within off-grid systems. Diesel engine mechanical losses are also largely independent of load. Hence, 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 [10]. Under variable speed application, diesel use is more about reserve supply, with diesel called upon to back up renewable generation. The lower you can sustainably run your diesel generators, the greater renewable energy penetration you can accept, and the lower your generation costs. Variable speed diesel technologies significantly reduce the cost of high penetrations of renewable energy into remote and off-grid power systems. Removing the barriers to low load operation promises to deliver the lowest cost pathway to reduce off-grid reliance on diesel generation.

A number of advanced components combine to deliver variable speed diesel capability, including low load diesel engines, permanent magnet generators 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 [3, 11].



**Figure 3 Variable Speed Diesel Component Benefits**

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. For this reason electrical solutions are preferred within off-grid applications. Electrical solutions entail replacement of the synchronous alternator with either a doubly fed induction generator or a permanent magnet generator (common technologies for wind turbine application) [12, 13]. A power converter is interfaced to meet the constant frequency requirement of the grid, and while converter adds to cost and complexity, the associated benefits are significant [10]. Fuel savings resultant from a variable speed application have been measured approaching 50%, 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.

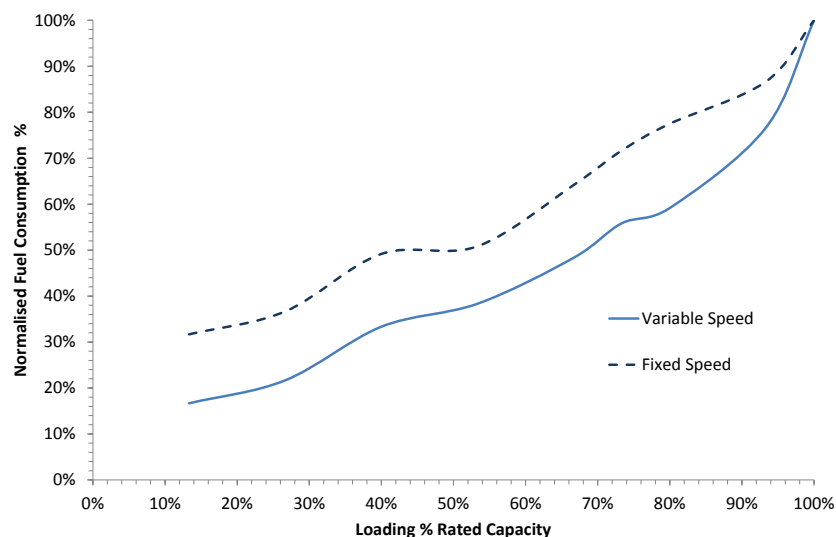


Figure 4 Measured Variable Speed Vs. Fixed Speed Fuel Comparison [14]

### Case Study – King island Power System

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 beef and dairy industries, as well as kelp farming and tourism industries. Generators supplying King Island include 4 diesel generator sets (1200kW - 1600kW), five wind turbines (three turbines 250kW and two turbines 850kW), a 3MW 1.5MWh advanced lead-acid battery, a 1500kW resistor bank, a dual axis solar array (100kW) and two Hitzinger D-UPS (1.0MW) units, Figure 5. King Island is also host to the University of Tasmania's low load diesel pilot project.

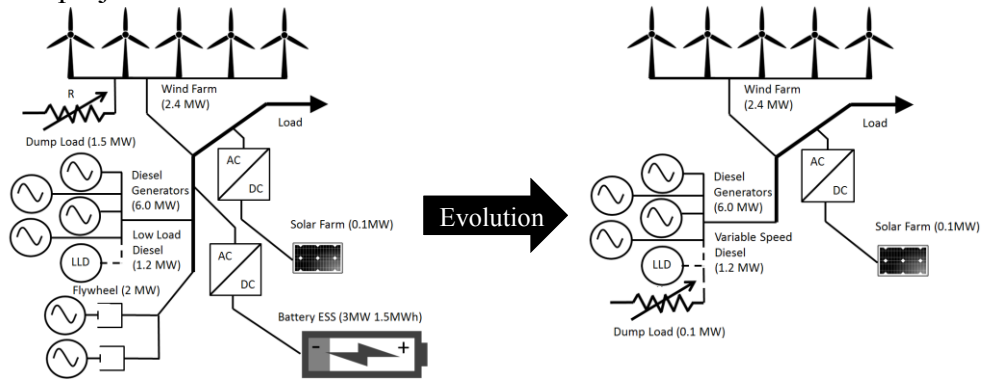


Figure 5 King Island Renewable Energy Integration Project (*left*) and Possible King Island Cost Optimised Configuration (*right*).

The wind 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 PCS which starts, stops and loads selected equipment, to optimise the available wind generation whilst maintaining supply security.

King Island is an impressive research facility, delivering 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 suggest a possible commercialisation pathway. Variable speed diesel represents a key enabler to this transition, given the ability to integrate many of the separate enabling technologies. The possible system configuration, Fig. 5, could serve to halve the capital costs of the project, while preserving the majority of the operational function and thus fuel savings. Variable speed integration within a typical hybrid diesel scenario presents a payback period of under 12 months.





## References

---

- [1] J. Hamilton, M. Negnevitsky, and X. Wang, "Low load diesel perceptions and practices within remote area power systems," in IEEE International Symposium on Smart Electric Distribution Systems and Technologies (EDST) CIGRE SC C6 Colloquium, September 8-11, pp. 121-126.
- [2] D. Nikolic, M. Negnevitsky, and M. d. Groot, "Effect of the Diesel Engine Delay on Stability of Isolated Power Systems with High Levels of Renewable Energy Penetration," IEEE International Symposium on Smart Electric Distribution Systems and Technologies (EDST) CIGRE SC C6 Colloquium, September 8-11, 2015.
- [3] J. Hamilton, M. Negnevitsky, X. Wang, A. Tavakoli, and M. Mueller-Stoffels, "Utilization and Optimization of Diesel Generation for Maximum Renewable Energy Integration," in Smart Energy Grid Design for Island Countries, 1st ed: Springer, 2017, pp. 21-70.
- [4] M. S. Peralta, J. Glassmire, M. Lazopoulou, K. Sumner, X. Vallvé, PeterLilienthal, et al., "INNOVATION OUTLOOK RENEWABLE MINI-GRIDS," International Renewable Energy Agency, 2016.
- [5] M. Negnevitsky, J. Hamilton, S. Lyden, and X. Wang, "Variable Speed Low Load Diesel Application to Maximise Renewable Energy Penetration in Isolated Power Systems," in IEEE Power and Energy Society General Meeting, Chicago, IL, USA, 2017.
- [6] I. Das and C. Canizares, "Feasibility study of variable speed generators for Canadian arctic communities," University of Waterloo, Ontario, Canada, 2017. Available online: <http://www.innovus-power.com/wp-content/uploads/2017/09/WISE-Innovus-Feasibility-Release.pdf>
- [7] Y. Fan, V. Rimali, M. Tang, and C. Nayar, "Design and implementation of stand-alone smart grid employing renewable energy resources on Pulau Ubin Island of Singapore," in 2012 Asia-Pacific Symposium on Electromagnetic Compatibility, APEMC, May 21-24, Singapore, 2012, pp. 441-444.
- [8] J. Hamilton, "Low Load Diesel," presented at the All Energy, Melbourne, Australia, 2017. Available online: <https://www.slideshare.net/jameshamilton10/low-load-diesel-all-energy-2017>
- [9] J. Hamilton, M. Negnevitsky, X. Wang, and A. Tavakoli, "No Load Diesel Application to Maximise Renewable Energy Penetration in Offgrid Hybrid Systems," CIGRE Biennial Session 46 (C6 PS3), August 21-26, 2016.
- [10] C. Nayar, "Innovative Remote Micro-Grid Systems," International Journal of Environment and Sustainability, vol. Vol. 1 No. 3, pp. 53-65, 2012.
- [11] M. Virmani and D. Hennessy, "Fully-Variable Fan Drives The Benefits of Fully-Variable Fan Drives on Generator Sets," Horton 2014. Available online: <https://www.hortonww.com/assets/documents/horton-whitepaper-12.12.16r10-fully-variable-fan-drives.pdf>
- [12] J. Manwell, W. Stein, A. Rogers, and J. McGowan, "An investigation of variable speed operation of diesel generators in hybrid energy systems," Renewable energy, vol. 2, pp. 563-571, 1992.
- [13] S. V. Mathews, S. Rajakaruna, and C. V. Nayar, "Design and implementation of an offgrid hybrid power supply with reduced battery energy storage," in 2013 Australasian Universities Power Engineering Conference, September 29- October 3, Hobart, TAS, Australia, 2013.
- [14] D. Wang, "A Novel Variable Speed Diesel Generator Using Doubly Fed Induction Generator and Its Application in Decentralised Distributed Generation Systems," Curtin University, Perth, Australia, 2012.