Variable speed generators for Naval Platforms

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Synopsis

Variable speed generation is widely used in commercial marine Direct Current (DC) distribution systems however had been limited in Naval applications until the recent championing of the technology by both the German F126 and Belgium / Dutch Anti-Submarine Warfare (ASW) Frigate programmes and more recently programs to the Spanish Armada and Portuguese Navy.

The introduction of DC Power Distribution enables variable speed generation by simply adding a diode or thyristor rectifier at the generator output. Insulated-Gate Bipolar Transistor (IGBT) Inverters can also be used, however these come with lower efficiency and at larger powers, above 1,5 MW, a further downside in the form of size and cost. For Alternating Current (AC) distribution systems, variable speed generation would require an additional inverter stage, i.e. a full frequency converter, which is not attractive due to Size, Weight Power and Cost (SWaP-C).

This paper first addresses the design challenges of the Naval Powerplant Engineer has when balancing demands and then present thoughts how well proven solutions with variable speed operations can resolve these challenges and add benefits to a platform. By eco-driving diesels: Increased fuel efficiency and increased range of up to 27% [4] giving allowance for larger Mission systems; Extended Maintenance Intervals of up to 20% or more; Lower Noise Emissions up to 30% [4] for the benefit of crew and strict noise compliances; Increased Power Density; and Adaptability to Load Variations, especially beneficially for platforms that operate with high percentages of low loads such as loitering or Dynamic Positioning (DP) standby.

The paper will then explore further Naval advantages and the operational scenarios they benefit: Time to start up and connect the generator to the DC distribution system is much faster compared to AC distribution systems, as the generator connects to the DC system at the lower end of the speed range, e.g. 50% of the rated speed, when the generator has reached the rated voltage. No synchronization for frequency and phase is required, just voltage matching provided by the Automatic Voltage Regulator (AVR), thus synchronization is much faster and more reliable than with AC systems. Allows to tune the system to void structural resonances, vibrations, thoughts for Signature management are presented.

The paper will then summarise these benefits, discuss the challenges to overcome and utilise real world commercial examples and benchmark against simulations of naval power plants.

Keywords: Variable speed generators; DC Grid; Naval powerplant design.

1. Introduction, challenges for Naval powerplant design

Designing modern powerplants for naval vessels presents a complex array of engineering challenges and strategic decisions. Marine engineers must balance operational demands, futureproofing, and regulatory compliance while navigating constraints in space, weight, and cost. Key considerations include:

- **High-Speed (HS) vs. Medium-Speed (MS) Gensets**: HS gensets offer significant space and weight savings but may be limited in Time-Between-Overhaul (TBO) and power range.
- **N-1 Redundancy Criteria**: Ensuring the vessel can operate without limitations even with one genset offline, common in Tier I or frontline combatants.
- **Operational Vessel and Load Profiles**: Accurate loads across operational modes are essential for effective genset sizing and powerplant design. Naval officers typically attempt to define the vessel's operational profile during the design phase; however, in practice, the vessel is often operated in ways that diverge significantly from these initial assumptions.
- **Power Growth Forecasting**: Future power demands can vary from 15% (Tier II - Mid-level combatants with regional or specialized role) to over 100% (Tier I), driven by systems like Directed Energy Weapons (DEW), advanced radars, Electronic Warfare (EW), and offboard asset charging.
- **Fuel Efficiency & Compliance**: Political and environmental pressures demand lower fuel consumption and compliance with IMO Tier III regulations.
- **Selective Catalytic Reduction (SCR)**: SCR systems require specific exhaust temperatures and loading conditions to function properly.

- **Operational Expenditure (OPEX)**: Future fuels like e-diesel may be more expensive or less energy-dense, influencing lifecycle costs, see Figure 1 for illustration.
- **Naval Architecture Constraints**: Weight and space limitations drive design trade-offs.
- **Electrical Selectivity & Safety**: High short-circuit currents affect protection systems and Personal Protective Equipment (PPE) requirements.
- **Damage Control & Zoning**: Firefighting, electrical zoning, and cable routing must be considered.
- **Ice Operations**: Over-torque requirements (e.g., 150–180%) for increased ice performance
- **Battery Energy Storage Systems (BESS)**: Batteries must be tailored to specific operational functions.
- **Crash Stop & Load Rejection**: Diesel ramp rate penalties and braking dynamics are critical.
- **Noise & Vibration**: Acoustic signatures and crew comfort are key design factors.
- **Blackship Recovery**: Strategies for restoring power in total blackout scenarios.
- **Naval Power Quality:** Meeting demands such as STANAG 1008

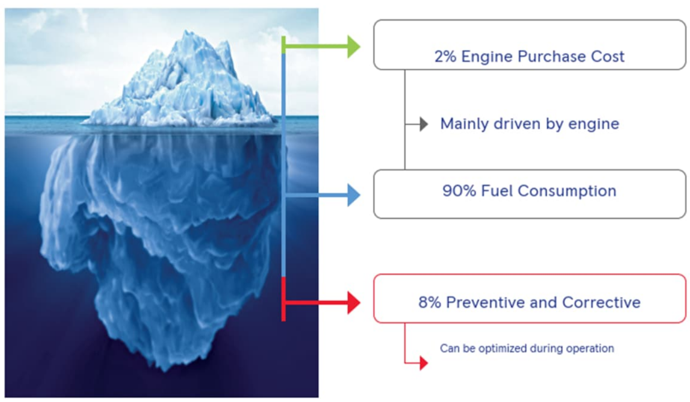


Figure 1: Through life cost of Marine Diesel [1]

As such, the design of naval powerplants is a multifaceted challenge that requires a delicate balance of various factors. Engineers must navigate the complexities of genset selection, redundancy, load management, and future power growth while adhering to stringent fuel efficiency and regulatory standards.

Ultimately, the success of naval powerplant design hinges on the ability to make informed trade-offs and optimize performance, reliability, and cost-effectiveness. By addressing these challenges head-on, marine engineers can develop powerplants that not only meet current demands but are also adaptable to future advancements and operational needs.

2. Lessons learned for existing platforms

Real-world naval platforms offer valuable insights into the consequences of these design decisions:

2.1. Over-Sized Installations:

Some vessels opted for large diesel installations to futureproof power capacity. However, this led to excessive short-circuit currents, requiring open bus ties and raising arc flash concerns—an operational limitation unlikely to be accepted by senior naval leadership. Conversely, platforms with excessive disparity between genset sizes (father-son configurations) experienced inadequate short-circuit levels, necessitating retrofits or genset idling.

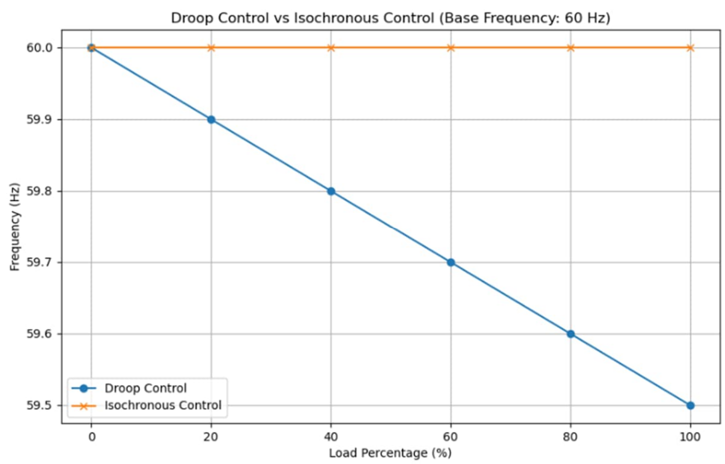
2.2. *Case Study: NATO Vessel*

The author has engaged with crew aboard a NATO vessel featuring four MS diesels and two HS gensets. Crew feedback highlights several issues:

- **"Swing" Generator Stress:** To reach peak power, all six gensets must operate. HS gensets, due to their low inertia, act as swing generators—ramping from 0–100% within seconds. This operational mode has raised concerns about genset health, leading the crew to rely solely on MS gensets, thereby limiting propulsion capability.
- **Mismatch in Operational Profile:** HS gensets are too large for harbour operations and incompatible with MS gensets on a fixed-frequency bus. As one crew member put it, "*They are in fact useless."*

Discussions to re-classify the Emergency generator for harbour mode have stranded because of the lack of SC capacity.

While frequency-based droop control and modern governors could theoretically resolve some of these issues, such solutions require significant redesign and testing—offering little relief to current operators.



- Figure 2: Governor frequency based droop control for active loadsharing.

3. Variable Speed Generation

What if there were proven, yet underutilized, technologies that could alleviate many of the design challenges outlined earlier? Variable Speed Generation (VSG) offers precisely that—enhancing efficiency, flexibility, and reliability in naval powerplant design. When integrated into modern architectures such as a CODELAD, Combined Diesel Electric and Diesel, DC grid with a two-split configuration (see Figure 3), VSG can significantly improve performance over traditional fixed speed AC systems.

By decoupling generator frequency from the electrical grid, VSG eliminates many of the limitations associated with fixed-frequency AC systems—such as minimum and maximum short-circuit levels and undervoltage constraints. This allows a broader range of gensets to operate on the same bus, improving design flexibility and system resilience.

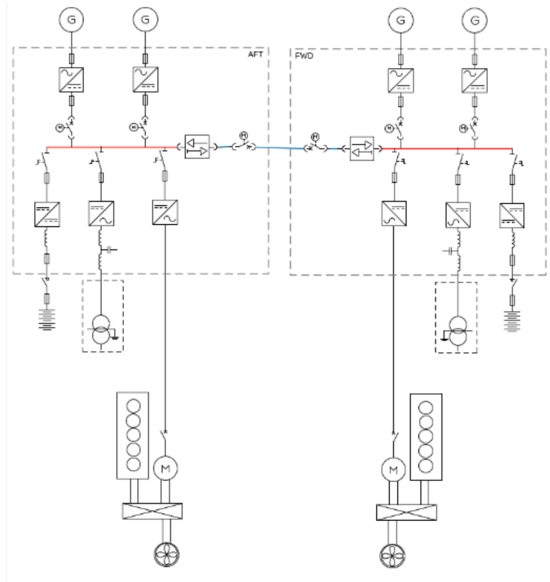


Figure 3: CODELAD Variable speed gensets SLD

3.1. Sizing Flexibility

Traditional designs often rely on "father and son" genset arrangements to match efficiency with operational profiles. For AC installations: A pivotal decision often lies between selecting a smaller powerplant that is efficient but limited in TBO and scalability, versus a larger system that may suffer from inefficiencies at low load and elevated short-circuit levels.

For example, a smaller truck-based diesel Corvette/Frigate setup operating 5,500 hours annually with a TBO of 14,000 hours would require major overhauls roughly once per year, or a full genset replacement every four years—an operational and cost burden that must be acceptable to the end user. In contrast, VSG enables the use of uniformly sized gensets, simplifying Life Cycle Management (LCM) and reducing logistical complexity.

As illustrated in Figure 4, fixed-speed diesels are typically efficient only down to 50% load. Variable-speed diesels, however, maintain efficiency down to 20% load. For example, a 3,000 kWe genset would have a minimum efficient load of only 1,500 kWe at fixed speed but be efficient down to 600 kWe with variable speed, ideal for hotel loads typically ranging from 600–800 kWe for a mid-size frigate.

3.2. Increased Energy Efficiency

VSG systems dynamically adjust engine speed to match load demand, significantly improving fuel efficiency. For Tier I combatants, this can result in annual fuel savings of approximately 15%, with specific load points achieving up to 27% savings [4]. These improvements translate into lower operational costs and reduced environmental impact.

3.3. Extended Maintenance Intervals

Operating at variable speeds reduces mechanical stress and wear on genset components, extending maintenance intervals by up to 20% [1]. Some HS gensets, typically rated for 14,000 hours TBO, have demonstrated operational lifespans of up to 29,000 hours under variable-speed conditions. In fact, some OEMs now offer service intervals based on fuel burn rather than operating hours.

3.4. More output power

As now the Diesel are not fixed to operate at 50 or 60 Hz – 1500 or 1800 RPM for Highspeed Diesels there is possibility to get more installed power by going to 1900 or 2000 rpm. To be noted that this is only for the top power need and the diesel would not spend a lot of time at max load with high exhaust temperature. Load dependent start and stop would start additional diesels and if all available power sources are running then the diesels will never be overload as there will be a power limit on the propulsion system.

3.5. Lower Noise Emissions

Variable-speed operation also reduces acoustic emissions, improving onboard working conditions and reducing the vessel's acoustic signature—an important factor in naval stealth. A reduction of 6 dB, as reported in [1], may seem modest, but it represents a doubling of sound pressure. Human perception equates this to nearly twice the loudness, underscoring the substantial benefit of quieter operations.

3.6. Improved Fault Tolerance

VSG systems inherently mitigate certain failure modes common in AC systems. For example, excitation faults and fuel rack failures that can cause reverse power trips in AC plants are not applicable in DC systems using diode or thyristor-based rectifiers. These faults have historically led to blackouts by tripping healthy gensets—a risk significantly eleminated in VSG architectures with diodes or Thyristors. While such issues are more commonly addressed in Dynamic Positioning (DP) vessels, similar incidents have occurred in non-DP naval platforms.

3.7. Speed Control and Generator Design

The genset's operating speed is typically governed by the engine's Specific Fuel Oil Consumption (SFOC) curve, with speed ranges tailored to expected load profiles. System Design decisions needs to be made for DC Switchboards voltage coordination, protection and Control

As can be seen in Figure 4 the closer to the MCR, Maximum Continous Rating, curve the diesel operates the more efficient. The loadstep and load rejection capabilities for the system needs also to be considering the total system including BESS, overvoltage choppers etc. However, a typical DC grid setting of load dependant start is 93% significantly higher than the typical 80% of AC plants.

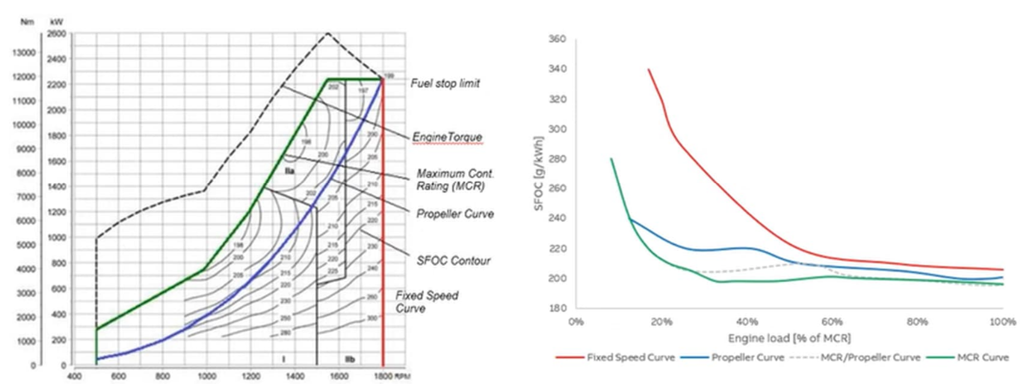


Figure 4: ABB Example of SFOC Curve for fixed and variable speed diesels,

4. Naval Advantages and Operational Scenarios

Variable Speed Generation (VSG) offers several distinct advantages for naval applications, enhancing both operational efficiency and tactical flexibility. These benefits extend beyond traditional commercial use cases and are particularly relevant in mission-critical naval environments.

4.1. Faster Startup and Connection Times

VSG systems can start and connect to a DC distribution network significantly faster than conventional AC systems. Generators can synchronize at the lower end of their speed range (e.g., 50% of rated speed) once the rated voltage is achieved. This rapid startup capability reduces downtime and enhances operational readiness—critical in combat and emergency scenarios.

4.2. Signature management

Unlike commercial vessels, naval platforms must manage acoustic and infrared (IR) signatures to avoid detection. VSG enables dynamic control of generator speed, which can be leveraged to:

- Alter acoustic signatures by varying genset RPMs, making it harder for enemy sonar to classify the vessel using FFT, Fast Fourier Transform analysis.
- Create a broader acoustic spectrum or “white noise” by operating multiple gensets at different speeds.
- Reduce IR signatures by running more gensets at lower speeds, thereby lowering exhaust temperatures.

These strategies offer promising avenues for enhancing stealth and survivability.

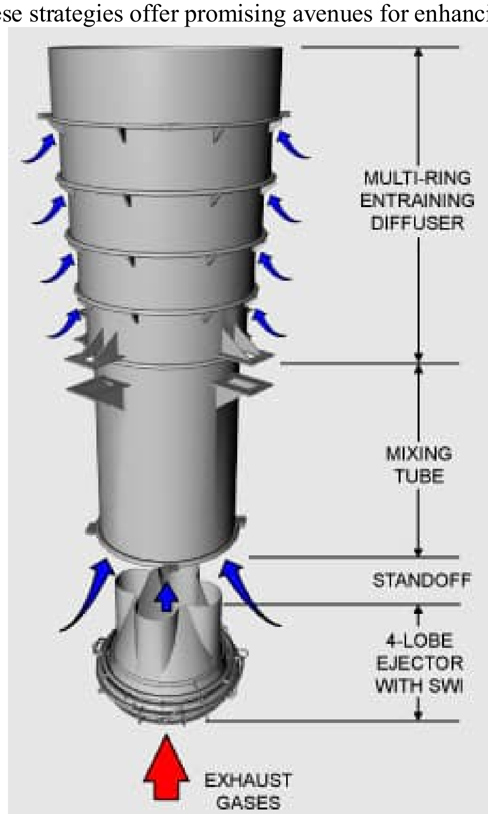


Figure 5 Exhaust diffuser, courtesty of Davis Engineering[5]

4.3. Structural Resonance and Vibration Tuning

VSG allows operators to avoid structural resonances and vibration issues by adjusting generator speeds. This is vital for maintaining structural integrity, crew comfort, and acoustic discretion—especially during Anti-Submarine Warfare (ASW) operations. Speed control also enables avoidance of problematic zones in the engine’s SFOC curve, such as turbo lag or eigenfrequencies.

5. Examples of simulation

Figure 6 presents simulation results based on real-world measurements from an existing naval vessel. These simulations compare two powerplant concepts under dynamic daily load profiles.

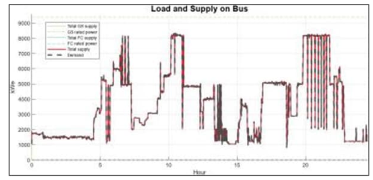
Note: Not all efficiency gains are attributable solely to VSG. The DC architecture also incorporates batteries for spinning reserve and peak shaving, enabling fewer generators to run simultaneously.

AC Distribution

Power Plant 252 MWh - Load 84 MWh = 168 MWh

25.3 t fuel   Fuel Efficiency = 33.3%

Genset running hours = 73.6 hours



DC Distribution

Power Plant 209 MWh - Load 84 MWh = 125 MWh

21.0 t fuel   Efficiency = 40.2%

Fuel: -4.3 t /day   Fuel Efficiency: +20.7 %

Genset running hours = 44 hours

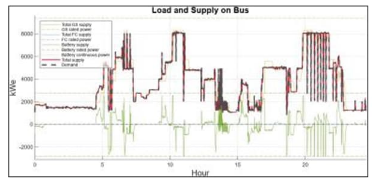


Figure 6 Dynamic simulation of a daily operational profile

5.1. *Achievable Savings Across Naval Platforms*

Recently ABB participated together with FMA and Grønskipsfartprogram together with the broader Norwegian Naval Industry in a study for the Norwegian Naval Forces for their future 28 standard vessels [3].

The Norwegian Navy released data from OPV KV Harstad from 2022 for the Industry to simulate and compare.

The key message: Power and propulsion solutions already tested in commercial shipping can give emissions reduction of 20-25 %

5.2. *Unlocking the Naval Potential with PEMS Control*

For commercial VSG focus have been fuel optimization to stay competitive. For Navies there are a broader usage that are not yet fully explored, the Author could foresee following PEMS, Power and Energy Management System, control modes for a combatant:

1) **Ecomode** – slow loadramps with, control for low SFOC and proper exhaust temp for SCRs to work
2) **Silent mode** – powerplant optimized for low SBN & ABN (Structural- and Air Borne Noise) noise ASW, most likely low RPM, fans control, lower DC link voltages and also adaptive damping technology for shafts.
3) **Combat** – fast ramps, extra power by allowing the genset to go above nominal RPM
4) **IR Management** mode – control loops focusing on low Exhaust temp for IR optimization [5]
5) **Adaptive Signature** mode – a mode where gensets and the corresponding propulsion never goes to a fixed frequency but varies to create a white noise spectrum delaying classification.

6. Challenges faced with VSG

Despite the extensive history and development of Variable Speed Generator (VSG) technology, several challenges persist. While technical hurdles have largely been addressed over time, the authors assert that the predominant challenges today are commercial in nature. These are discussed in detail below.

Historically, generator sets (gensets) were delivered as integrated packages by diesel engine original equipment manufacturers (OEMs), encompassing both mechanical and electrical components. In contrast, VSG systems require a more nuanced approach to electrical integration. The electrical characteristics of the generator must be carefully matched to the broader electrical system, significantly expanding the scope of integration beyond traditional mechanical considerations.

Mechanical integration typically involves concerns such as eigenfrequencies, vibration zones, and operational limitations defined by the engine's shell curve. Diesel OEMs are primarily focused on avoiding these problematic operating points. In contrast, electrical OEMs approach the system design from a control and performance perspective, engineering the system to simply avoid these zones through operational constraints.

As a result, the responsibility for the VSG alternator design and supply typically resides with the electrical system OEM and are delivered to the Diesel OEM for HS on a common skid. This allocation ensures that the alternator is appropriately selected and integrated to meet the system's electrical requirements.

Key considerations for electrical integration include:

-Alternator Type: Selection among permanent magnet (PM), synchronous, or induction machines.
-Voltage Adaptation: Ensuring compatibility with the system's voltage levels and requirements.
-Control Strategy and BESS: Implementing appropriate control mechanisms for dynamic operation. As mentioned in [1] the ramp up of speed can be slower however if needed this is handled by the instant power from Battery Energy Storage System.

When comparing alternator sizing between fixed-speed and variable-speed configurations, the physical dimensions are often comparable. However, there are instances where VSG alternators may be either larger or smaller, depending on specific application requirements and design choices.

7. Conclusion

The evolution of naval powerplant design is increasingly shaped by the need for greater efficiency, operational flexibility, and futureproofing against emerging mission demands. This paper has explored the multifaceted challenges faced by marine engineers—ranging from genset sizing and redundancy to stealth, emissions compliance, and lifecycle costs.

Variable Speed Generation (VSG), particularly when integrated into hybrid DC architectures, presents a compelling solution to many of these challenges. By decoupling generator speed from grid frequency, VSG enables:

- Enhanced fuel efficiency across a broader load range
- Reduced maintenance through lower mechanical stress
- Improved acoustic and infrared signature management
- Greater flexibility in system sizing and configuration
- Faster startup and simplified synchronization
- Opportunities for structural vibration tuning and stealth optimization
- If needed more power from each diesel as the max speed is not now limited to nominal RPM for the 50 or 60 Hz.

Simulation studies and real-world audits confirm that VSG can deliver fuel savings of 15–25%, extend maintenance intervals, and reduce installed power requirements—without compromising mission capability. These benefits are particularly relevant for next-generation naval platforms, including ASW frigates, patrol vessels, and multi-role combatants.

As naval forces worldwide seek to modernize fleets and meet evolving operational and environmental standards, VSG offers a proven, scalable, and strategically advantageous path forward. Its adoption not only enhances platform performance but also contributes to long-term sustainability and mission readiness.

Further control strategies, testing and validation is required to fully explore the Naval VSG potential.

Acknowledgements

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References

1. Joerg Habermaas & Jochen Thurner, *Rolls-Royce Power Systems / MTU Solutions*.
Title: *Variable Speed Generator Sets Offer Advantages for Commercial Ships*.
URL: https://www.mtu-solutions.com/eu/en/technical-articles/2020/variable-speed-generator-sets-offer-advantages-for-commercial-sh.html

2. J.F. Polglaze, *PGM Environment, Australia*.
Title: *'Alternative Fuels' or 'Koolaid'?: Maintaining Focus and Perspective When Considering Options for Future Naval Fuels*.
Published at: INEC 2024, Institute of Marine Engineering, Science & Technology (IMarEST).
URL: https://library.imarest.org/nanna/record/11171/files/INEC_2024_paper_15.pdf

3. Forsvarsmateriell, in collaboration with *Grønt Skipsfartsprogram (DNV)*.
Title: *Mulighetsrom for bærekraftige løsninger for Forsvarets fartøyer*.
URL: https://grontskipsfartsprogram.no/wp-content/uploads/2025/05/Baerekraftige-losninger-for-Forsvarets-fartoyer-FINAL.pdf

4. ABB Group.
Title: *Tests Confirm Up to 27% Fuel Savings on Ships from Onboard DC Grid*.
URL: https://new.abb.com/news/detail/13107/abb-tests-confirm-up-to-27-fuel-savings-on-ships-from-onboard-dc-grid

5. W.R. Davis Engineering Ltd.
Title: *Engine Exhaust Suppression Technologies*.
URL: https://www.davis-eng.com/exhaust_suppression.html