Electric Power System Concepts for Integration of Advanced Sensor and Pulsed Loads in the DDG-51 Class Ships

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ABSTRACT

Advanced weapons and sensors increase demand on the electric power systems of Navy surface combatants, driving the need for fully Integrated Power Systems (IPS) such as those found in the DDG-1000 Zumwalt class of ships. The goal of this paper is to introduce novel power system configurations that could potentially be integrated into future flights of the DDG-51 class to support expanded electric power system capability at reasonable cost. Two concepts are presented: the first addresses the need for additional power for advanced sensor systems and the second addresses the need for a more significant increase in capacity to support higher power electric loads.

INTRODUCTION

Advanced weapon and sensor technologies are placing increasing demands on the electric power systems of Navy surface combatants, driving the need for fully Integrated Power Systems (IPS) such as those found in the DDG-1000 Zumwalt Class of ships. While IPS architectures address the increased electric power system loads, the cost of the DDG-1000 class ships is still high, resulting in a reduction in the number of ships planned in this class. The goal of this paper is to identify novel power system configurations that could be effectively integrated into the current DDG-51 Arleigh-Burke class of surface ships to support expanded electric power system capability at reasonable cost.

It is well known that higher speed electric machines can be smaller and lighter than comparable 60 Hz machines which are limited to 3,600 rpm. DC distribution and advances in solid-state power conversion allow the designer to decouple the power generation frequency from the distribution or load frequency, enabling the integration of higher frequency power generation into existing 60 Hz power systems. Combining the application of higher power density high speed machines with an understanding of the constraints of naval architecture provides a path to enhanced electric power system capability for the DDG-51.

The first concept addresses the need for additional power from the ship service electric system to power advanced sensor systems by replacing the existing AG9140 Gas Turbine Generator (GTG) sets. The new GTG's would feature two independent direct drive high speed generators and the associated power electronics to interface with the ship service distribution system and new sensor loads. With careful design, it may be possible to accommodate the new power system concept using significant portions of the AG9140 skid and enclosure design while maintaining the skid mounting and interface locations to minimize the impact on the DDG 51 installation.

The second concept addresses the need for a more significant increase in the installed electric capacity of the DDG-51 to support higher power electric loads such as directed energy weapons or electromagnetic launchers. This concept requires significant modifications to the existing equipment layout and power distribution systems and targets a new flight of DDG-51 class ships specifically configured to take full advantage of the IPS architecture. The concept provides a flexible power system to support a variety of higher power electric loads and could potentially extend the useful life of the DDG-51 class.

The two power system concepts presented here have not yet been the subject of a detailed engineering study; however, the concepts are believed to warrant further study and continued evaluation is recommended. The following sections provide more detailed descriptions of the two DDG-51 electric power system upgrades and identify technical issues that should be addressed in more detailed studies.

Enhanced Sensor Power Supply

This concept involves replacement (or modification) of the existing AG9140 gas turbine generator sets (GTGs) to provide additional power generation capability. The DDG-51 class has three ship service GTG sets each providing a nominal 2.5 MWe to a 450 V, 60 Hz ac power distribution system. Each AG9140 GTG consists of a Rolls-Royce/Allison 501 gas turbine driving an 1,800 rpm synchronous generator through a speed reduction gearbox. Figure 1 shows the basic layout of the current AG9140 GTG with rough dimensions [1].

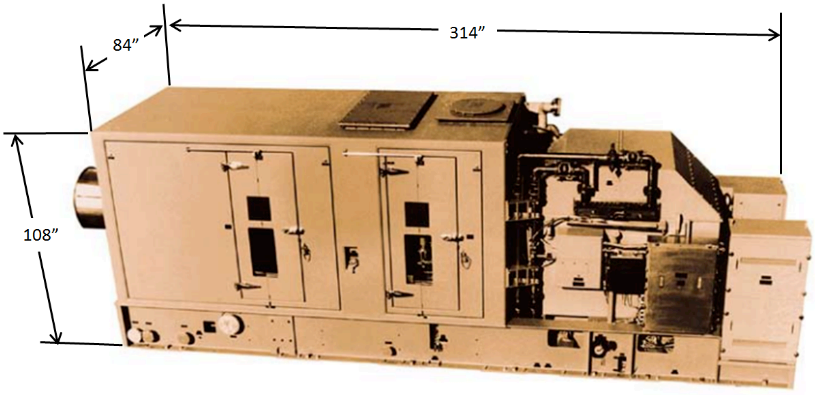


Figure 1. Basic layout of the AG9140 GTG.

In this concept, the Allison 501 turbine, gearbox and low speed generator of the AG9140 would be replaced with a pair of higher efficiency, twin-shaft, gas turbines directly coupled to high speed generators. Solid-state power converters enable the modified system to provide 60 Hz power to the existing 450 V ac ship service distribution system and to independently supply a separate electric load dedicated to enhanced sensor systems. The increased power density of the new turbine/generator configuration allows the placement of the required power conditioning electronics and all auxiliaries within the original AG9140 footprint. With appropriate packaging, the new turbines, generators, and power conditioning equipment could potentially be installed without major structural changes to the DDG-51. If the transition to twin high-speed generators can be accomplished with minimal modification to the existing AG9140 module it could enable cost-effective backfit of the system onto existing DDG-51 class ships.

The impact of higher speed operation on the power density of electric machines is significant because of the reduced torque required for a given power. For a rotating machine (e.g. motors, generators) the output power is equal to the product of torque and speed. For synchronous electric machines this can be illustrated with a more general power equation:

$$P \propto \underbrace{B \times A_s \times D^2 \times L}_{\textbf{Torque}} \times \omega \qquad (1)$$

where

P= power
B= air gap flux density
A_s= stator line current density
L= machine active length
D = airgap diameter
ω= angular velocity

This relationship illustrates the significant reduction in generator size that can be achieved by operating the generator at the 14,340 rpm speed of the Allison 501K power turbine as opposed to the current 1,800 rpm synchronous speed. If we keep the airgap flux density and stator line current density fixed, the product $D^2 \times L$ can be reduced by a factor of approximately eight.

Gas Turbine Engines

The enhanced sensor power system concept employs advanced twin-shaft gas turbines to provide improved performance relative to the current single spool Allison 501. Although other options exist, two candidates are presented here; the Vericor TF40B/ETF40B and the Rolls-Royce AE1107. In conjunction with elimination of the gearbox losses the improved Specific Fuel Consumption (SFC) of modern turbine engines offsets the losses in the power conversion system, resulting in slightly lower SFC than the AG9140. Table 1 summarizes the SFC performance of the two GTG options. The Navy-qualified Vericor ETF40B used in the current LCAC program also offers a 20% higher power rating than the Allison 501 turbine. Using realistic generator and power conversion efficiencies, when coupled to a high-speed generator, the improved power output using the ETF40B can be provided with essentially the same SFC as the AG9140.

Table 1. Comparison of specific fuel consumption of baseline and retrofit DDG51 ship service power generation options.

		Specific Fuel Consumption	
	Power	(turbine)	(system)
	MW	lb/shp/hr	lb/shp/hr
AG9140	3.0[1]		0.50[1]
ETF40B + HSG	3.7[2]	0.46[2]	0.49[5]
AE1107C + HSG	4.6[3]	0.42[4]	0.45[5]

Notes:

1) http://www.rolls-royce.com/marine/products/diesels_gas_turbines/gas_turbines/ag9140.jsp
2) http://www.vericor.com/pdf/Marine_tfseries_datasheet.pdf
3) http://www.rolls-royce.com/Images/AE1107C_tcm92-6702.pdf
4) "Conceptual Design of a Commercial Tilt-rotor Aircraft" Priyanka, Guha, November 2011
5) Calculated by applying 96% generator and 98% power-converter efficiency to turbine only SFC

High Speed Generators

The University of Texas Center for Electromechanics (UT-CEM) previously developed and tested a 3 MW high speed generator and turbine drive system as part of the Federal Railroad Administration's Advanced Locomotive Propulsion System (ALPS) Program. The ALPS hybrid electric propulsion system consisted of a 3 MW turbine/alternator prime mover coupled with a 480 MJ, 2 MW energy storage flywheel for supplemental power during acceleration and to recover braking energy. Although this specific package was designed to be the prime mover for a high speed passenger locomotive, a compact turbine/alternator package is well suited for use in marine applications. Advances in thermal management and structural materials should enable increased power density relative to the ALPS generator design.

The ALPS high speed generator is designed to deliver up to 3.0 MW while directly coupled to a gas turbine with a power turbine shaft speed of 12,000 to 15,400 rpm. The generator is a wound field, salient-pole synchronous alternator with an integrated 20 kW brushless exciter and diode rectifier assembly. The electrical output of the eight pole alternator is nominally rated 1,660 V and 865 to 1040 A at 800 to 1024 Hz, corresponding to 12,000 to 15,400 rpm. The baseline generator was cooled with a combination of oil and open-loop air cooling; conversion to a water-cooled or totally enclosed water to air cooled configuration should be straightforward, although the

TEWAC configuration will increase the size of the package. The generator is 0.7 m (28 in.) diameter by 1.45 m (57 in.) long and has just under twice the mass of the TF40B turbine, at 1160 kg (2560 lb).

Figure 2 shows the ALPS generator coupled with a Honeywell TF40B engine. In this view the cooling air manifolds, electrical terminals, and axial end oil connections of the generator can be clearly seen.

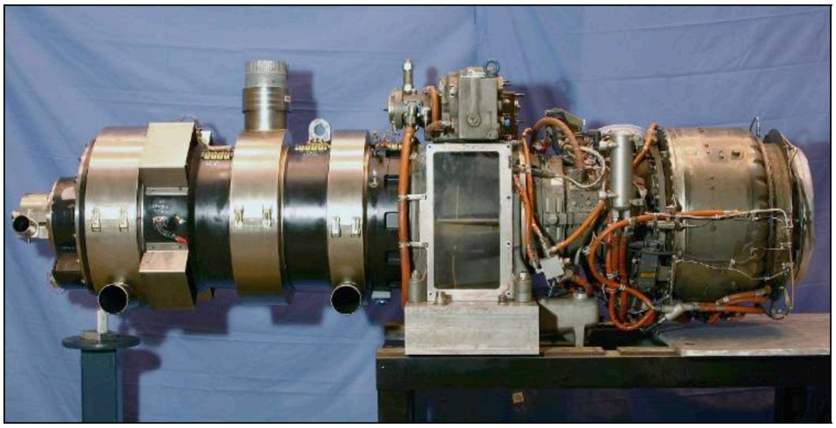


Figure 2. Navy TF40B Turbine driving the ALPS 3MW High-speed Generator

Although the ALPS generator is a wound field machine, for the new concept, voltage regulation can be provided by the active power conversion system, potentially enabling the use of permanent magnet machines (PMM) in a new system. UT-CEM developed a detailed preliminary design of a 5 MW 15,000 rpm PM generator as part of a ship power system study that could easily be adapted for this application as well [2]. This study shows that in this power range, PM machines have higher power density than comparable wound field machines so this option should be explored. A preliminary layout of the enhanced sensor system power supply concept using two ETF40B high-speed generators is shown in Figure 3.

Power Electronics

As shown in Figure 3, the upgraded power module includes the required solid state power conversion modules within the original AG9140 envelope. These consist of two 3 MW rectifiers and one 3 MW inverter: the ac output of one turbine generator can be rectified to provide dc power directly to the advanced sensor load and the output of the second turbine generator can be rectified and inverted to provide 60 Hz power to the ship's service loads. The two power sources can also be connected at the output of the rectifiers to form a local dc bus where the total 6 MW power capacity is available to the sensor and service loads (Figure 4).

The rectifiers are expected to be water cooled 12-pulse type that can be fed directly by the generators provided these are built as 6-phase machines, which can be accomplished with minimal, if any, cost premium to the generators (Figure 5). This will ensure a good performance from the standpoint of total harmonic distortion (THD). The use of rectifier topologies with more pulses (thus requiring generators with more phases) can be considered and weighed on the basis of the added complexity versus the benefits derived. Figure 6 shows the progression of current THD versus rectifier number of pulses and in-line filter inductive impedance. Similar plots apply to THD on the voltage waveforms.

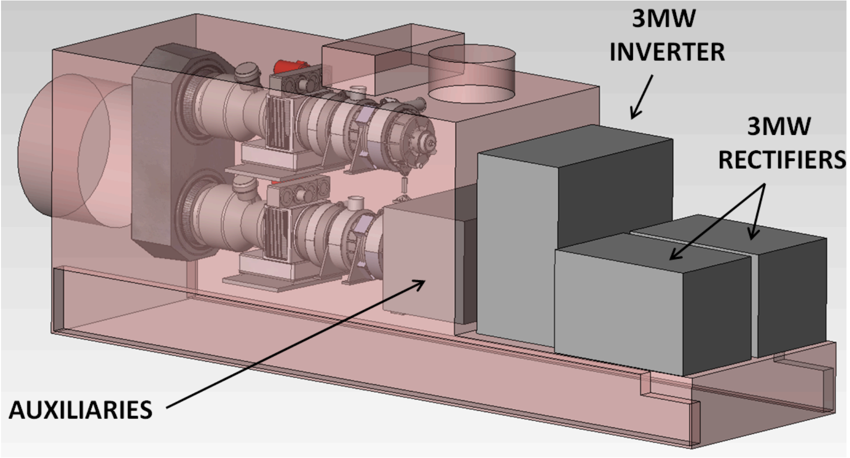


Figure 3. Layout of major components for upgraded ship service power within AG9140 envelope.

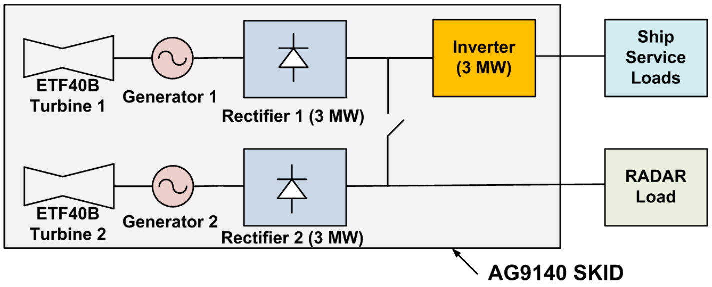


Figure 4. Schematic electrical diagram of the AG9140 upgrade

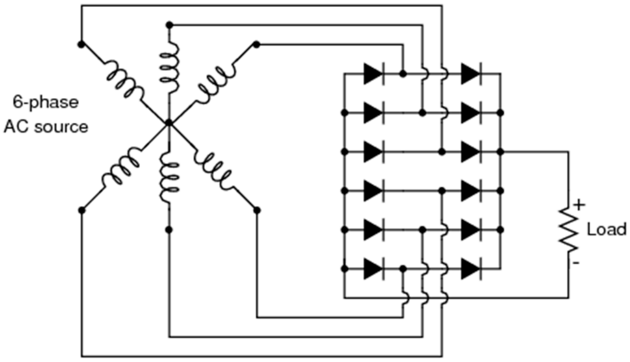


Figure 5. Diagram of a 12-pulse rectifier fed by a 6-phase generator

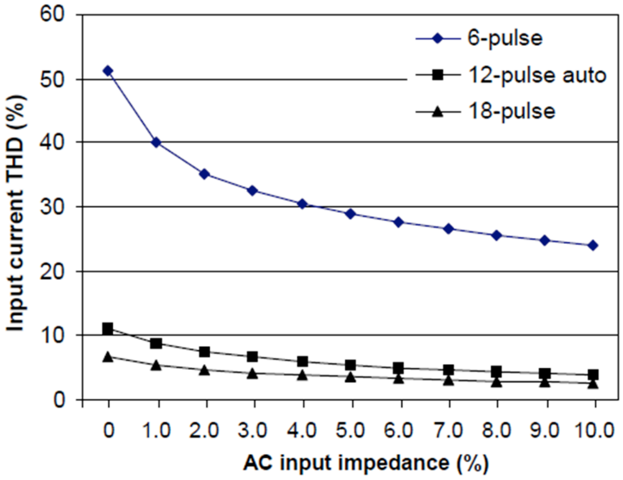


Figure 6. Current THD versus rectifier number of pulses and filtering impedance [18].

The inverter used to provide the 60 Hz power for the ship service load is also designed to be water cooled like the rectifiers. Its design is according to standard voltage source inverter topologies but it is equipped with suitable filtering to ensure that its output meets the requirements of MIL-STD-1399-300B. The electronic power conversion modules are shown to scale in Figure 3. This results in a power density of less than 2 MW/m^3 for the rectifiers and of 1 MW/m^3 for the inverter. Both these figures are conservative as they are already exceeded by equivalent commercial units today.

In addition to the basic sizing of the major components, a preliminary pressure drop analysis was conducted to assess the impact of the increased exhaust flow. For the initial study, a representative uptake geometry consisting of 100 linear feet of 48 inch diameter ductwork with two 90 degree bends was analyzed. Preliminary results of the analysis indicate that with appropriately designed exhaust collectors, the pressure drop within the uptake ducting is not significantly increased for the upgraded ship service power system. Further, it is likely that any pressure drop increases in the ductwork can be mitigated with very small increases in ductwork diameter. Insufficient information was available to calculate the increased pressure drop on the intakes; however, the impact on turbine performance is not expected to be significant.

AE1107C/PMM

For a more significant ship service upgrade, the Rolls Royce AE1107C gas turbine could be coupled with a more advanced high speed generator, such as a permanent magnet machine (PMM). UT-CEM has previously reported the performance benefits that can be achieved with PMM's [2]. Similar to other generator designs, a directly coupled PMM eliminates the need for a speed reduction gearbox, but a PMM provides the additional advantage of eliminating the need for an exciter that adds to size and losses. The AE1107C turbine is capable of producing 4.6 MW output power, with similar or slightly lower specific fuel consumption. A 5 MW range PMM would be very similar in size to the 3 MW wound synchronous generator.

More detailed analysis of the enhanced sensor power system upgrade concept is recommended. The next step in the investigation should include detailed solid modeling of the module, modeling and simulation of the impact on the power distribution system, power cable routing, enclosure ventilation, fuel supply, and integration of controls.

DDG 51 Integrated Power System Concept

The need for electric power on future naval surface combatants is expected to continue to increase (Figure 7) as more advanced sensors and weapons are introduced [3]. Government, industry and academic research into Integrated Power Systems (IPS) for future naval vessels is being conducted at many organizations within the United States as well as in foreign countries. Most of the concepts for new IPS surface combatants (e.g. the UK's

Type 45 Daring Class and the US Zumwalt Class) are fully integrated designs that include electric propulsion [4,5,6,7]. These ships have been designed from the keel up for full electric propulsion and provisions for integration of the major elements of their electric power distribution systems (e.g. high power, low speed propulsion motors and the associated motor drives) have been included from the beginning of their development. IPS concepts for integration into existing mechanically driven ships like the DDG 51 have proven to be very challenging, in part because of the size and weight of the propulsion motors and drives to match the current 40 MW per shaft capability of the DDG 51.

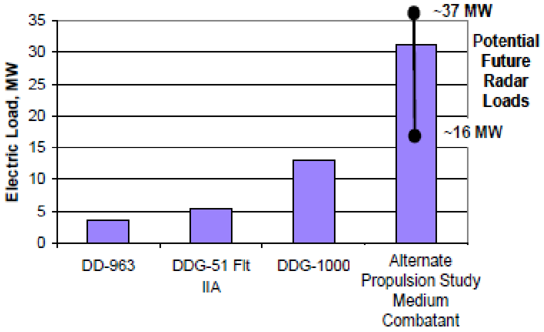


Figure 7. Historic and Predicted Growth in Maximum Margined Ship Service Loads.

The DDG 51 Integrated Power System Concept (IPS) presented here provides an approach to a significant increase in the electric power generation on the DDG 51 or for similar hull forms. Electric weapon and sensor technologies (e.g. electromagnetic guns, advanced radars, and LaWS) are actively being developed for future naval applications; however, accommodations for the weight and volume of these systems have not yet been defined. The selection and integration of these new systems and their impact on future electric power system requirements will require extensive design trade studies on both required capabilities as well as physical integration. For example, it might be possible to trade a portion of the current Vertical Launch System (VLS) capability to free weight and volume within the hull for an electromagnetic gun system. Extending the length of the DDG 51 through the use of a hull plug has also been studied as a way to increase the available payload and volume available for future mission systems. [8].

In order to minimize the impact on existing ship structures, this concept proposes a hybrid mechanical/electrical propulsion system to take full advantage of the efficiency of mechanical power transmission while incorporating the flexibility of electric power distribution. This concept is similar to the Hybrid Electric Drive (HED) concept or the hybrid electrical/mechanical power system architecture of the LHD8 *Makin Island* but at significantly higher power levels and with the ability to support high power electrical loads beyond propulsion [10].

In its full embodiment, the concept replaces two of the AG9140 GTG skids with another module composed of an LM2500+/Vectra 40G turbine and high speed generator, and the third AG9140 with an LM1600 high speed generator set. This approach would increase the available electric power generation from the present 9 MWe to approximately 70 MWe. To complete the modification, one of the LM2500 turbines used for mechanical power input into each Main Reduction Gear (MRG) would be replaced by a 20 MW high speed electric motor and associated electronic power converter. The drive motors could also be made up of smaller modules to provide redundancy and improve partial load efficiency. While the use of turbines of different sizes and speed ratings favors the use of a medium voltage dc (MVDC) distribution system (to decouple the power generation frequencies among the prime movers) with appropriate design, the hybrid mechanical/electrical concept can be implemented with almost any electric power distribution architecture.

The proposed mechanical/electrical hybrid propulsion drive combined with upgrades in the electrical power distribution system of the DDG-51 would enhance the available power and enable improved efficiency over a range of mission profiles, allow enhancements to power radar and sensor systems, and provide a flexible power distribution architecture to accommodate future weapon and sensor loads. Using the information on the general arrangement described in training materials for the Arleigh Burke class and ONR BAA07-029 the power system arrangement shown in Figure 8 can be developed [11].

This arrangement allows for electric drive using power from the electric power distribution system while both LM2500 gas turbines connected to the MRGs are disconnected using the existing mechanical clutches. This mode enables variable speed operation of the motors or they can be operated at constant speed using the controllable pitch propellers (CPPs) to modulate propulsion load. Alternatively, one or both LM2500's can be used to drive the propulsion shafts mechanically with the electric motor/generators clutched out of the system. Propulsion cross-connect can also be implemented; one LM2500 drives the shaft and associated electric machine as a generator and the other electric machine is operated as a motor to drive the second shaft. Propulsion derived power generation is also feasible using one or both electric machines to provide power to the electric power distribution system. In this mode, the LM2500 drives the propeller shaft and the electric machine as a generator. Variable speed operation is possible for electric power systems with dc distribution; ac distribution systems will require fixed speed operation to enable synchronization with the distribution frequency. Since there is not a clutch on the main shaft, the CPPs will be used to modulate propulsion load with the remaining power from the LM2500 available for electric power generation. With other GTG modules available, it should not be necessary to operate the shaft at high speed for electric power generation with no significant propulsion load.

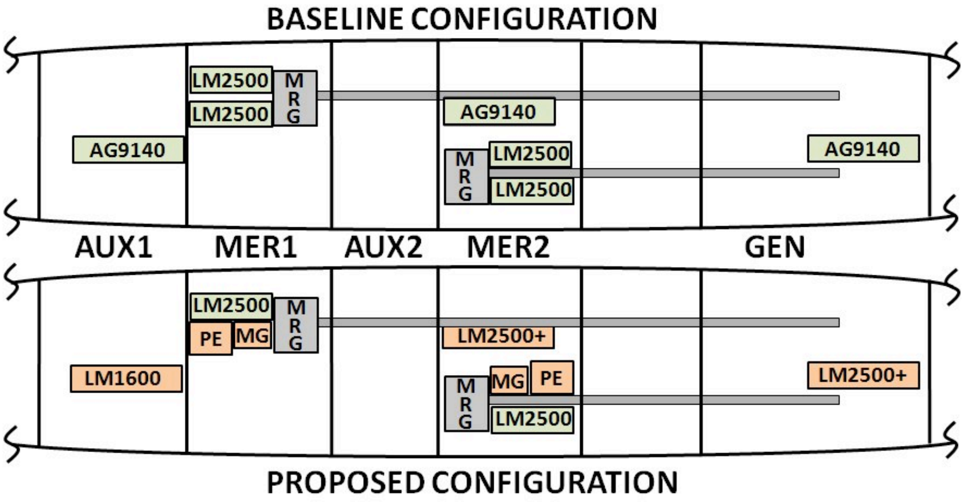


Figure 8. Block diagram illustrating the general arrangement of the proposed DDG 51 IPS power generation and propulsion system concept.

Even with retention of the MRG, two mechanical drive LM2500s and the propulsion shafting, this concept does require significant modifications to the existing equipment layout and power distribution systems and targets a new flight of DDG-51 ships specifically configured to take advantage of the hybrid electrical-mechanical architecture.

Like the enhanced sensor power supply concept presented above, the DDG 51 IPS concept takes advantage of advanced power generation and power conversion technologies to increase the power density of the system components:

- Enhanced power of the LM2500+
- Vectra power turbine for the LM2500+
- High speed generators

The GE LM2500 currently used for mechanical propulsion in the DDG 51 is nominally rated at 20 MW and the Navy module is only 8.23 m L x 2.74 m W x 3.05m H. By taking advantage of an additional stage of compression and a higher compression ratio, the new LM2500+ is nominally rated at 30 MW and the module is only 7.16 m L x 2.74 m W x 3.05 m H. As delivered by GE, both engines operate with a nominal 3,600 rpm power turbine speed, enabling synchronous 60 Hz power generation with a two pole generator.

In 1996 Dresser-Rand introduced the Vectra 40G power turbine designed for integration with the LM2500+ gas generator to enable direct drive of high power gas compressors [12]. This configuration retains a rating of 30 MW but features a maximum continuous operating speed of 6,500 RPM.

While this is a new turbine/generator combination for naval applications, the LM2500+ is installed in the *USS Makin Island*. The Vectra 40G power turbine has not been Navy qualified; however, it was specifically designed for long term use in marine environments on offshore oil and gas production platforms, so it is robust marine equipment.

As noted above, for a given power rating, higher speed operation reduces the size of electric machines due to the lower torque required. Although not a direct proportionality due to construction constraints, increasing the speed of the generator from 3,600 to 6,200 rpm enables a significant reduction in the size of the generator. This power generation configuration has been explored in [8]; when coupled with a water cooled generator, the resulting turbine generator set design was only 11.3 m L x 2.28 m W x 4.06 m H.

The final piece of this concept involves consideration of the existing AG9140 ship service gas turbine generator sets on the DDG 51. As noted above, the AG9140 uses a single shaft Allison 501 gas turbine driving an 1,800 rpm generator through a reduction gearbox; the basic dimensions of the AG9140 skid are available from the Roll-Royce website [13]. Note the axial exhaust duct of the GTG package (Figure 1) which interfaces to the ship's uptake ducting through a 90-degree elbow. If one assumes ANSI B16.9 standard pipe geometry for a 40 inch pipe [15], when the swept volume of the uptake elbow is considered the rectangular volume of the LM2500+/Vectra 40G generator set is comparable to the overall package dimensions of the AG9140. (The LM2500+/Vectra 40G skid package includes an internal right angle exhaust collector, replacing the elbow in the existing uptake ductwork.) Figure 9 shows the AG9140 module in comparison to the new turbine/generator skid.

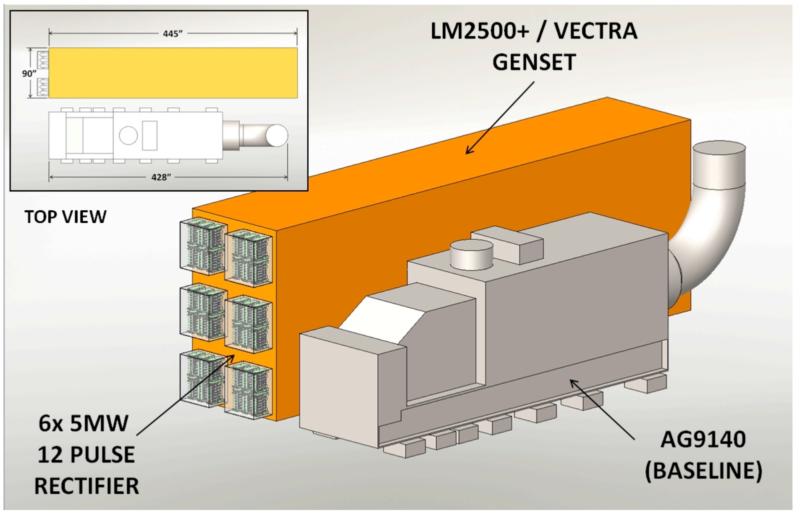


Figure 9. Comparison of AG9140 GTG with LM2500+/Vectra 40G high speed generator design envelope.

The wound-field synchronous generator design in this package operates with a rotor tip speed of less than 200 m/s. Due to the squared relationship of torque with diameter (see equation (1)) even modest increases in the airgap diameter enable relatively large reductions in the active length, so further reductions in the overall length of the LM2500+/Vectra 40G package are possible.

The relationship show in equation (1) can also be used to illustrate a particular challenge for integrated power systems -- the size of propulsion motors required for direct drive of the propeller shafts. Because of the low operational speed – typically around 150 rpm – and the 40 MW power rating for each DDG 51 propeller, the motor must generate significant torque to achieve the required power levels. Recall that:

P = Torque x speed,

And thus,

$$P \propto \underbrace{B \times A_s \times D^2 \times L}_{\text{Torque}} \times \omega \tag{2}$$

where

B = air gap flux density
L = machine active length
D = airgap diameter
A_s= stator line current density

Since the stator line current density, A_s, and airgap flux density, B, are limited by thermal and material constraints, respectively, to generate more torque the diameter and length, and thus the volume of the machine must increase. Since the DDG51 hullform and compartments were not designed for these large motors, backfit of direct drive propulsion motors does not appear practical. The weight and volume of the associated motor drives must also be accommodated in these designs. The DDG 51 IPS concept presented here takes advantage of the existing main reduction gear (MRG) and propulsion shafting to reduce the size of the electric propulsion motors and minimize the modifications to the propulsion system.

To affect the change, one of the two LM2500 propulsion engines connected to each MRG is replaced with a 3,600 rpm 20 MW permanent magnet electric motor. The size of this component is based on a PM electric machine designed as a direct-coupled generator for the LM2500 [2]. Prior design studies indicate that the motor and power conversion equipment for variable speed operation can be installed in the volume of the original LM2500 turbine module. The size of the electric motor could be further reduced by increasing its speed; however, this would require changes to the gear ratios in the MRG. An MRG redesign or the use of an intermediate gearbox would also allow for multiple motors in place of the single 20 MW unit; this would provide additional redundancy and opportunities to maximize propulsion efficiency at low power. The sizing of the power conversion modules to interface the electric motors to the power distribution bus is based on a volumetric power density of approximately 0.5 MW/m^3; this capability is available in current, commercial-off-the-shelf converters (e.g. ABB)[16].

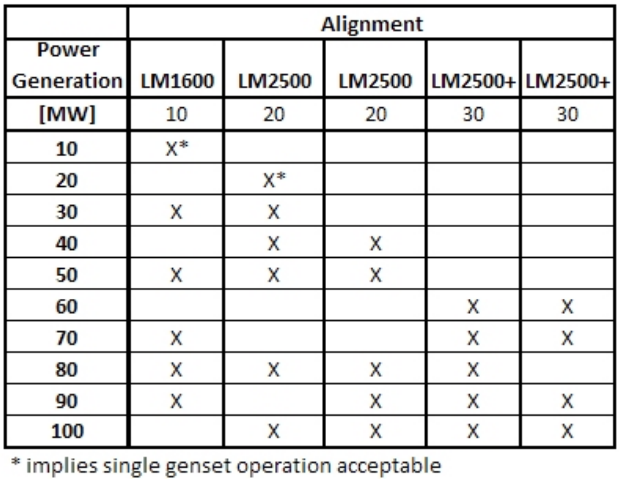
As shown in Figure 8. Block diagram illustrating the general arrangement of the proposed DDG 51 IPS power generation and propulsion system concept., the most significant hardware changes take place in main engine room number two (MER2) where in addition to the new electric machinery, GTG2 is replaced with the LM2500+/Vectra 40G high speed turbine generator and rectifiers. This design will require changes to the auxiliary, ventilation, and cooling systems as the installed power in this compartment increases from a nominal 43 MW to approximately 50 MW. As noted above, the increased intake/uptake flow rate for the higher installed power must also be considered. While it is not possible to accurately calculate the increased pressure drop through the existing intakes/uptakes using publicly available information, based on the analysis presented above, the nominal 16% increase in installed power is not expected to result in significant pressure drop and gas turbine performance penalties.

A second LM2500+/Vectra 40G gas turbine generator set can also be installed in place of the AG9140 GTG in the Generator Room located at the aft end of the ship. Unlike the changes to MER 2 where the installed power increase was only 16%, this modification will increase the installed power in the generator room from a nominal 3 MW to 30 MW. This location near the helicopter landing deck and hangers will minimize the impact of the larger intake/uptake volume required to support the higher installed power in this compartment.

The final element of the DDG 51 IPS concept involves the final GTG located in auxiliary room 1. In this compartment, the AG9140 skid is replaced with the twin engine/generator concept presented above or with an LM1600 high speed generator combination. Direct drive high speed generator designs have been developed for the LM1600 and the smaller turbine and generator for this package will provide space for integration of the power conversion system within the original envelope of the AG9140.

The modifications to the DDG 51 electric power generation systems presented here provide the flexibility to generate a wide range of power levels to match future mission loads and profiles. Although other combinations are possible, Table 2 summarizes the power generation alignments to provide power generation levels from 10 to 100 MW.

Table 2. Power generation alignments for a range of total power generation.



	Alignment				
Power Generation [MW]	LM1600 10	LM2500 20	LM2500 20	LM2500+ 30	LM2500+ 30
10	X*				
20		X*			
30	X	X			
40		X	X		
50	X	X	X		
60				X	X
70	X			X	X
80	X	X	X	X	
90	X		X	X	X
100		X	X	X	X

* implies single genset operation acceptable

Although this concept has not been the subject of extensive analysis, some comparisons to current DDG 51 performance have been conducted using the the methodology described in reference [17] The comparison assumed the system would be running one LM2500+ and one Allison 501 for electric power generation, and had an auxiliary/hotel load of 5.1 MW (current DDG-51 2.5 MW plant load plus AMDR and LaWS). The comparison used an all electric mode in place of the DDG-51 trail shaft, a hybrid mode of one LM2500 and one electric drive shaft in place of split plant mode, and both LM2500 and either 1 or 2 LM2500+ for full power mode. Using CONOPS data from the USS Gaffney (DDG-90) shows the hybrid plant produces almost the exact same fuel consumption, with a max savings of 1.2% depending on which specific operational profile is used. Figure 10 shows the results of this comparison.

Using propulsion derived power generation as the backup for single generator set operations of the LM2500+ would decrease the fuel consumption by as much as 3.5% over the current DDG 51 system while enabling the support of advanced electric weapons and sensors.

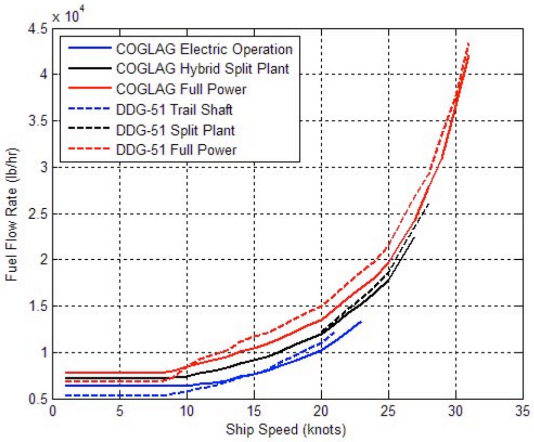


Figure 10. Comparison of proposed concept with DDG 51 trail shaft and split plant operation.

CONCLUSION

This paper presents two concepts for enhancing the electric power generation capacity of both current and future flights of the DDG 51 Arlegith Burke class of ships. The first concept addresses the near-term need for additional power for advanced sensor systems -- even in Flight III class ships –by installing a pair of twin shaft turbines and direct-drive high speed generators in place of the Allison 501 turbine in the existing AG9140 GTG enclosure. To simplify logistics, multiple turbine options were identified, including the Vericor ETF40B engines used in the LCAC program and the Rolls-Royce AE1107 in the V22 Osprey. The second concept presents a hybrid mechanical-electric integrated propulsion system using the currently available LM2500+/Vectra 40G gas turbine package to drive a high speed generator to provide an additional 61 MW of electric power generation. Electric motors connected to the existing MRGs enable full-electric, full-mechanical, or hybrid propulsion while still providing power to future electric loads.

These preliminary concepts are proposed improvements based on publically available information concerning fundamental ship power system components. Detailed design and analysis are required to assess the approaches fully and will not likely be done in a public environment.

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