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Adaptive Power System for Managing Large Dynamic Loads

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ABSTRACT- The Navy's future and near-term high-energy sensors and energy weapons will consume a large portion of the resources of the intended ship platform. Many of these new systems will have extreme dynamic power profiles, including both periodic and periodic characteristics. These dynamics can cause sudden changes in power at the prime power system that can be stressing to platform systems, both to the generators and prime movers as well as other loads sharing the common distribution bus. This paper presents the use of a new adaptive power system (APS) to mitigate the negative impacts levied on the platforms resulting from large dynamic loads. A notional size of the hardware required to implement the APS design is presented along with simulation results verifying the concept.

INTRODUCTION:

The Navy’s future and near-term high-energy sensors and energy weapons present a challenge to the existing shipboard gensets and power distribution systems. These systems not only require higher power levels than seen in the past, but also have more extreme dynamic profiles. The profiles can range from periodic and predictable to a periodic and unpredictable. Duty cycles can vary from small to continuous and, for some cases, the peak power demands can be above the capability of the ship power plant. These types of extreme power profiles cannot be supported with conventional power systems.

WORKING

A block diagram of a conventional shipboard power system is shown in the dashed box of Fig. 1. Conventional systems have focused heavily on providing well-regulated voltages and clean power to the corresponding load. If the voltage dynamics seen at the load are to be minimized, the output impedance of each converter stage is minimized by using small series inductance values, large shunt capacitance values, and control loops with high bandwidths. However, this type of system does little to

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prevent the mid to low frequency load dynamics from propagating back to the distribution bus and generator.

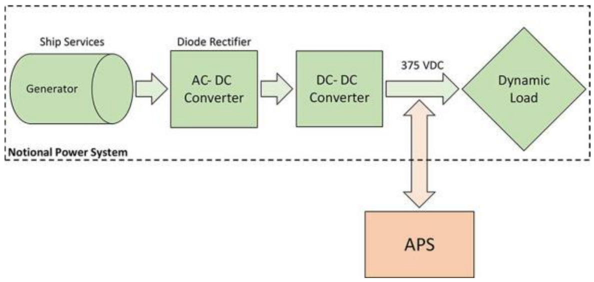

Fig 1. Block diagram of a notional power system with the APS attached.

If the dynamic profiles propagate back to the ship's electric plant, significant power-quality issues and generator/distribution losses can occur [1], [2]. In addition, the dynamic pulse loading may cause wear and tear on the gensets' mechanical parts [3]–[5]. Torsional stresses to the shaft of the ship's prime mover can result due to the very large and quickly changing electromagnetic load torques. These dynamic electromagnetic load torques may also excite the shaft's torsional resonances, typically referred to as sub synchronous resonances [2], [6], adding additional stresses to the shaft.

III. SYNOPISIS

A. CONVENTIONAL METHODS

Present-day methods that can be used to buffer the prime power system from dynamic loads include the following:

1) **The *brute-force method*:** where passive filters are used to smooth the dynamics of the load profile; although this method results in minimal additional power losses, achieving the smoothing or filtering needed by the shipboard power system requires filter sizes and weights that are impractical and prohibitive for ship installation.
2) **The *throw-away-power method*:** where when the load is not using the maximum power allocated, the excess power is dissipated in an active load [7]. This type of system maintains a constant load profile to the generators, thus addressing the genset reliability and bus disturbance concerns. However, it can have severe impacts on system efficiency resulting from the large additional power dissipation, increasing cooling requirements and fueling costs for ship platforms.
3) **The *restricted-timeline method*:** which requires a defined charging time for the system where the pulse power can only be supplied at predefined scheduled time intervals. For these systems, the successive launch times or fire times (repetition rate) and corresponding

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system performances are limited by the charging times of the system. Some examples of such systems are the electromagnetic aircraft launch system (EMALS) and rail guns [8], [9].

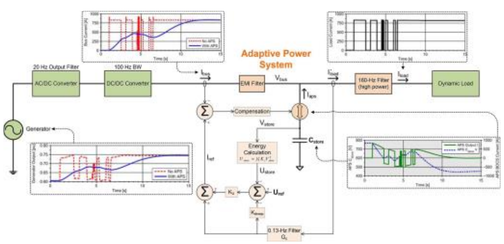

Fig 2: Overview of the functionality of the APS system.

Consequently, a new approach is needed to manage the load dynamics of emerging Navy systems—one that is not compromised by the disadvantages noted before for existing systems. The new adaptive power system (APS) specifically addresses this need. The APS can be used to efficiently mitigate bus disturbances and reduce stress to the shipboard gensets by converting the dynamic power load seen by the shipboard power system into an equivalent rolling time average—essentially serving as an active low-pass filter to the load dynamics. As shown in Fig. 1, the APS can be added to an existing system. The APS consists of energy storage, a passive power filter, a bidirectional current source, and innovative control loops, as shown in Fig. 2. The bidirectional current source efficiently delivers the pulsed power demand from the APS energy storage to the desired sensor or weapon system, thus providing a buffer to the upstream power equipment.

Section B proposes a requirement for the APS that considers the generator and prime-mover capabilities and limitations. Section III provides the operational overview and the detailed design for the APS to support a 300-kW dynamic load. Closed form equations for sizing the energy storage are also provided in this section along with the necessary transfer function for optimizing and controlling the system. In addition, Section B provides full system simulations (combined generator/APS/load) of this 300-kW notional configuration, demonstrating a significant improvement in generator voltage and frequency deviations during a large load disturbance when using the APS.

B. PROPOSED REQUIREMENTS

Proposed Pulsed Load Requirement: The combined three phase peak power ripple as seen by the shipboard generator(s) at any single frequency generated by the load shall be less than the limits defined by Fig. 3.

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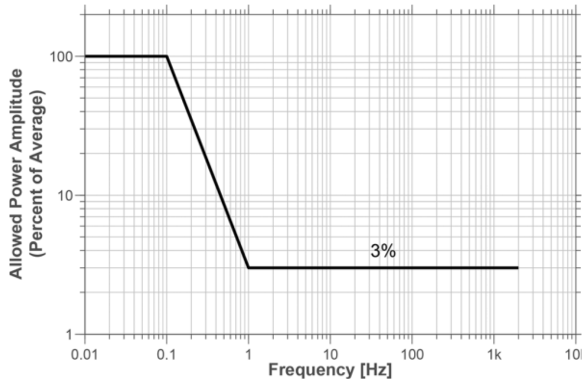

Fig 3: Power ripple filtering requirement of the APS.

ADAPTIVE POWER SYSTEM (APS)

The goal of the APS is to minimize bus disturbances and stress to prime-power equipment by converting the dynamic power load into an equivalent rolling average of the power demand. The APS is designed to meet the proposed requirement as shown in Fig. 3. In addition, the APS implementation must also not interfere with maintaining a stiff voltage (tightly regulated voltage) to the load.

The top-level components of the APS include the energy storage capacitance and two control loops. One loop controls the APS output current to provide the required dynamic current to the load using the energy from the storage capacitance, and the other loop maintains the voltage across the energy-storage capacitance to within the allowed rating.

TABLE I

SIZE AND WEIGHT OF THE APS SYSTEM

Component	Value	Size (ft^3)	Weight (lbs.)
Module			
$L_{of} + R_{lof}$	$10\ \mu H + 1\ m\Omega$	0.001	0.15
C_2*	$3.3\ \mu F$	--	--
RC_2branch*	$0.91\ \Omega + 68\ \mu F$	--	--
$L_{sw} + R_{sw}$	$0.1\ mH + 6\ m\Omega$	0.004	1.4
C_{store}	86.7 mF	2.1	169.2
Heat Sinks	-	0.1	4
Miscellaneous	-	0.1	10
Total Modules			38
EMI Filter			
$L_1 + R_1$	$25\ \mu H + 0.3\ m\Omega$	0.12	49
C_1	$94\ \mu F$	0.01	1
RC_1branch	$0.31\ \Omega + 1.9\ mF$	0.03	5
Low-Pass Filter			
$L_f + R_{fs}$	$25\ \mu H + 0.3\ m\Omega$	0.12	49
C_f	40 mF	0.13	21.9
$C_s + R_s$	$0.2\ F + 25\ m\Omega$	1.25	217.7
R^*_{fp}	$33\ m\Omega$	--	--
Grand Total		93.0	7364

*Weight and size included in Miscellaneous

TABLE II

POWER LOSSES OF THE APS SYSTEM

Single Module Losses	
Max FET (two Cree SiC FETs)	91.9 W
Switching Inductor	32.0 W
Output Filter Inductor	0.5 W
C_{store} Leakage and Balance Resistors	2.6 W
Total Module Losses	127.0 W
Number of Modules	38
Total BDCS Converter Losses	4826 W
Other Losses	
EMI or Low Pass Filter	210 W
Low Pass Filter Damping	2 W
Miscellaneous & Margin	1512 W
Total System Losses	6550 W

CONCLUSION

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The Adaptive Power System (APS) concept presented in this paper can be an enabling technology for sensors or weapons with large dynamic loads, which without the APS would be incompatible with the upstream shipboard generator and distribution bus. The APS consists of energy storage, a bidirectional current source, and innovative control techniques this innovative control techniques increase the energy storage utilization, thus minimizing the energy storage size. In addition, because of the linear behavior of the outer-energy loop regulation technique, performance is maintained overall operating conditions. The APS shapes the dynamics seen by the generator to be slower than the response times of the prime-mover's speed or generator's voltage regulation loops, thus allowing the genset to maintain speed and voltage regulation during these large load dynamics. Not only can the APS help to maintain generator/prime-mover reliability, but the APS can also be used to improve sensor/weapon performance or improve metrics such as system weight, cooling demands, and ship fueling costs. Performance of the APS has been demonstrated through the use of Matlab Simulink simulations. Calculated losses and size of a 300-kW system have also been provided, demonstrating that the APS is a viable solution for integrating high-energy sensors and weapons onto Navy platforms..

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