

Adaptive Power System for Managing Large Dynamic Load

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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 aperiodic 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.

KEYWORDS:AC/DC converter, active filter, buck converter, dynamic power profile, Simulink,

I. INTRODUCTION

THE Navy's future and near-term high-energy sensors and energy weapons present a challenge to the existing ship-board 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 aperiodic 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.

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 prevent the mid to low frequency load dynamics from propagating back to the distribution bus and generator. 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 subsynchronous resonances [2], [6], adding additional stresses to the shaft.

II. LITERATURE SURVEY

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

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. Secondly, 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 and 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. 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].

III. PROPOSED SYSTEM

A. OVERVIEW

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. 1. In addition, the APS implementation must also not interfere with maintaining a stiff voltage (tightly regulated voltage) to the load.

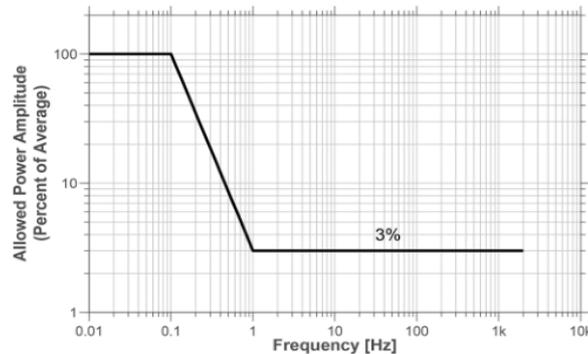


Fig. 1. Power ripple filtering requirement of the APS.

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. This provides the detail voltage and current waveforms for the APS as well as the generator power waveform during the application of a dynamic load profile. Operation of the APS is as follows.

- The current provided from the upstream power system is regulated by the APS to be equal to the filtered (0.13 Hz) current profile of the load demand. The compensation block regulates the to be equal to by controlling the output current of the bidirectional current source (BDCS); see the bus-current and BDCS-current waveforms in Fig. 2. The BDCS is a dc/dc converter that can process power in both directions—it can both absorb and deliver power.

- Hence, the ac component or dynamics of the load profile is not part of the but is provided by the energy-storage capacitance via the BDCS

- This provides significant weight and size savings compared to using an in-line high-powered low-pass filter (brute-force method).

- The voltage variation across is also decoupled from the load, allowing tight regulation of the bus voltage seen by the load to be maintained.

- The energy-storage capacitance value is chosen to be large enough to supply the source and sink currents to support the periodic load demand. The worth for the energy-storage capacitance is decreased by permitting the voltage across C_{store} to vary considerably. To reduce the energy-storage capacitance needed, an adaptive reference for the energy-storage loop is used, where the reference is biased by the 0.13-Hz filtered load current. This technique is very similar to droop compensation regulation. If the 0.13-Hz filtered load current is at the maximum value, then the reference for the energy storage will be set to the minimum value, putting the capacitor in the optimal state for absorbing energy. If the 0.13-Hz filtered load current is at 0A, then the reference for the energy storage will be set to the maximum value, putting the capacitor in the optimal state for providing energy. This adaptive control maximizes energy-storage utilization by reducing the required capacitance by a factor of 2. The Adaptive control increases the energy storage utilization.

B. APS REQUIREMENTS FOR NOTIONAL SYSTEM

300KW system is designed and simulated to prove the APS function and to show the performance.



TABLE 1
WEIGHT and SIZE OF THE APS SYSTEM

Component	Value	Size (ft ³)	Weight (lbs.)
Module			
$L_{of} + R_{lof}$	10 μ H + 1 m Ω	0.001	0.15
C_2^*	3.3 μ F	--	--
RC ₂ branch*	0.91 Ω + 68 μ F	--	--
$L_{sw} + R_{sw}$	0.1 mH + 6 m Ω	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 μ H + 0.3 m Ω	0.12	49
C_1	94 μ F	0.01	1
RC ₁ branch	0.31 Ω + 1.9 mF	0.03	5
Low-Pass Filter			
$L_f + R_{fs}$	25 μ H + 0.3 m Ω	0.12	49
C_f	40 mF	0.13	21.9
$C_s + R_s$	0.2 F + 25 m Ω	1.25	217.7
R_{fp}^*	33 m Ω	--	--
Grand Total		93.0	7364

C. APS DESIGN DETAILS FOR THE NOTIONAL SYSTEM

Major details for design of APS are shown in this section. Specifically, information measure issues for the assorted management loops are provided together with the derivation of a closed-form equation for the transfer operate of load current to bus current Ibus/Iload and therefore the derivation of the equation for determination of Cstorevalue.APS is designed based on these two equations. By allowing presentation metrics, such as power dissipation and sizing for 300kw system are shown in Table 1 and Table 2

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

Control loop Bandwidth Considerations: Design of APS shown in Fig .6.BDCS cOnsists of 38- eight KW parts. By using a 100 KHz Switching frequency and average current control, the sizing and performance is build it is called as The Bidirectional buck topology. To obtain necessary control loop bandwidths, switching frequency is chosen high enough. It is low enough to get average switching losses. APS filtering performance is get by this method. To allow outer current loop of APS to 4 KHz, bidirectional current source must be between 15 to 25 KHz.

The bandwidth is set to 0.02Hz and it usually selected high value but also it should maintain the voltage passivity and energy. Bandwidth must be low to reach current ripple requirement. To regulate the energy on the capacitor chosen reference command of current is taken greater value and it is weighted as control loop has high bandwidth. By all these reasons APS output current get altered so APS cant compensated for required load current.

Transfer Function I_{bus}/I_{load} and C_{store} : There is a requirement of Transfer function and C_{store} to get essential energy storage size. Because the desired energy storage capacitance is determined by behavior of APS at rate of lower frequencies that will be less than 1Hz and higher bandwidths are assumed to be constant that is between 4 KHz to 15 KHz. Further simplifications are shown in Fig.4 , some assumptions are made that is bus voltage is taken as constant vale at lower frequency and it is lossless bus, that is energy absorb or supplied is equal to V_{bus} . EMI filter and 160Hz filter does not show any effect.

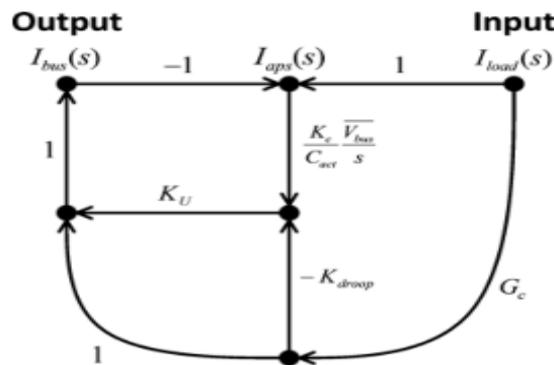


Fig.4: Signal flow graph

Fig 4 shows the signal flow graph in which Bus current(I_{bus}) equals to reference current(I_{ref}) and I_{load} equals to I_{load} at lower frequencies of Adaptive power system. Energy outer loop is determined by energy gain that is K_u . Adaptive power system part values, Size and losses, The major parts for loss calculation is selected and calculated. Listing the summary of all elements which are used in APS design. The selected values should be more precise than selecting in previous method called Brute force method.

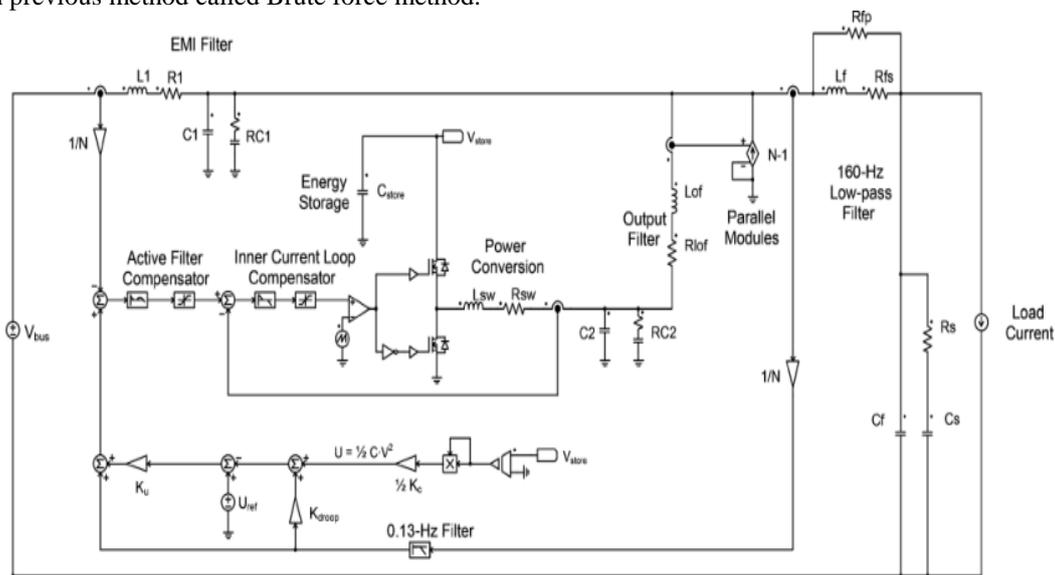


Fig.5: High level representation design details for Adaptive power system

The metal-oxide semiconductor field effect transistors (MOSFETs) utilized as a part of the usage of the BDCS are silicon carbide gadgets. Silicon carbide gadgets are chosen due to the inalienably low deplete to source parasitic capacitance, which is urgent to limiting the exchanging misfortunes while working at high-voltage levels with hard exchanging. The magnetic material utilized for estimating the inductors and ascertaining the inductor misfortunes is Nano crystalline Vitroperm 500F from Vacuumschmeize. Both of these enhanced qualities result in less turns required,

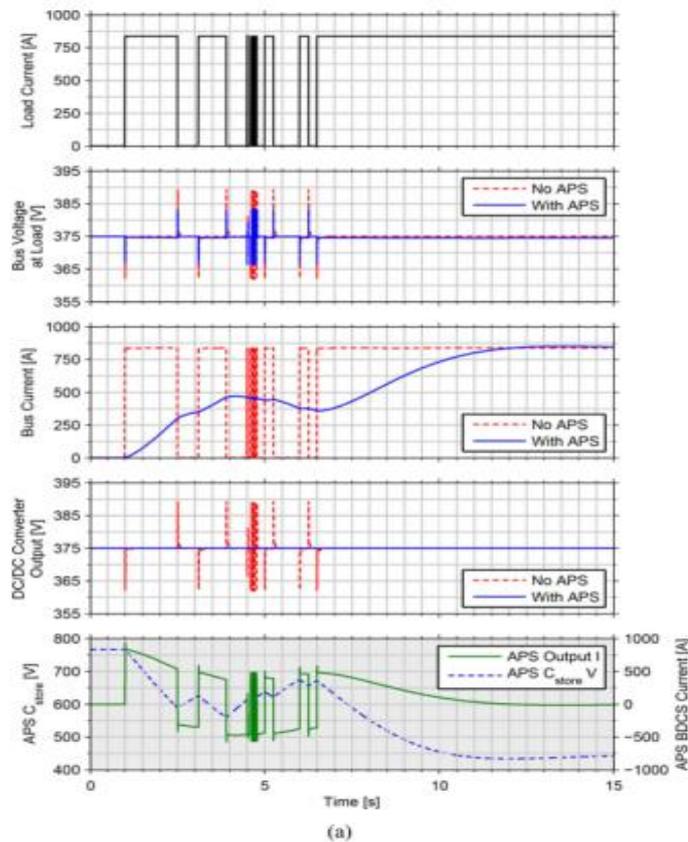
and therefore bring down winding loss. The design methods used for EMI and Low filter are same. Dropping or obtaining maximum current depends on activity of APS. If APS is not in working condition EMI and Low-pass filter will come into the action and release power. High level representation design details for Adaptive power system is shown in Fig.5. There will be thirty four similar sequences of storage capacitors (5.1nF). Every capacitor is rated for 550v. 2 capacitors will be places in series to get required voltage level. The total current drawn will be 100 micro amps per capacitor. Resistive current will be more than leak current to make voltage stable.

VI.RESULTS

Fig. 6(a) also shows the voltage waveform of the storage capacitor and the current waveform of the bidirectional current source, demonstrating the APS's capability of providing the dynamic demand of the load resulting in the generator only having to provide the rolling average of the load power profile. The 375-V bus voltage delivered to the load is also shown in Fig. 6(a), indicating that the 5% transient regulation requirement is met.

At time 6.5 s in Fig. 6(a), the load switches to a constant load and the APS consumes no power (APS output current goes to zero) after about 5 s from this point in time, demonstrating the efficient conditioning method provided by the APS. If the APS is used for a periodic dynamic load application, the generator will see essentially a constant load with only a benign very small power ripple riding on top of the load's average power draw.

Fig. 6 demonstrates the filtering capability of the APS in the frequency domain. The solid blue line in this figure shows the load rejection provided by the APS as viewed from the output of the upstream 375-V converter. The proposed filtering requirement (dashed red line with the 100% and the 3% limits annotated) has been superimposed on the APS results, showing that the APS satisfies the requirement. As can be seen from Fig. 6, the APS removes the low to mid frequencies that can degrade the generator shaft or could excite potentially hazardous resonances. In addition, removing these frequencies from the electric plant distribution bus means the bus quality for other users has improved—meaning fewer disturbances will exist due to the load dynamics interacting with the bus impedances and the generator.



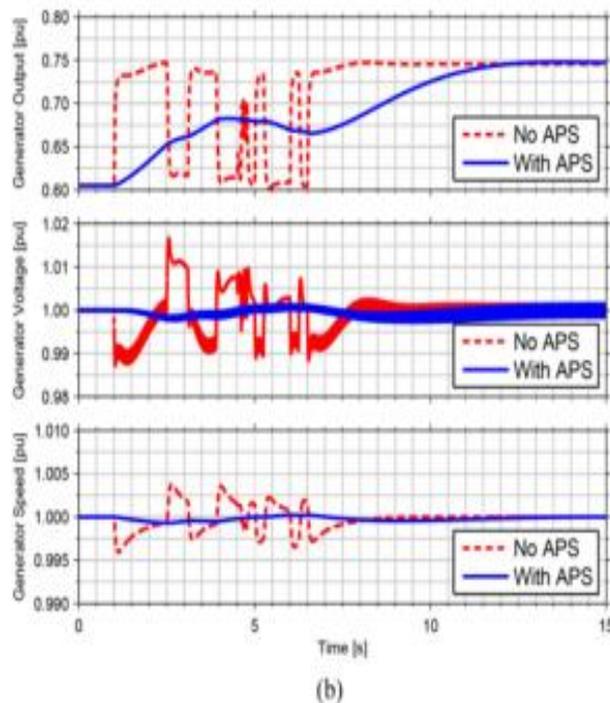


Fig. 6. Simulation results of the first load profile. (a) Load and APS results. (b) Generator results.

V. CONCLUSION

The 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 up stream shipboard generator and distribution bus. The APS consists of energy storage, a bidirectional current source, and innovative control techniques. These innovative control techniques increase the energy-storage utilization, thus minimizing energy storage size. In addition, because of the linear behavior of the outer-energy-loop regulation technique, performance is maintained over all 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 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 the size of a 300-kW system have also been provided, demonstrating that the APS is a viable solution for integrating high energy sensors and weaponson to Navy platforms.

In addition to this work, Fuzzy logic controller is used instead of PI controller, It has several advantages over PI controller such as they are cheaper to develop, they cover wider range of operating conditions and increases the quality factor

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