Naval Power Systems Flexibility

Workshop organized by the
Electric Ship Research & Development Consortium (ESRDC)
held December 4-5, 2018, at the Center for Advanced Power Systems,
The Florida State University

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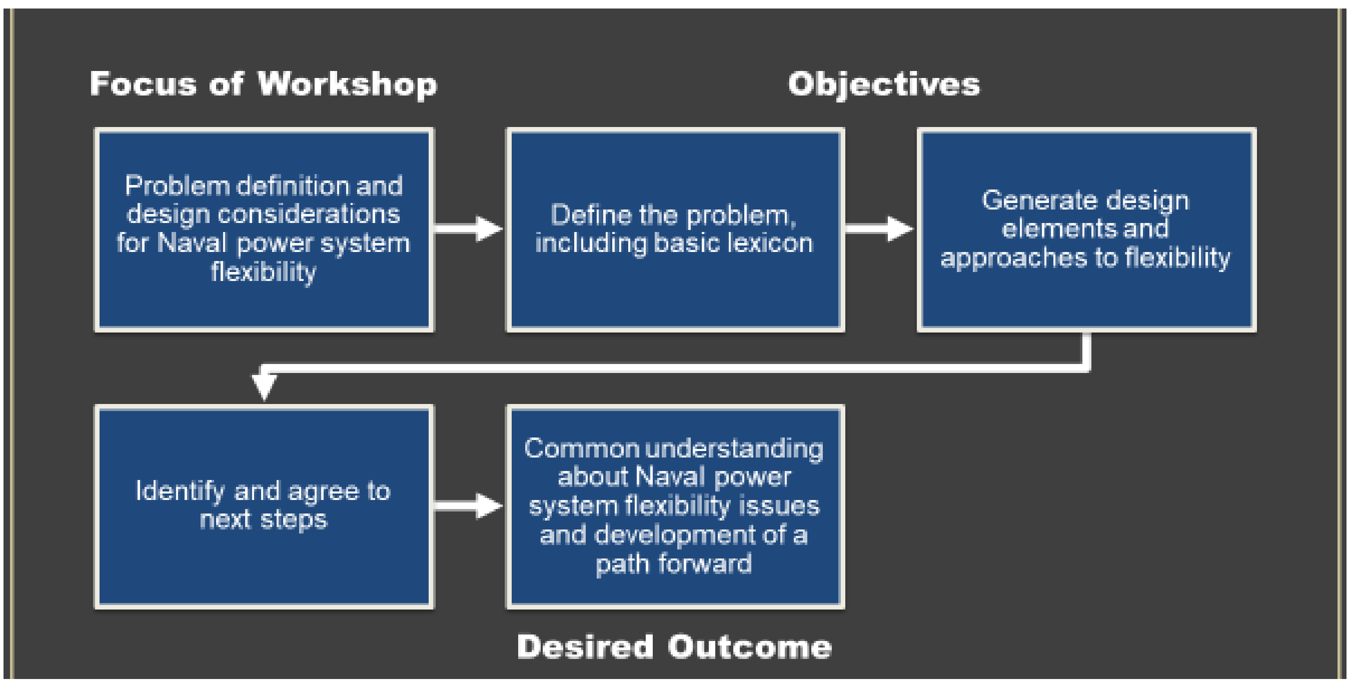
Purpose

The workshop held at Florida State University's Center for Advanced Power Systems on December 4-5, 2018 convened Navy, industry, and academic partners to generate dialogue and advance commonality in thinking about flexibility for unknown future requirements. The goal to achieve a common, definitional understanding about the concept of flexibility in future navy ship design and operation. This intent was scoped to include bounding the problem with initial lexicon as well as generating design considerations, areas of focus, and possible approaches to flexibility. The result was a structured facilitation approach with a generative workshop design.

The group also had a stretch goal of developing a path forward for building flexibility into Naval Power and Energy Systems. However, the discussion about lexicon continued for a more significant portion of the Day 2 agenda, resulting in clearer agreement about common attributes of flexibility as a power and energy system concept but forgoing the road mapping activity in the initial workshop design. Preparatory sessions with the workshop team were integral in correctly scoping the focus of the workshop and defining its intended objectives. These objectives are the basis for the final workshop plan and facilitation design.



Pre-framing Flexibility for Naval Power & Energy Systems

In preparation for the workshop, PMS 320 and FSU CAPS collaborated on generating a preliminary framework for the *as-is* ("from") and *to-be* ("to") states for flexibility in power and energy (Figure 3).

	From	To
Design	Service life allowance, which does not sufficiently accommodate anticipated change.	Lifetime upgradability, which anticipates transformative technology changes and affordably achieves enhancements.
Production	Ship building and acquisition approaches with limited and often costly upgradability.	Advanced ship building approaches that affordably incorporate technological advances.
Operation	Rigid relationship between load and source. Controls with limited, pre-defined states.	On-demand adjustment of control algorithms to extend state space, along with "plug-and-play" interfaces.

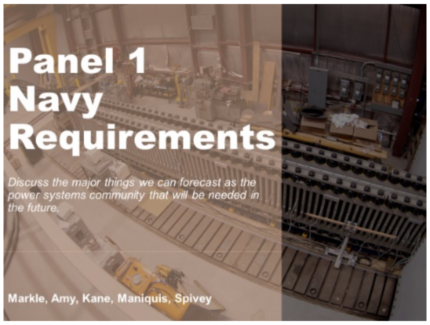
Figure 1. From-To Framework for Naval Power & Energy System Flexibility

In having pre-workshop conversations about this framework, the workshop team refined and solidified their perspective about the three categories of flexibility (Design – Production – Operation) and conceptualized possible answers to their initial question of "*flexibility for what*?" They recognized that time scales were intrinsic to this concept. They realized that the term "flexibility" was ambiguous in that it could be used as a process and production construct or could be used in a design and enabler construct, both of which have very different meanings and applications. Repeatedly in these conversations, the fundamentally unpredictable uncertainty – of warfighter requirements and in anticipating transformative technology – was at the heart of the problem that flexibility was attempting to address.

Day 1

Mr. Stephen Markle framed the opportunity and the need for flexibility in power and energy. The directive to the fleet has been to acquire as much power as can be afforded. The power and energy community has been challenged to develop the ability to move and supply this power across the ship at the timescales required by the mission, ideally with the additional ability to modernize systems without overhaul. Further, disruptive technology in weapons and sensors has created an immediate need for a more agile power system. Therefore, the power and energy community needs to provide more dynamic architectures and components than were used in the past. Building in flexibility across design, production, and operation is mission essential.

Panels



Panelists on Panel 1 "Navy Requirements"[1] addressed the question – *What are the major things we can forecast as the power systems community that will be needed for the future? Flexibility to do what?* In addition to a focus on warfighter requirements, the panelists emphasized the need for more active, agile design approaches. Some of the cultural and process barriers associated with adopting these approaches were raised. The Navy is also trying to solve for "real-time" power availability for the operator that so that electric power is not mission limiting. Conventional deterministic engineering approaches cannot deliver this capability because uncertainty – such as that associated with future load requirements – cannot be estimated with fidelity. Uncertainty itself butts against cultural norms in the Navy associated with decision-making and the risk tolerance built into affordability assessments. From the standpoint of survivability, resilience of power and energy solutions cannot be traded for flexibility.

Panel 2 "Design and Ship Integration" panelists[2] raised issues about Navy culture and the acquisition/procurement processes as well while discussing flexibility in response to the prompt – *How does power systems flexibility impact your domain?* Panelists highlighted the need for a shift in process, suggesting that standards for flexibility could be developed with product development to create a more agile process overall. They recommended that flexibility be included in every stage of design (across all players). Further, they suggested that flexibility requirements be negotiated in the earlier stages of design since they drive cost. When asked what the biggest impediments are to achieving flexibility today, panelists responded with the following three areas:

(1) Software/Hardware accommodation
(2) Legacy designs/models
(3) Decision-making/Evaluation process

One unresolved highlight of Panel 2's discussion involves the need to reconcile shipbuilding requirements with uncertainty with respect to both technology advances and changes in mission. The panelists highlighted the criticality of a good design model and accurate metrics for shipbuilding. They also debated the ability to estimate uncertainty in a scalable way for key attributes of the power and energy system. Fundamentally, the existing opportunities to employ flexible engineering practices while

[1] Markle, Amy, Maniquis, Kane, Spivey
[2] Tempkin, Doerry, Steurer, Belkhayat, Shegirian

designing and modeling are not yet reconciled with some of the rigidity of current and foreseeable production practices used by the Navy.

Panel 3 “Technological Enablers” panelists[3] discussed technological enablers from a variety of domain perspectives including thermal, controls, architecture, and power electronics. During the panel discussion, ten tangible solutions were identified by SMEs that might enable greater power and energy systems flexibility. These were:

- Integrated Power Corridor
- Network of controllers & convertors (i.e., Power Electronic Power Distribution System)
- Load shedding
- Rotating machines
- Modeling & Simulation Platform (an attribute of which would be standard interfaces)
- Nano-structured materials
- Energy storage attributes such as “on main bus distribution” and “available to any load”
- Thermal Architecture Modeling & Simulation Tool (a relational or flow description being co-design with the power & energy community)
- Plug-in Connectors (an attribute of which would be higher voltage levels)
- Programmable Power Electronics

The facilitator asked each panelist to choose one technological enabler that will anticipate disruptive technology or deal with uncertainty of power and energy needed in the future. Panelists responded:

(1) Integrated Power Corridor,
(2) Programmable Power Electronics,
(3) Thermal Energy Storage,
(4) Optimal Controls, and
(5) Rotating Machines.

During the panels, considerations for and approaches to flexibility were also being captured from the discussion and overlaid on the “from-to” framework (Figure 4).

Figure 2. Capture of From-To Framework with Input from Panels

Day 2

Like day 1, day 2 began with framing remarks from Mr. Stephen Markle, specifically pertaining to integrated power and energy systems (IPES). To advocate for IPES, he suggested that the community:

(1) Characterize uncertainty,
(2) Identify flexibility,
(3) Evaluate alternatives,
(4) Put flexibility in place to minimize the effects of uncertainty, and
(5) Express benefits of flexibility.

[3] Petersen, Schegen, Chalfant, Spector, Heinzel

The facilitator also encouraged the participants to frame their work in terms of “concrete things”: specific recommendations to develop certain outputs or products, specific recommendations for projects, identification of specific questions that will need to be answered, and specific recommendations for what design or engineering practices to adopt.

“Proposals for Flexibility”: Systems Diagramming

Participants defined the design boundaries/dimensions of flexibility as they pertain to Naval Power and Energy Systems (Figure 6) using a systems diagramming construct. These diagrams allowed the group to refine flexibility concepts and shift its thinking from an emphasis on the physical power system itself to an emphasis on the entities and dimensions of flexibility, i.e., addressing the question of “flexibility for what”.

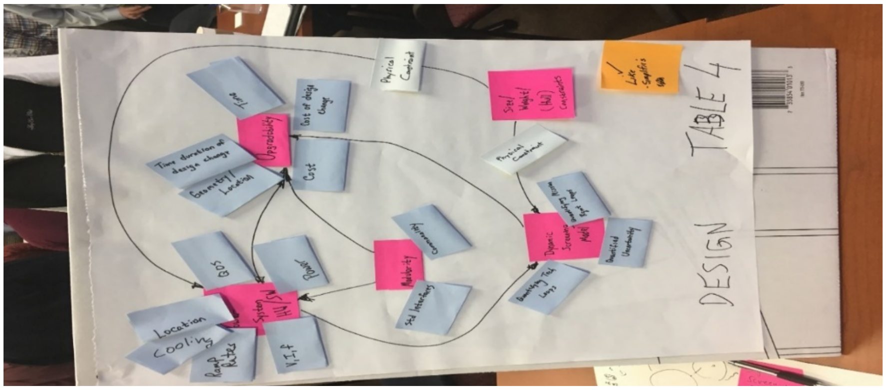
Refining Flexibility Concepts

Initially, the traditional engineering approach to power and energy systems appeared across 8.5 of 9 diagrams developed by breakout groups – diagrams neatly connected power distribution with energy storage, etcetera. What emerged was great unanimity about what a Navy integrated power and energy system should look like based on current thinking. It suggested that the dominant contributors among the attendees assume the basic entities comprising a power system today are also the basic entities comprising a flexible power system of the future. The question to be answered is whether this is a valid assumption.

In reviewing the initial results and progress, the facilitator identified some conceptual areas of commonality achieved by the group – flexibility likely involves modularity, scalability, integration, and uncertainty. This provided the group something to build upon, while further defining the design space for flexibility and the dimensions of that space.

Throughout the activity, groups were received contradictory input regarding pushing their thinking beyond current modalities, processes, flows, and adopted technologies. While pushing boundaries was an objective, the group also contained many participants that had firm opinions that the present boundaries were important and significant optimization had been achieved within those boundaries. They were also encouraged to ensure their diagrams were unique to the concept of flexibility, that they captured any measures or numbers for which they had a point of view (e.g., “higher voltage levels” rather than “voltage levels”), and that any specific methods or tools were attached to relations or flows (e.g., “co-design with thermal”).

The assertion was made that “Without uncertainty, there is no impetus for flexibility”. While this approach ignores the efficiency and effectiveness benefits of flexibility, four of the breakout groups explicitly built uncertainty into the conceptual “system” of flexibility.



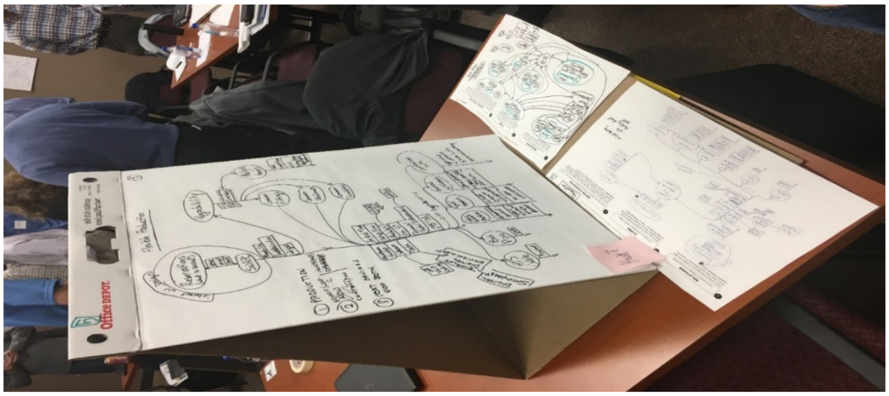


Figure 3. Two Systems Diagrams Generated on Day 2

Results

- Flexibility timescales using metrics, such as time, cost, and magnitude. One breakout group suggested that the level of flexibility in a system could be characterized through a transition definition: "*time and magnitude of the transition.*" The level of characterization for individual entities of flexibility requires further discussion, however (e.g., interfaces – standardization versus adaptability, simplicity versus complexity).
- Most groups assumed that "flexibility" meant cross platform over different time scales. It also was represented by *modularity* and *upgradability* as entities or attributes within systems. It also presented as *configurability*/*reconfigurability*.

Discussion

Advancing towards a definition of "flexibility"

The workshop team presented a basic definition of flexibility to the group. The challenge was to test the legitimacy of this definition in principle, then to advance the definition with greater detail across the three categories of design, use/operation, and production.

FLEXIBILITY

…the ability of power systems to adapt to dynamic and changing requirements.

Figure 4. Conceptual Definition for Flexibility

Themes

From this discussion, three themes emerged:

- The most vocal participants agreed upon key dimensions of flexibility in power and energy systems. These include **– modularity, configurability and reconfigurability, scalability, upgradability, dynamic range of mission scenarios, and process**. These dimensions will need to be further defined.
- Although often a part of the conversation, the most vocal participants agreed that power continuity, electric system stability, survivability, and maintainability are *not* unique to the concept of flexibility and do not belong in its definition.
- Flexibility concepts require more intercommunication among layers (i.e., design/production/operation) and process. This intercommunication and process integration will butt against larger cultural barriers in Navy. For example, flexible design is largely agreed upon and known by the community but has not yet been adopted by the Navy due to acquisition and organizational barriers. Flexibility in operation is a newer concept for Navy and may represent a paradigm shift for how the power and energy community works with operators.

Possible Design Principles

Based on recurring comments throughout the workshop, additional themes emerged that are not definitional but imply a convening of thought about design principles for flexibility. These include:

- Relative rather than validated design/Flexible standards based in a scientific standard
- Metrics and techniques in engineering decision-making aligned with affordability decision-making
- Physics-based models
- Flexible design balanced with resiliency of solution
- Uses some mechanism to bring design advancements in industry to Navy

Material Achievements for Flexibility

In 11 workshop hours, the group accomplished the following:

Achievement	Applications / Potential Use
Developed a "from-to" (i.e., *as-is*/*to-be*) framework for flexibility across three categories	• Binding the problem statement • Defining high-level Navy requirements • Setting an end-state for a roadmap • Foundation for lexicon
Generated 10 diagrams for flexibility/flexible Naval power and energy systems, which identified key entities and attributes	• Source for lexicon • Source for design approaches to flexibility • Source for specifications and standards • Source for metrics
Created a roughed-out innovation timeline	• Provides historical basis and justification for flexibility in power and energy systems • Identification of drivers, lessons learned, and technological enablers
Agreed that uncertainty is a driver/requirement for flexibility	• Provides direction for further definition / specification and standards development
Discovered common entities or attributes of flexibility – modularity, configurability and reconfigurability, scalability, upgradability, dynamic range of mission scenarios, and process	• Source for lexicon • Source for metrics • Provides direction for further definition / specification and standards development
Identified 10 technological enablers for flexibility, specifically naming a "top 5" for future flexibility	• Source for a roadmap • Source for modeling, simulation, and testing
Introduced design principles for flexibility from which 5 initial design themes emerged	• Source for design principles • Guidelines for planning • Guidelines for modeling

Figure 5. Active Working Sessions

Appendix A: Attendee & Table Assignment List

Table	Last Name	First Name	Organization
1	Amy	John	Navy
1	Hebner	Bob	ESRDC
1	Superczynski	Matt	Northrop Grumman Mission Systems
1	Van Wert	Thomas	Navy
1	Widmann	Jarrod	DRS
1	McMullen	David	Navy
2	Temkin	Deanna	JHU
2	Cunningham	Daniel	DOE
2	Kane	Vincent	Navy
2	Krolick	Cy	Private
2	Sudhoff	Scott	ESRDC
2	Ware	Dawn	Navy
3	Dwight	Alexander	Northrop Grumman Marine Systems
3	Fikse	Thomas	Navy
3	Mahoney	Dennis	RCT
3	McDowell	Bob	L3 Power Distribution
3	Petersen	Lynn	Navy
3	Ginn	Herb	ESRDC
4	Schegan	Christian	Navy
4	Fuller	Bryant	Siemens
4	Maniquis	Nilo	Navy
4	Pekarek	Steve	ESRDC
4	Shegirian	John	GD-EB
4	Steurer	Mischa	ESRDC

Table	Last Name	First Name	Organization
5	Hepburn	Rick	Hepburn & Sons
5	Page	Jon	Navy
5	Ulliman	John	American Superconductor
5	Voth	Jeff	Herren Associates
5	Markle	Steve	Navy
5	Bosworth	Matthew	ESRDC
6	Doug	Jones	HHI-INGALS
6	Borraccini	Joseph	Navy
6	McCoy	Tim	University of Michigan
6	Salinas	Angel	CACI (support Navy - IWS)
6	Lounsberry	Brian	Cardinal Engineering (supports PMS320)
6	Plew	Stephen	Navy
7	Dalton	Thomas	Navy
7	Belkhayat	Mohamed	HII-NNS
7	Chalfant	Julie	ESRDC
7	Spivey	Nathan	Navy
7	Steinrock	Greg	RR Naval Marine
7	Crews	Scott	Herren-Associates
8	Glover	Steve	SNL
8	Heinzel	John	Navy
8	Awiszus	George	GE Aviation
8	Bowles	Edward	General Atomics
8	Spector	Mark	Navy
8	Longo	Donald	Navy
9	Kuseian	John	Navy
9	Boehmer	Tyler	JHU
9	Cherry	Jignas	Cardinal Engineering (supports PMS320)
9	Doerry	Norbert	Navy
9	Makevich	Steven	GE Power Conversion
x	Van Steen	Erica	Herren Associates