***Project:*** Framework for Analysis of Distributed Energy Storage

***Project Completion:*** 2016

***Output:*** A technical report [1] was developed, describing the proposed framework, and describing techniques that could be employed for the different portions of the framework. Software tools (MATLAB functions and classes) were also developed to implement portions of the framework.

***Outcome:*** Existing tools and techniques were identified to be suitable for several portions of the proposed framework, and software tools were implemented for the most critical portions of the framework, in order to explore interfaces between the various modules of the framework. In the process, the importance of accounting for the role of energy management controls was noted, and an initial algorithm for including the effects of these controls was proposed and implemented.

***Project Motivation:***

The size and placement of energy storage systems are important considerations that can directly impact the ability to power critical loads for short periods of time. In order to support the consideration of distributed energy storage in early-stage ship designs, a framework for analysis was proposed based on the following considerations.

- Explicitly consider the topology and component ratings of the power system.
- Consider effects of load buffering, leveling, and shedding.
- Support incorporation of uncertainty.
- Consider size, weight, and cost as counterbalance in the optimization process.

Based on these considerations, the framework illustrated by Figure 1 was proposed. This framework was intended to make use of static power flow solutions (based on linear programming solutions of a graph-based power flow) at the lowest level, which could be extended as an efficient time-domain simulation. Component objects could then be developed to interface with the time domain simulation, with component models updating capacity, priority, and load demands to the time-domain solver. These component models would make use of load profiles and priority rules from separate modules. Other modules were intended to provide size, weight, and cost estimates with uncertainty bounds, making use of uncertainty propagation techniques and interval analysis. Other modules for optimization and uncertainty propagation were intended to be employed at the highest levels to drive parametric studies. This modular framework was intended to allow graceful evolution, allowing individual modules to be replaced and/or extended over time.

In order to construct an initial implementation of the framework, an attempt was made to first identify suitable techniques and tools that may be sufficient for each of the modules. With numerous tools available for optimization and uncertainty propagation, little focus was given to these for the first implementation. Similarly, emerging techniques for the generation of load profiles using operation vignettes were noted. Thus, the primary efforts were directed toward the shaded modules. An existing power flow solution tool, inherently accounting for load shedding and load leveling, was modified to allow time-domain simulation, and classes for components were developed for sources, loads, and energy storage units to support necessary features for the studies. However, in this process, it was noted that a module was also needed to account for the effects of energy management controls. An example system showed that the use of standard backup power approaches (in which energy storage systems provide power to any loads that would otherwise be shed) may lead to incorrect conclusions when comparing the effectiveness of alternative designs with different allocations of stored energy. The example showed that, by making more effective use of stored energy resources, an alternative design may outperform a design that appears to be superior when only making use of a standard backup power approach. For this reason, substantial effort was devoted to developing an algorithm to make optimal use of stored energy during a scenario, in order to capture the effects of a well-designed energy management system (the details of which would not likely be available in the early stages of design).

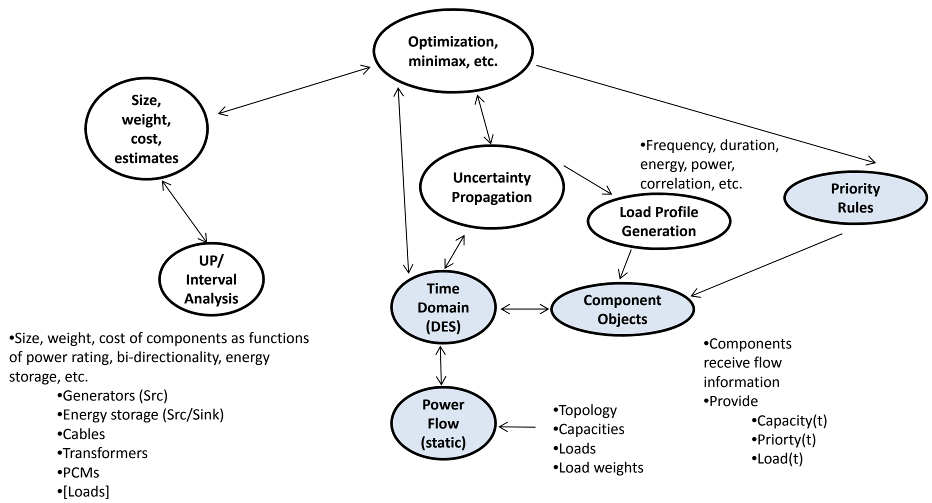


***Figure 1: Overview of Proposed Framework***

The algorithm that was developed provided a time-dependent power discharge limit to each energy storage module, such that the operability of the system was maximized. The algorithm was able to take advantage of full knowledge of the future load demands, but the algorithm was intended to provide an indication of the best possible performance of an energy management system. Overall, this effort served to identify key characteristics of the interfaces between modules, identify existing tools and techniques that could be leveraged in the framework, and identify the critical need for techniques to account for the role of the energy management system in the early-stage design. This work also resulted in the implementation of software tools for the time-domain power flow solution, an initial algorithm for optimal allocation of stored energy, and class implementations for several types of component models needed for these studies.

***Project Extent:*** This project involved multiple researchers from one ESRDC institution and is documented in a technical report [1] and paper [2].

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## ***References:***

[1] James Langston, Karl Schoder, Mark Stanovich, Michael Andrus, and Mischa Steurer. Framework for analysis of distributed energy storage, version 2.0. Technical report, Electric Ship Research and Development Consortium, October 2016.

[2] J. Langston, M. Stanovich, K. Schoder, and M. Steurer. Distributed energy storage allocation algorithm for early stage design. In *2017 IEEE Electric Ship Technologies Symposium (ESTS)*, pages 345–351, Aug 2017.

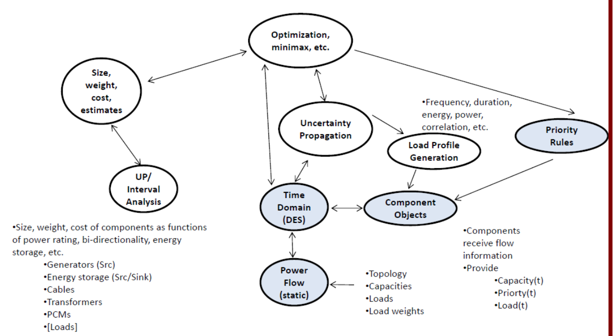
ELECTRIC SHIP RESEARCH ESRDC AND DEVELOPMENT CONSORTIUM

## Framework for Analysis of Distributed Energy Storage

### Motivation

Develop framework for sizing and placement of energy storage in early-stage design, including

- Explicitly consider the topology and component ratings of the power system.
- Consider effects of load buffering, leveling, and shedding.
- Support incorporation of uncertainty.
- Consider size, weight, and cost as counterbalance in the optimization process.




### Challenges

- Identified need to account for energy management controls
  - Illustrated with example case
    - Compared two simple systems with different distribution of energy storage resources
    - For stable backup power approach (i.e. energy storage provides power to any loads in order to avoid load shedding), showed that system A exhibited superior performance (in terms of operability) to system B for a given scenario
    - For alternative energy managment strategy (i.e. withholding power from lower priority load to save energy for higher priority load later in the engagement), showed that performance for both systems was improved, with system B showing the best performance
  - Details of these controls would not be known in early stage design
  - Need to account for optimal performance of system (i.e. consider results for optimal energy managment system)

### Outcomes

- Identified suitable tools/techniques for several portions of the framework
- Leveraged graph-based power flow (using linear programming approach) for static power flow
- Extended power flow to include time-domain simulation
- Implemented component models for generators, loads, and energy storage units
- Identified need to consider effects of energy management systems – illustrated through example case
- Developed and implemented algorithm for optimization of energy resources