***Project:*** Metamodeling of Power System Components

***Project Completion:*** 2017

***Output:*** Methodology to rapidly predict motor and generator size and loss within S3D.

***Outcome:*** The Navy has a critical need for a tool to improve ship design and performance leading to a more capable fleet. One such tool is S3D, and this effort resulted in S3D code to estimate generator and motor size and loss and the tradeoff between size and loss.

***Project Motivation***: The objective of this task is to support naval architectural tools with respect to power system components. In early stage ship design, the naval architect and system designers need to select and place equipment on the ship. Focusing on power system components, the designer will select and place generators, propulsion motors, and other equipment.

This task focuses on how the selection is made. Suppose a generator is required. One approach is to select the generator from a catalog of available devices. This can be an excellent approach since choosing from an existing machine catalog provides high confidence in the generators characteristics such as loss, size, and mass. However, the approach does have its limitations. It certainly provides information on what *has* been achieved – but does not give information on what *could be* achieved. Suppose that on a given ship design the size of the power system components was of intense interest. The machines in the ‘generator catalog’ may have been designed based on criteria that were not in alignment of the design requirements of the system. Another disadvantage of the catalog approach is that for most power system components, it is possible to make a trade-off between the size of that components and its efficiency. This trade-off could be exploited by the architect in designing the ship. However, unless a truly extensive catalog is available a catalog approach does not support this tradeoff in a continuous way.

An alternate approach to using catalog data is to base component selection on sizing rules – for example by assuming a certain torque density, power density, or efficiency. However, such an approach is uncertain as reasonable metric values are a function of the scale, and in the case of electric machinery, speed.

In this task, a third alternate approach to component selection is developed – that of the design metamodel. This approach to power system component design is aimed at giving the system designer knowledge of the fundamental tradeoff between size and loss for that component, and knowledge of what is practically achievable. It is even possible to give the designer some choice in terms of the aspect ratio of the component – for example in the case of electric machinery the ratio of diameter to length could be left to the system architect.

A metamodel is a model of a model. With respect to this effort, the metamodel is a model of a design model. The design model itself is fairly detailed, and is scaled in such a way that is normalized relative to some base. In this way, the design model is made scale independent. Based on the design model, a constrained optimization of the desired metrics is obtained. Typically this involves a two-objective optimization minimizing volume and loss or mass and loss, although in theory any number of objectives could be included. The result is a large number of designs in which no design is better than any other in terms of both objectives. This is known as the Pareto-optimal front of designs, which consists of a large discrete set of designs, typically numbering in the thousands. The metamodeling procedure involves a curve fitting process to fit the properties of the discrete set of designs to continuous functional fits. These functional fits can then be used by the naval architect as a means to select a particular design.

Significant progress was made in four areas:

* *Non-dimensional machine modeling optimization*

Perhaps the first breakthrough of this work was rather theoretical. A means of making the electric machine (motor/generator) design codes non-dimensional was set forth. This was necessary in order to have an optimization-based metamodel.

* *Metamodeling*

The non-dimensional optimization runs are conducted and over a large range of normalized speeds. A means of capturing the non-dimensional optimization results and using them to generate dimensional results in a computationally trivial way was developed.

* *S3D Implementation*

Supported by Purdue, the University of South Carolina implemented the methodology in S3D so that the work could be used by the marine community.

* *Post Effort Epiphany / Future Work*

After the effort was concluded, an important observations was made. This is that once it is known that it is possible to represent the machine design equations in a normalized way, it is not actually necessary to write non-dimensional design code. Rather, existing design codes could be used and the parameter sets scaled appropriately to formulate the meta-model. The significance of this is that metamodels can be created for other types of electric machinery with a fraction of the effort needed to formulate the metamodel in this effort (which was based on a permanent magnet ac machine).

***Project Extent***: This project involved researchers from primarily three ESRDC member institutions (Purdue and the University of South Carolina with support from MIT) and is documented in an IEEE transaction paper and a report.

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