UNCERTAINTY QUANTIFICATION “CORRELATION FINGERPRINTING” TO CHARACTERIZE THE PERFORMANCE OF REDUCED ORDER MODELS

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***Abstract* – Digitalization of industrial processes is the inevitable route for most industries. This requires the creation of digital twins which are computationally efficient. Advanced computation models are typically not fast enough to be applied as digital twins in digitalization applications. Reduced Order Modelling is a good approach for the creation of faster digital twins. A major challenge is to identify and /or create suitable digital twins, and to map the sensitivity of those simplified models. Uncertainty Quantification Correlation Fingerprinting (UQCF) allows to systematically identify the best approaches for reduced order modelling and to compare the performance of the original complex and the simplified system models in a glance while gaining insight to fundamental behaviour.**

I. INTRODUCTION

In the digitalization transformation it is inevitable to create computationally efficient digital twins. Electrical drive systems are important targets for the digitalization effort. The balancing between computation accuracy and computation speed is an important aspect of the model making.

The only practical engineering approach to complex simulations is to aim to utilize the required level of fidelity for solving a problem, and not to aim to use the highest fidelity available. The evaluation of the required fidelity levels in different parts of a system model is a challenging task, as it includes the fidelity of the component models and the fidelity of the coupling methods also [1][2]. Without a systematic approach the optimization of the computational resources and the accuracy of the system modelling and embedded control is extremely challenging [3].

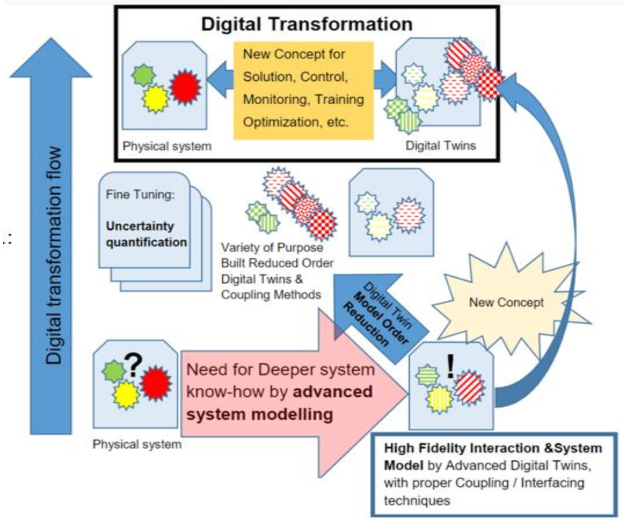


Fig.1. The proposed role of Uncertainty Quantification to fine tune digital twins in the Digital transformation flow.

Uncertainty quantification provides the tools for identifying the sensitivity and the performance of reduced order models compared to their high fidelity counter parts. Fig. 1 shows a block diagram of the digital transformation flow and the role of the uncertainty quantification as to fine tune reduced order models to utilize them as purpose built digital twins.

II. UNCERTAINTY QUANTIFICATION TO CHARACTERIZE A DRIVE SYSTEM MODEL

Uncertainty quantification (UQ) can be used to systematically analyse and characterize the sensitivity of an engineering outcome but it can also describe the performance of a computation methods in a complex system model [4].

While the sources of the uncertainty in modelling can often range from manufacturing tolerances to material parameter variation, the effect of different modelling methods can similarly be characterized.

The UQ tool utilized for this study is called Dakota, which is an open source tool box developed by Sandia National Laboratories, USA [5].

Dakota provides several optimized methods to provide an optimal sampling coverage of the variable space. The most commonly used approach was the Latin Hypercube Sampling (LHS) for this paper.

The calculations were executed by an in-house computation tool modelling the drive system, the electrical machine and the drive. Dakota provided certain level of automated post-processing. A more detailed explanation of Dakota will be provided in the full paper due to the space limitations of this abstract.

The goal of the UQCF study was to identify best modelling method candidates for model order reduction for digital twins, and to create a tool to verify them against more complex models.

III. UQ FINGER PRINTING TO CHARACETIZE MODELING SENSITIVITY AND PERFORMANCE

Utilizing the UQ results the different modelling methods – including reduced order of modelling – can be characterized by their UQ Correlation Fingerprints (UQCF) in several ways. A combination of these sets of fingerprints can provide a systematic characterization of each model.

Very telling UQ fingerprints of a simulation model are visible in the sensitivity plots between variables. As a result of a multiparametric UQ analysis one can establish a characteristic plot of one variable depending on another while the rest are varied. When the variables are selected as one characterizing the order of the model, while the other characterizing a system performance, plotting the system variables as a function of the order variable can provide valuable insight to the performance of the computation models. Fig. 2 provides the plot of the drive system efficiency as a function of the order of shape functions of the finite element electrical machine model, including all results of the UQ analysis of the drive train.

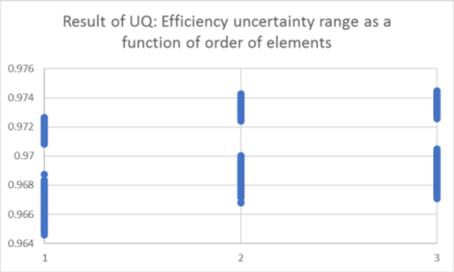


Fig. 2. Uncertainty / sensitivity plot of the efficiency of the electrical machine as a function of order of the finite elements.

Another exciting representation of the performance of the model from a UQ analysis is the linear correlation matrix.

This can provide a qualitative picture of the effect of one variable on another as a result of all computations in the large variable space. An analysis of the correlation between model order describing variables against system performance variables can provide easy to grasp performance pictures of models with variable fidelity. In reduced order models one might suspect new – originally non existent – correlations between input variables or between input and output variables as a result of simplifications. These can also be very interesting to acknowledge. Due to this fact it is recommended to look at the full UQ correlation fingerprint of the model by observing the plot of the correlation matrix of the whole variable space not just the model order and system performance variables as shown on Fig. 2. This provides an easier comparison than analysing the many linear correlation matrix values one by one.

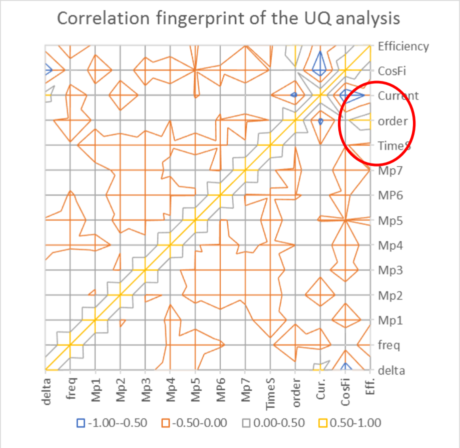
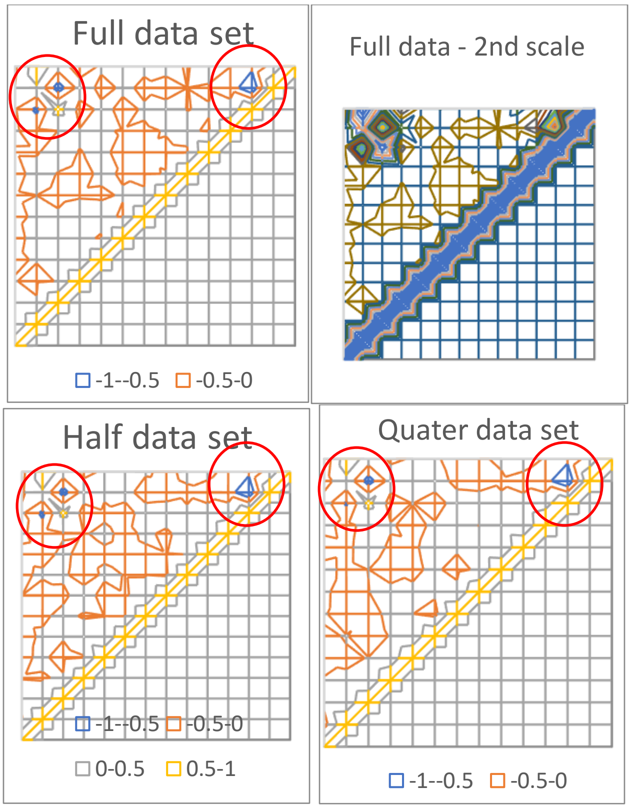


Fig.3. UQ Correlation fingerprint of the of a drive system model

The UQ fingerprint in Fig. 3 shows that there is a strong negative correlation between the efficiency of the machine and the order of elements. This clearly shows that the reduced order model has a weakness in the loss computation and the error is quantified in Fig. 2.

To study the robustness of the fingerprinting approach several variations of the data set for a detailed finite element machine model have been analysed.

An investigation of the correlation finger prints below have been created based on different sizes of data samples. They highlight the easily identifiable characteristics at some key points of the correlation fingerprint, indicated in red circles.



IV. CONCLUSIONS

The proposed UQ digital fingerprints provided a straightforward qualitative way to characterize the performance of the models and quantify the sensitivity of the reduced order models in the drive system example above. The full paper will provide further examples of the technique and provide a more comprehensive description of its benefits and limitations of the method.

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