Engineering Optimisation

Towards reliable and Efficient Optimisation of Energy-Efficient Electric Drive Systems

Situation

Research on optimisation techniques carried out by researchers in computer sciences and mathematics have provided a plethora of different optimisation techniques and tools. At the same time, modern power-electronics based electric drive system have the potential to lead to a significant energy savings world-wide. However, optimisation of these systems is still achieved using conventional “trial-and-error” techniques, parametric studies, and the engineer’s own subjective judgment. Very few are the results in which optimisation tools are discussed with respect to their reliability (e.g. computational effort and implementation effort.)

In this project, different sets of optimisation problems will be created and analysed with respect to their performance, notably their reliability and efficiency. Here, the “problem” includes the mathematical formulation of physics-based model, the application of different solvers, and the influence of different boundary conditions. Emphasis will be placed on the identification of those instantiations that show some extreme performance as these allow to identify the key aspects of the underlying system that influence the overall behaviour. To this aim, the analytical models will be kept small. Given the cost and the many elements of uncertainty involved with the conventional design approach, this project aims to further catalyse advances in the design of modern electric drive system and thereby to enable the full exploitation of their energy savings potential.

Problem

Presented as a physics based model within GAMS (General Algebraic Modelling System), the research required the mathematical manipulation of the model to maximise optimisation. The task was to investigate and analyse the effects of such manipulation, concluding with a recommendation of the most efficient method. Some of the techniques trialled included:

- -Bracket removal
- -Auxiliary variable removal
- -Variable reduction
- -Fraction to product conversion

GAMS uses solvers to locate solutions and each of these solvers uses its own unique method to conclude the problem. Another dimension of this problem was to include solvers into this analysis. By testing each approach with various solvers, deeper insight into potential optimisations were revealed.

Sensitivity Analysis investigates the impact of variance on key parameters. This is especially relevant in manufacturing where the variance of vital components dictate profit margins. Measuring how this variation effects the overall outcome of a model and ranking the importance of each parameter, allows a manufacturer to know which components require tighter tolerance bands (and thus higher costs), and which can be more lenient, therefore lowering costs.

Reflections on the Undergraduate Scholarship Scheme

My time during the undergraduate research scholarship scheme has been a rollercoaster ride. Along with its highs and lows, I feel that I have truly come to appreciate the nature of research. Prior to starting the scheme, I had little knowledge of academic research and thus, my preconceptions were that it was potentially mundane and subject to huge follow-up reports.

As soon as I was briefed on my project, I realised that I was very wrong. Having spent 16 years understanding accepted and proven theories, the feeling of being on the cutting edge of societies knowledge, pushing the boundaries with your work is incomparable. However, this does not come without it’s lows. New discoveries do not come without hard work. The almost iterative process sometimes wore me down, but perseverance was to key to success.

Having previously had very little exposure to university research, this experience has not only taught me patience, but it has also honed my analytical skills. Being presented with a wealth of information, I could have analysed infinite numbers of relationships, but applying my own judgement and selecting the most relevant was a key skill learnt. Learning how to use a widely used optimisation tool—GAMS was also a significant milestone in the project.

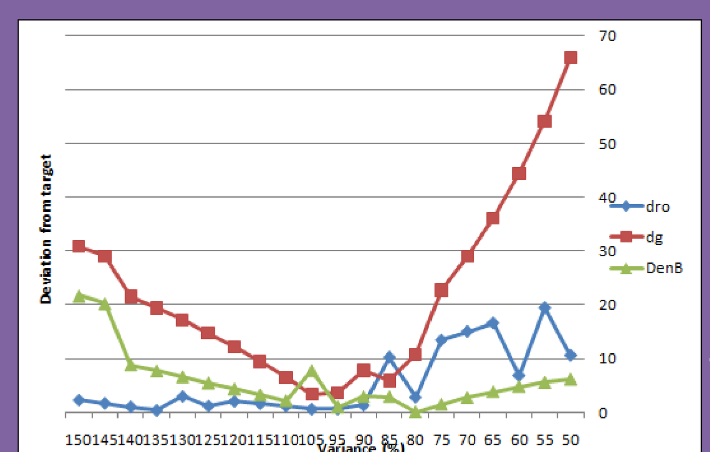
Results

Rigorous testing of each approach using a range of fixed variables, allowed a detailed insight into the effects of each change. Each of these methods allowed assessment into how GAMS dealt with the model, and by altering the size of the fixed variables, it became possible to evaluate the effects and create performance comparisons. Three of the solvers used an iterative process where the number of iterations was closely linked with the solving time. Thus, iterations was used as a performance metric for these solvers. For the non iterative solvers, solving time was the main performance indicator.

For the iterative solvers, methods such as “fraction to product conversion” and “bracket removal” all resulted in a negative impact. The experiments suggest that the physical size of the model slows down the computation and the benefit of decreasing complexity is relatively small. In contrast, when reducing the number of variables in the model, all solvers observed an improvement in their performance. In particular, the iterative solvers had up to an 85% improvement in their performance metrics. Finally, the removal of auxiliary variables (dro, dg & DenB) required analysis of each combination to determine if there was any substantial performance increase. Following separated testing of each variable, it became clear that only DenB provided a boost in solving time. This could be due to the fact that this variable was the most mathematically complex.

Conclusion

Following close evaluation and analysis of the model, it became clear which method was the most effective in creating an uplift in optimisation. Reducing the number of variables was the most successful technique trialled, with reductions in iterative solvers of around 65 - 85%. When scaled up to larger and more complex models, this size of improvement could become significant. By increasing the speed of automated optimisation it encourages its use, thus relieving the reliance on traditional methods of optimisation. A future possibility would be to reduce models to a minimal number of variables and measure the effects of this.



The sensitivity analysis also produced clear results. A test into each auxiliary parameter and the effect of variance showed that the dg parameter was incredibly susceptible. This graph shows how far the final output deviates as a result of fluctuations in the parameter. Above 10% variance, “dg” begins to significantly alter the final output by as much as 65%. Thus it is suggested that in this instance, the cost of maintaining low variance on any variables relating to dg, is justifiable. Whereas other components relating to the other parameters, could withstand a variance of up to 30%.

Student and Supervisor Profile

Annette Muetze received the Dipl.-Ing. degree in electrical engineering from Darmstadt University of Technology, Darmstadt, Germany and the degree in general engineering from the Ecole Centrale de Lyon, Ecully, France, both in 1999, and the Dr. Tech. degree in electrical engineering from Darmstadt University of Technology in 2004. From 2004 to 2007, she was an Assistant Professor at the Electrical and Computer Engineering Department, University of Wisconsin-Madison, Madison, US and is now an Associate Professor at the School of Engineering, University of Warwick in the UK. Her research interests are the interplay of the different elements of electric drive systems, including parasitic effects, performance evaluation, design optimisation, and decision making criteria.

I completed my BEng in Engineering and Business Management in the summer of 2009. Engineering has always been a keen interest of mine, in particular electronic engineering. Structurally decomposing and comprehending complex systems is something I find myself often doing subconsciously and taken into an academic context, I find myself with an insatiable appetite to understand everything. My completion of internships in the electronic engineering sector allowed me to not only apply my understanding, but to learn the critical importance of engineering in our society.