Application to the Research Program TURBOPOWER

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Process 52: OPTISTEAM Continuation

Steam Turbine Optimization for Power Plant Operation: Start-up Improvements

prepared by:

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Executive Summary

This research project is aimed at developing and enabling improvements related to start-up and flexibility in the operation of steam turbines. The proposed project is a direct continuation of OPTISTEAM part I, a currently ongoing project within the framework of the TURBOPOWER program. Successful prior research on turbomachinery in solar thermal power plants has been performed since the start of the project in August 2012. The intention with this continuation is to consolidate the results obtained so far and expand the knowledge towards more generalized steam turbine start-up strategies.

In the present proposal the objective is divided in three parts: to extend and improve the thermal turbine simulation model, to validate such model for different turbines and plant configurations and to develop improved start-up strategies. As in part I, the present work will continue to deepen the competence and knowledge necessary to maintain the Swedish turbomachinery industries' competitive edge and to allow for continued steam turbine development at SIT in Sweden. This is realized in the context of the well-established collaboration between the Division of Heat and Power Technology at KTH and the Swedish steam turbine industry. Through this collaboration the research findings are directly realized and implemented in the industrial value chain.

This project proposal is divided in six sections. Section one starts with background information and framework of the OPTISTEAM project. Then section two focuses on reviewing the objectives and progress accomplished during the first part of the project. Since part I is still on-going, the objectives expected to be completed are also stated in this section. The third section presents the objectives and planned work for the continuation of OPTISTEAM. Lastly, sections four, five and six state important information for the completion of the proposed project related to the time plan, the budget and the personnel, respectively.

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1. Background

The research work for the first part of OPTISTEAM began on August 2012. The initial project plan specified 4 years' of research to be performed with an evaluation/decision point for continuation on year 2 directed towards the optimization of steam turbine operation in CSP plants. If the work performed during the first half, up to a Licentiate thesis, was considered to be satisfactory, then the study should be continued towards a Doctoral thesis in order to cover all of its objectives.

Not only has the project part I been followed very well and the objectives have been met, it has been recognized during the first two years that "Optisteam" links very well into SIT key projects regarding steam turbine start up:

- SIT has had several customer requests (e.g. from Ivanpah plant operator and CCGT operators) to evaluate and implement measures for improved steam turbine start-up times to enhance plant efficiency and revenue, where earlier results obtained within Turbopower have been mentioned as potential improvement measures by the customers, referring to our publications.
- Siemens has a global project ongoing between major Siemens steam turbine sites *on start-up time improvements*. This includes not only CSP plants, but also conventional power plants.
- The methods and tools developed in the present Turbopower project have been recognized to potentially fill an important gap in the prediction of thermal states for faster steam turbine start-ups for all power plant configurations where start-up times matter.
- For this reason, an internship exchange program has been initiated such that the methods can be further developed locally. This involves planned internships for Monika Topel at SIT Finspång, and potentially other Siemens locations in Germany in the next 2 years period. Monika Topel has successfully applied for an InnoEnergy PhD school stipendium that will cover all extra costs for travel and accommodation concerning this internship program.
- From SIT Finspång perspective, the continuation of the present project is regarded as an important contribution to strengthening the competiveness of the steam turbine development in Sweden and the competence in the field of power plant flexibility.
- The project is also run with support from Associate Prof. Magnus Genrup from Lund University. Magnus acts as a co-supervisor for Monika and contributes with his expertize on steam turbine start-up improvements.

2. OPTISTEAM part I review

As a general overview of the progress performed in OPTISTEAM I, it is worth mentioning that the project has developed adequately in terms of timeframes, scientific publications and cooperation with related partners. A licentiate thesis defense is scheduled for the last trimester of 2014. Three scientific publications will be included in this work, all of which are based on studies that comply with the objectives of the project. The studies for these publications were performed with the involvement of industry partners in Siemens (Markus Jöcker) and academic partners in Lund University (Magnus Genrup) resulting in their co-authorship on the papers.

The initial key objectives of the OPTISTEAM project were twofold and it comprised two parts within the project plan in order to cover both objectives. The first part of the project will be on-going until August 2014. The current status of the objectives and project work to be accomplished and completed for part I will be stated in the upcoming subsections.

2.1 Accomplished Objectives

The objectives to be completed during OPTISTEAM I are:

Extend the study beyond conventional technology by investigating the demands and optimization potential of steam turbines operating in the next generation of tower-based CSP plants. This work comprises both tower based direct steam generating as well as molten salt based configurations.

Complement the existing work on solar steam turbines performed as part of the TURBOPOWER research program Phase I by analyzing promising operating strategies during transient operation in order to decrease turbine start-up time.

In detail the following is covered:

- Evaluation of operational measures for solar steam turbines with a view to maintaining turbine temperatures and improving start-up times.
- Development of prediction models for the evaluation of different operating strategies for steam turbine tower-based solar thermal power plants.
- Operation optimization, including different turbine temperature-maintaining modifications on the power plant models to assess the impact on annual electrical output.
- Modeling of air-cooled condensers for future study of the impact of water-use reduction strategies in solar power plants.

2.2 Performed Project Plan

The planned work, in accordance with the original work plan in OPTISTEAM I, to be carried out during the first half of the research project dealt with tower-based CSP systems. The work that is carried out in the first 2 years comprises:

- A literature study of the new tower-based CSP configurations
- Modeling of Gemasolar, one of the two existing tower-based CSP plants with the help of our in-house DYESOPT tool to establish boundary and operating conditions for the steam turbines in these plants.
- Modification of the steam turbine model from TURBOPOWER, Phase I, to be adaptable for the steam turbines operating in the tower based CSP plants.
- Identification of the most important issues concerning steam turbine operation and performance improvements.
- Modeling of Ivanpah, one of the two existing tower-based CSP plan with the help of our in-house DYESOPT tool to establish boundary and operating conditions for the steam turbines in these plants.
- Analysis of the steam turbine with respect to performance and thermo-mechanical properties under representative operation in the two tower-based CSP configurations.

The work performed so far in part I has followed the project plan successfully and it is foreseen that all objectives will be met at the end of part I.

3. OPTISTEAM Continuation

The outcomes of the performed work on OPTISTEAM I shall serve as a basis for the continuation of the project into a second part. This will cover the remainder of the project plan and objectives from part I and will focus mainly on the generalization of start-up strategies for steam turbines with the possibility to contribute to some global Siemens development goals as stated in the Background section above. The main emphasis for the generalization strategies will consist on the application of the developed thermal modeling scheme on different turbines for a variety of plant configurations including combined cycle applications and validate the model.

3.1 Objectives and Goals

In detail, the objectives for OPTISTEAM Continuation will consist of:

Extend and improve the thermal turbine simulation model established in the OPTISTEAM part I project to enable it to calculate rotor expansion and temperature gradients for general turbine configurations based on a modular modeling approach.

Confirmation and tuning of the generalized thermal modeling scheme for start-up calculations for different turbine models and plant configurations linking into ongoing work at Siemens.

Develop improved start-up strategies for steam turbines in conventional CCGT and CSP plant configurations through coupled turbine and power plant enhancements and evaluation of the economic benefit with DYESOPT

3.2 Project Plan

In order to achieve the previously stated objectives, a work plan has been developed. The work is centered around the turbine thermal model developed in part I and it basically consists of three steps: refinement, validation and application of the modeling tool. The project plan consists of the following

- Refinement of the existing in-house steam turbine model to enable it to determine the location of the highest stress-points, allowing use of the model for establishing new start-up curves.
- Development of a tuned thermal model that is validated either against available existing 1D and 3D FEM models in industry, against measured differential expansion or against experimental data.
- Sensitivity analysis of parameters and additional modifications (e.g. controls, design, material, operation strategies) to the steam turbines in order to define and improve the thermal limiting criteria.
- Design generalized strategies for faster steam turbine and power plant start-up based on evaluations against allowable temperature differences and combined turbine/plant enhancements.
- Transform the model developed at the Department of Heat and Power Technology into a user-friendly tool for optimal steam turbine thermal calculations

3.3 Work Packages

The work package description is given below. Within each work package associated milestones (M) and deliverables (D) are identified.

<u>Year 3-4</u>

<u>WP 5: Steam Turbine Model Refinement and Validation</u>

- Introduction of improvements to the steam turbine model (thermal stress, rotor expansion, etc)
- Validation of model against existing data (temperature gradients and differential expansion)
- Transformation of the model into a user-friendly tool

M5.1: Refinement improvements applied successfully

M5.2: Turbine model validated

M5.3: User Friendly tool completed

D5.1: Report on ST model improvement and validation

D5.2: Software tool introduced to industry

D5.3: Scientific Publication 4 *Analysis of rotor expansion and its impact on turbine start-up*

<u>WP 6: Start-up Improvement Strategies</u>

- Perform sensitivity studies.

- Design fast start-up strategies.

M6.1. Key parameters and limiting criteria for faster start-up strategies identified.

M6.2 Start-up strategies for improvement of power plant and turbine operation designed.

M6.3 Successful defense of PhD thesis.

D6.1 Report on proposed and evaluated generalized start-up strategies

D6.2 Scientific Publication 5 *Strategies for faster start-up of Steam turbines*

D6.3 PhD Thesis

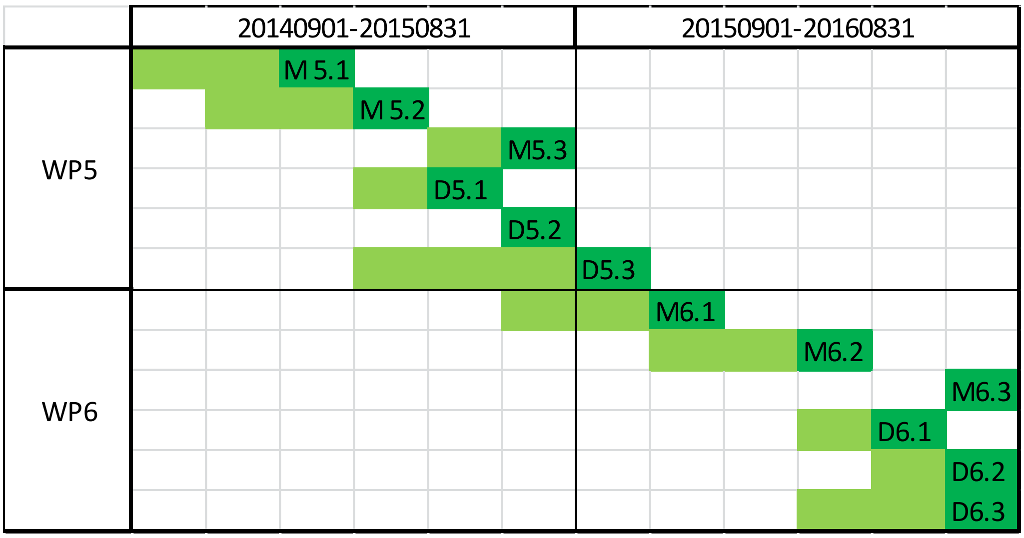
4. Scientific Benefit

As seen from the oucome of the part I of the project, the subject matter has received high atttention and was very well received in the research community. The value lies in the combination of detailed analysis of the complex transient thermodynamic/thermomechanical processes and optimisation towards desired objective functions, such as cost. In this way, changes in the complex thermodynamic cycle set-up and thermomechanical behavior of the turbines can directly and reliably be express in terms of cost improvements or environmental gains. From the authors best knowledge there are no other scientific efforts being published in this field apart from what has been pursued by the Department of Heat and Power Technology.

5. Industrial Relevance

The results of the steam turbine thermal and optimisation studies will allow the promotion of new measures for maintaining steam turbine temperatures during standby and idle periods. As this is a major issue in steam turbine operation, opportunities will be created for the Swedish industry. Proactive engineering analysis of the upgrading potential of existing plants can also create business through repowering of conventional and solar steam turbine plants. As in the preceding project part I, outcomes can potentially find direct application in planned and existing conventional CCGT and solar thermal power plants, where steam turbines are supplied by Siemens Industrial Turbomachinery AB. It will help the Swedish steam turbine industry to keep their leading market position as it will establish an important, directly applicable knowledge base for safe and cost-efficient operation of the turbines in these plant configurations. Both industry and academia will benefit from a close cooperation which will lead to future competitive products and experienced engineers.

6. Time Plan



7. Project Budget

The total project budget is 1.8 MSEK distributed over two years according to the table below.

Project budget ST Optimisation (university) all in kSEK			
	Year 1	**Year 2**	**Total**
Salary cost	547	547	**1094**
Computer	40	40	**80**
Material			
Equipment			
Travel	40	40	**80**
Others	40	40	**80**
Overhead (max 35%)	233	233	**466**
SUM (kSEK)	**900**	**900**	**1800**

As the TURBOPOWER program phase II ends at the end of 2015, the budget for the current phase is the following:

Project budget ST Optimisation (university) all in kSEK			
	Year 1	**Year 2**	**Total**
Salary cost	547	273,5	**820,5**
Computer	40	20	**60**
Material			
Equipment			
Travel	40	20	**60**
Others	40	20	**60**
Overhead (max 35%)	233	116,5	**349,5**
SUM (kSEK)	**900**	**450**	**1350**

The salary cost is related to the cost for one graduate student with and senior support and supervision. The cost Others is related to license costs for necessary software programs.

The rest of the budget to cover the last half year of the project is thought to be financed through an eventual continuation of the TURBOPOWER program in a third phase.

8. Personnel

In order to meet the requirements on gender distribution, potential female applicants will be encouraged to apply for the new PhD student position that will be established for the project. Currently, Monika Topel has been working on the first half of the project and she has shown her ability to meet the project's objectives excellently. The intention is to shorten the take-off of the research suggested in this proposal by being able to recruit her once her evaluation for continuation in the Licentiate Thesis is completed.

The CSP-Turbomachinery group operates a close-knit working with regular meetings to disseminate ongoing activities to all members (Seniors, PhD students and MSc. thesis students). The work is steered and monitored by a senior research leader who also will act as supervisor and project leader in this project.

For the success of the project, the active participation of key industry players in the reference group will be of vital importance. This type of collaboration has been very successful up to now in the project and shall be continued for the second part.