# Report

## Results report for the project Modulator

**NFR project N. 284231**


**Author:**

Salvatore D'Arco



**Report No:**

2022:00634 - Unrestricted


**Client(s)**:

The Research Council of Norway

SINTEF Energy Research
Postal address:
Postboks 4761 Torgarden
7465 Trondheim, Norway
Switchboard: +47 45456000
energy.research@sintef.no
Enterprise /VAT No:
NO 939 350 675 MVA

# Report

# Results report for the project Modulator

NFR project N. 284231

**KEYWORDS**
AC
MTDC
Offshore Grid

**VERSION**
1.0

**DATE**
2022-06-22

**AUTHOR(S)**
Salvatore D'Arco

**CLIENT(S)**
NFR

**CLIENT'S REFERENCE**
-

**PROJECT NO.**
502001940

**NO. OF PAGES/APPENDICES**
7

**SUMMARY**
This report summarizes the results achieved during the whole period of project activities. The document is intended for the Norwegian Research Council reporting website and is therefore organized according to the recommended guidelines.

**PREPARED BY**
Salvatore D'Arco
SIGNATURE

**CHECKED BY**
Hans Chr Bolstad
SIGNATURE

**APPROVED BY**
Knut Samdal
SIGNATURE
Knut Samdal | Jun 25, 2022 09:10 GMT+2)

**REPORT NO.**
2022:00634

**ISBN**
978-82-14-07615-8

**CLASSIFICATION**
Unrestricted

**CLASSIFICATION THIS PAGE**
Unrestricted

# Document history

| VERSION | DATE | VERSION DESCRIPTION |
|---|---|---|
| 1.0 | 2022-06-22 | Submitted version |

# Table of contents

# 1 Project objectives and background

- A brief description of the project's objectives and background.

The project Module-Aware Modeling and Assessment of Performance of Interconnected AC/MTDC Power Grids, NFR project N. 284217) is a EU-Japan research cooperation project that has been funded under the umbrella of EIG-CONCERT Japan.

The project consortium thus includes two European partners and a Japanese partner:

- Sintef Energi AS, Norway (project leader)
- Fraunhofer IEE, Germany
- Osaka Prefecture University, Japan

The project originated from the consideration that existing methods and software tools for power system analysis and optimization are mostly tailored for the conventional AC transmission system. The study of mixed configurations where both AC and MTDC grids coexists is normally conducted with time domain simulations and detailed models, but this approach can be limiting and extremely time consuming. Approaches based on small-signal or large-signal stability assessment could offer a valid alternative, but when the application was submitted were still object of research and the commercially available solutions were still in a rapid development phase.

The main objective of this project as stated in the application is to leverage on the experience of the project partners to develop a framework of bottom-up and modular modelling of interconnected AC/MTDC grids where each subsystem is treated as a pluggable building module. This can be the basis for developing state-of-the-art and highly scalable software tools for load flow analysis, small and large signal stability and optimization of interconnected AC/MTDC grids.

The project pursued the following secondary objectives:

(i) Synthesis of component models (“modules”) such as power converters and cables and definition of interfaces between them.

(ii) Implementation of scalable methods for small and large signal stability analysis.

(iii) Development of an integrated tool for optimizing the operation of interconnected AC/MTDC grids taking into account boundary conditions e.g. minimizing total power losses accounting for stability constraints.

(iv) Validation of the tools with a relevant example of an MTDC interconnected to the AC power system.

Moreover, the project aimed at strengthening the cooperation between the partners by planning for research stays, joint workshops and joint publications.

# 2 Project results

- An account of the results achieved under the project explained in the context of the project objectives.

The project successfully achieved the intended objectives in terms of scientific outcome. The plans for mobility have been followed in the first phase of the project before the pandemic. In the last years research stays have been cancelled and physical workshops and meeting replaced with their corresponding virtual counterparts.

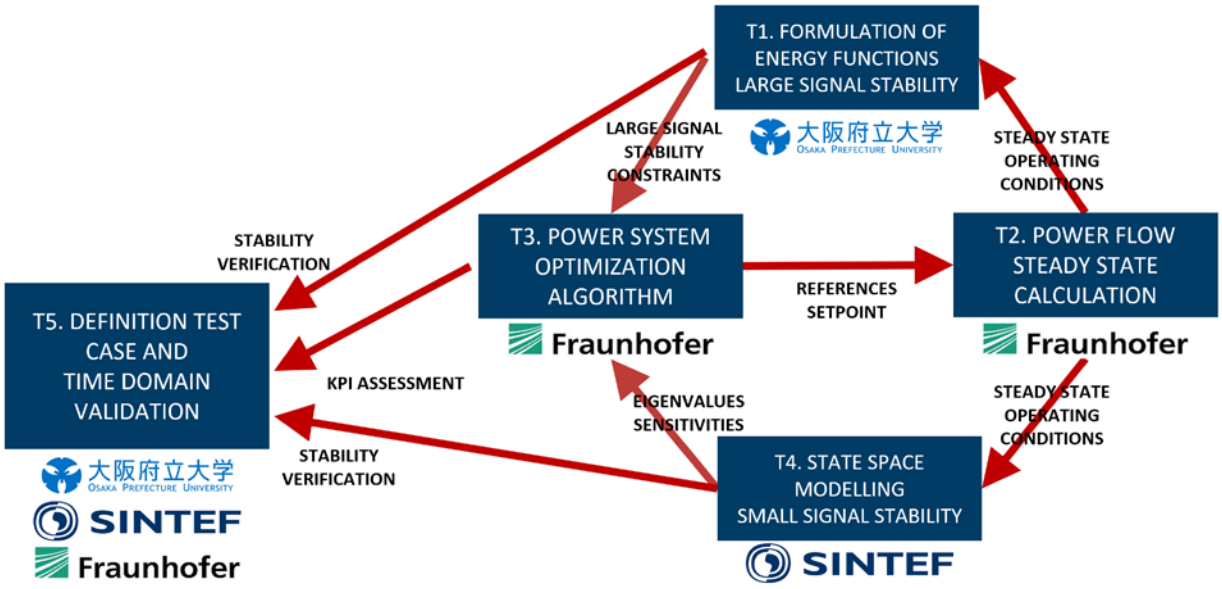
This joint research achieved three main scientific outputs. First, a new module-based technique for evaluating the control performance of AC-MTDC systems with small-signal dynamics, in which the systems’ dynamics evolve near the steady-state operation, was developed as a joint work between Norway and Germany. As second, in collaboration with Japan and Norway, a new module-based technique for modelling and analysis of AC-MTDC systems with large-signal dynamics, in which the systems’ dynamics evolve apart from a steady-state operating condition, was developed. Finally, the stability assessment was integrated in workflow for optimization leading to a stability constrained optimal power flow approach

where the control setpoints and the operational state can be optimized according to both classic static value indicators and of dynamic stability considerations with joint work in the three countries.
The project financed a Ph.D. position in Japan that was successfully defended (**Naoki Kawamoto,** Studies on Voltage and Transient Stability of Interconnected AC/Multi-terminal DC Systems). The project led to 9 scientific publications and 1 paper to be submitted after the project end. In terms of mobility, the projected hosted 3 research stay (2 in Norway and one in Germany) and 8 physical meetings. Finally, the results have been presented in an open workshop organized by the project.

# 3 Tasks

- A description of the most important R&D tasks that have been carried out and the groups that have played a key role in the project implementation.
- A brief assessment of the project?s implementation and use of resources.

The project was organized around five R&D tasks as indicated in the figure below together with the main contributors and an overview of the interactions between the tasks. These tasks are closely linked to implementation of these models and of these computational approaches in software like Matlab and AMPL.




**T1 – Large signal stability and definition of energy functions**. This task aimed at developing the models and the tools for performing large signal stability assessments on the hybrid power systems. The formulation has been based primarily on energy functions. The Osaka prefecture university has led and executed the task with minor contribution from SINTEF. The task has been also linked to the research effort for the Ph.D. candidate at Osaka Prefecture University supported by the project.
**T2 – Power flow steady state calculation**. This task provided the formulation and the implementation of the power flow for calculating the steady state operating conditions of the power system. This is necessary for initializing both the small signal and the large signal stability assessment. The activities have been conducted primarily by Fraunhofer with support from SINTEF and Osaka Prefecture University.
**T3 – Small signal stability and state space modelling**. This task focused on the small signal modelling of the modules and on the development of the framework to assemble these models in a larger system model. The modelling has been based on a state space approach and stability assessed by eigenvalue analysis.

SINTEF has carried out the activity with support from Fraunhofer especially in the definition of the interfaces with the steady state calculation and with the optimization toolbox.

**T4 – Power System Optimization Algorithm.** The task objective has been to formulate an optimization problem accounting for the input of the small and large signal stability considerations. This has been implemented in a state-of-the-art commercial software for optimization. The general outcome is the optimization of a hybrid power system with embedded stability constrains. Fraunhofer participated in the task with minor support from SINTEF.

**T5 – definition test case and time domain validation.** This task aimed at a verification of the results by time domain and in the definition of a relevant hybrid configuration and scenarios to illustrate the operation of the methods developed during the project. All partners participated almost in equal terms in conducting the task.

# 4 International cooperation

- Where there has been research stay abroad during the project period, write briefly about what it has contributed to in the project.

The Modulator project was financed under the EU-Japan cooperation program CONCERT-Japan and a significant share of the budget was allocated to mobility. In the first years of the project, researcher stays of researchers from the partners institutions have been conducted according to the plans. This included a long stay of the Ph.D. candidate from Osaka Prefecture University, a few weeks stay of two research scientists from Fraunhofer in Trondheim, and a shorter research stay of three SINTEF scientists in Germany. Additionally, the partners have been participating in joint workshops and in a few physical meetings in all the three countries involved in the project. The main contribution of these research stays and mobility have been the possibility to better identify a relevant scenario for the validation and in the definition of the interfaces between the code implemented by the individual institutions. Moreover, the joint discussions facilitated to identify a practical workflow for executing the code developed. For example, the constrained optimization in T4 required the exchange of data about eigenvalue position and their sensitivity at each iteration. This required a rather tight cooperation between the code development at SINTEF and in Fraunhofer.

After the pandemic the original plans for mobility have been disrupted being not feasible international travel until the end of the project. Since the definition of the interfaces to connect the code developed has been carried out in the beginning of the project, the impact was limited only in the validation part. However, the physical exchanges were replaced by more frequent online meeting to compensate.

# 5 Project impact

- A description of the anticipated significance/benefits of the results (e.g. for the research field, for development of expertise, for trade and industry and society as a whole).

Hybrid ac/dc power system are presently even more relevant that when the application was submitted especially due to the ambitious targets for integration of large-scale renewables in the power systems. It is indeed rather likely that future transmission power systems will have a combination of the conventional AC transmission with HVDC transmission. A main deliverable of the project has been the development of code and a workflow for performing stability assessments and optimization for interconnected AC and MTDC grids. These tools and the general ideas behind their development has been published in normal publication channels and presented in open workshops. This leads to the possibly that these approaches and part of the code developed will be more refined by the three partners or by other institutions to be operated by a larger user group. The project developed software tools that will be further applied by the project partners in future projects. For example, the small signal analysis framework developed at SINTEF will be further used also in the FME Northwind in application for offshore grids.

An additional aspect to consider is that the three project participants brought different individual expertise areas to the project and that this facilitated the learning of new methods and software tools from each

partner. Finally, one Ph.D. position was financed in Japan and the candidate is presently working in R&D for a large Japanese company.

# 6 Dissemination and future plans

- A description of the plans for disseminating and utilising the results.
- A description of the results that are expected to be finalised after the completion of the project.

The project relied on the conventional publication channels for the dissemination of results with focus on technical conferences and journals. 9 publications have been published and another will be submitted after the project ending. Moreover, a digital open workshop has been held in the last months of the project with a good participation of external attendees to present results from the projects and to establish a stronger dialogue with industry operating in the sector.

It is expected that the partners will further develop the results from the project in national and international research initiatives. For example, there are plans for both the group at SINTEF and in Fraunhofer to jointly participate to EU calls.

SINTEF aims to further apply the results of the project in the FME Northwind and in the Ocean Grid Research project. The long-term plan is to be able to acquire the necessary competence on stability assessment, system optimization and modelling of hybrid ac/dc system to be able to support the Norwegian TSO and the offshore operators in developing an integrated power system with an offshore grid in Norwegian water.