HydroCen
NORWEGIAN RESEARCH CENTRE FOR HYDROPOWER TECHNOLOGY

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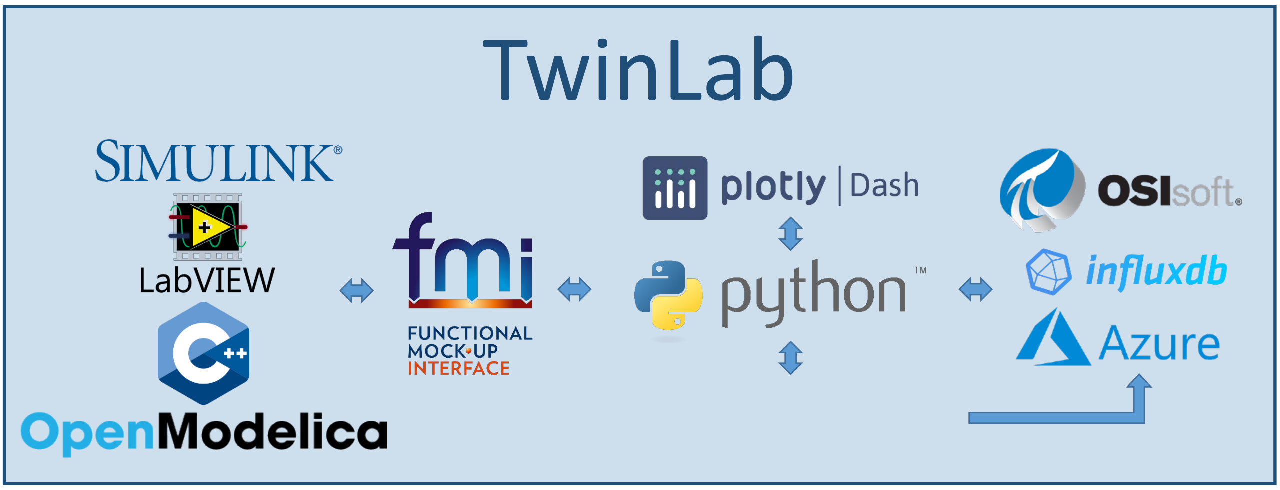
HydroCen Report nr. 27

TwinLab

Digital Twin Laboratory for Hydropower

Hans Ivar Skjelbred, Bjørnar Fjelldal, Bjørn Winther Solemslie, Ingrid Vilberg



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HydroCen

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The research areas include:

- Hydropower structures
- Turbine and generators
- Market and services
- Environmental design

The Norwegian University of Science and Technology (NTNU) is the host institution and is the main research partner together with SINTEF Energy Research and the Norwegian Institute for Nature Research (NINA).

HydroCen has about 50 national and international partners from industry, R&D institutes and universities.

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The FME-centres can be established for a maximum period of eight years HydroCen was established in 2016.

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Abstract

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This report summarizes the results from the TwinLab project in 2021. The project was funded by HydroCen OpenCalls and is a multidisciplinary project with partners from all work packages in HydroCen.

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Content

1 Introduction

This report summarizes the results from the TwinLab project in 2021. The project was funded by HydroCen OpenCalls and is a multidisciplinary project with partners from all work packages in HydroCen.

The overall goal of the project was to establish a digital laboratory where researchers, industry partners and students/PhDs can collaborate openly on methods and data for digital twins of hydropower plants and waterways and machine learning applications. By choosing open and accessible solutions, the development can be accelerated with increased co-creation and cooperation between researchers and industry partners both nationally and internationally.

The hydropower industry is entering a phase of digital transformation, both in terms of monitoring, modelling and big data analytics. Being able to utilize data to ensure that the future requirements for supply, flexibility and efficient operation can be met is a prerequisite for the success of this transformation.

The TwinLab project was initiated to streamline the process of data utilization and development of digital twins and machine learning applications. TwinLab has established a framework, or workbench, for integrating measurement data (real time or historical) and different models of hydropower components. The main data infrastructure is based on industry standards, which makes TwinLab a link between research results, simulation models, industry demonstration, and implementation for digitalization projects.

Among the main activities in TwinLab in 2021 was to establish the digital infrastructure for a framework to implement both measurement data (real-time or historical) and different models of hydropower components. We have emphasized coordinating with ongoing relevant projects and initiatives within digitalization of hydropower, for instance the SmartKraft project lead by The Norwegian Smartgrid Centre, the RDS-Hydro standardisation initiative from Statkraft and Energi Norge, the GenericLife discussion group in HydroCen and several initiatives based on the MoU between the Norwegian Ministry of Petroleum and Energy and US Department of Energy.

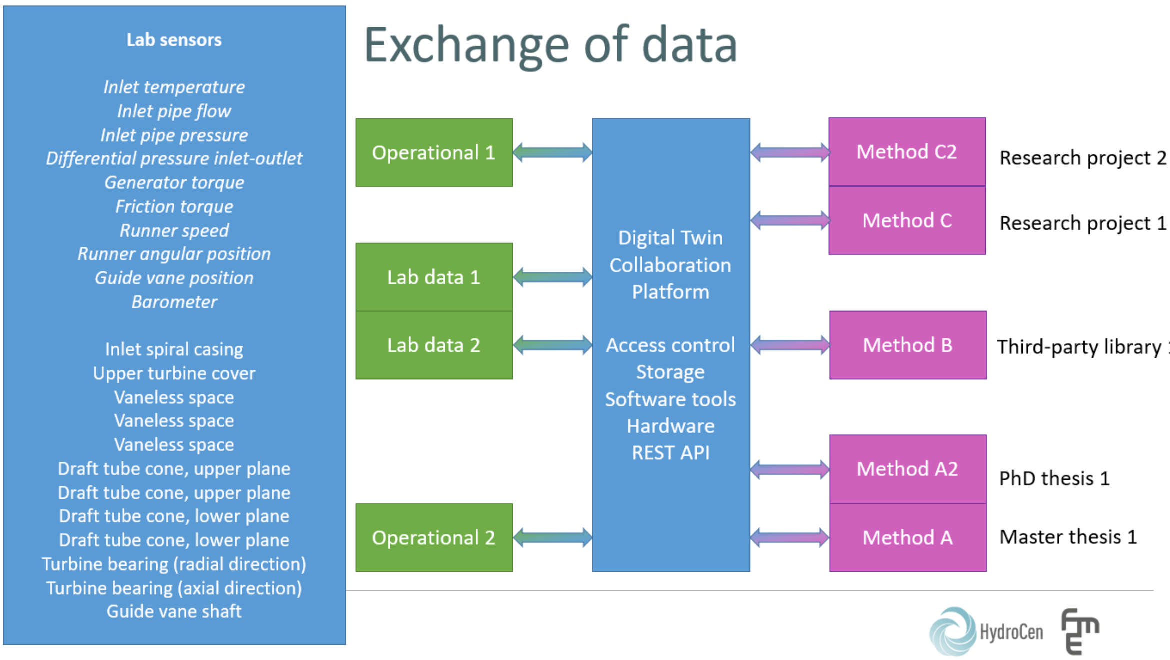

Figure 1: TwinLab Digital Collaboration platform

2 TwinLab platform architecture

This section describes the chosen solutions and software for the digital platform TwinLab. Open and accessible solutions have been preferred. The main architecture is based on industry standards.

2.1 Set-up

TwinLab is built to be robust and secure while still being accessible for all parties involved in the project. The Microsoft Azure platform with designated servers located in Norway is chosen as the hosting provider. It is highly scalable and flexible with dynamic deployments and management of hardware and software through the use of Kubernetes, which means the experience will be the same regardless of the number of users. Kubernetes goes hand in hand with Docker, the preferred way of serving applications and keeping them up to date. Jupyter Notebooks and Jupyterlab has become the “de facto” platform used by data scientists and users of models in general, and in this stack, we are utilizing it to its full potential.

Figure 2: TwinLab infrastructure and software stack

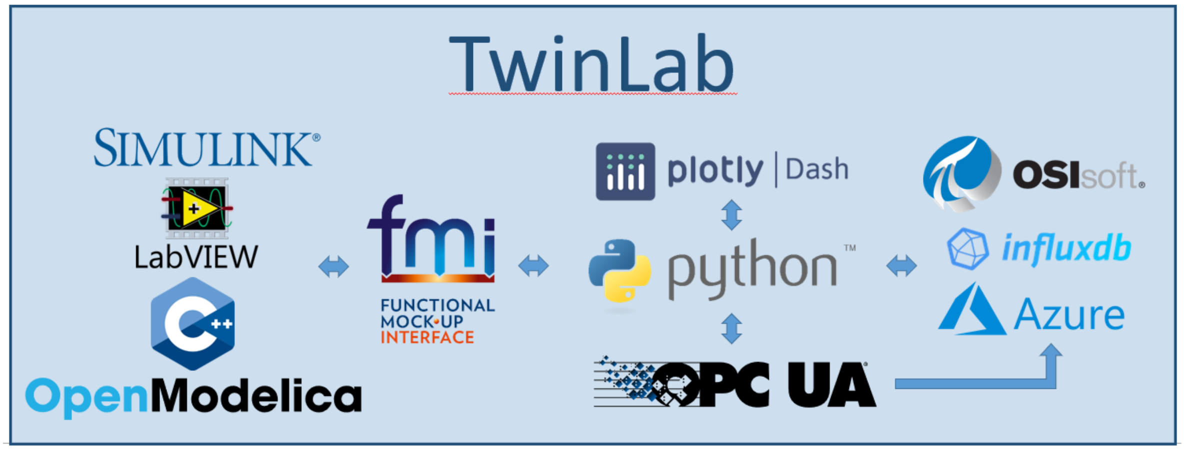

Figure 3: TwinLab building blocks

2.2 Access control

External users can get access to TwinLab after being registered with a username and password. When logging on to TwinLab, the user will get access to a dedicated virtual computer. This is dynamically scalable, as a new virtual computer is set up for each user. The user can work privately on this computer and develop methods etc and actively publish the methods to a common library to share with other users.

The Kubernetes deployment of JupyterHub is used to handle log-in and access to different images and resources in the digital lab. Documentation and examples are attached to open repository on GitHub, thus meaning interactive content can be synched and ready to be executed at the TwinLab at any time.

2.3 Storage

Every user will be granted a secure and personal storage space linked to their TwinLab user account. The default storage quota is set to 10GB but can be modified based on needs.

2.4 Software

Through Docker we are providing a pre-configured and pre-compiled environment containing relevant tools, models and packages available by default. However, since every user are granted their own personal storage space and their own individual container instance, any software that can run on Linux (Ubuntu 20.04) can be added and installed by the user. We also gladly accept suggestions on tools that should be available in the initial configuration of TwinLab so that it benefits all users without any additional configuration.

2.5 Standards and APIs

The vast diversity of data sources following different conventions and approaches in terms of syntaxes and semantics constitutes a major challenge towards utilizing the possibilities of digitalization. To mitigate this, ontologies implemented using W3C recommendations for semantic technologies are becoming instrumental to facilitate data exchange and improve data interoperability (Guarino et al. 2009, W3 2022). The hydropower industry is also developing a version of IEC/ISO 81346 specifically for hydropower (RDS Hydro) (Balslev 2019) and assessing the integration with other standards such as IEC 61850, for the description of signals and IEC 61360 for the description of properties of system components (IEC 61850 2022, IEC 61360 2017).

TwinLab will use the latest developments for standards for data interoperability, following the RDS Hydro naming system.

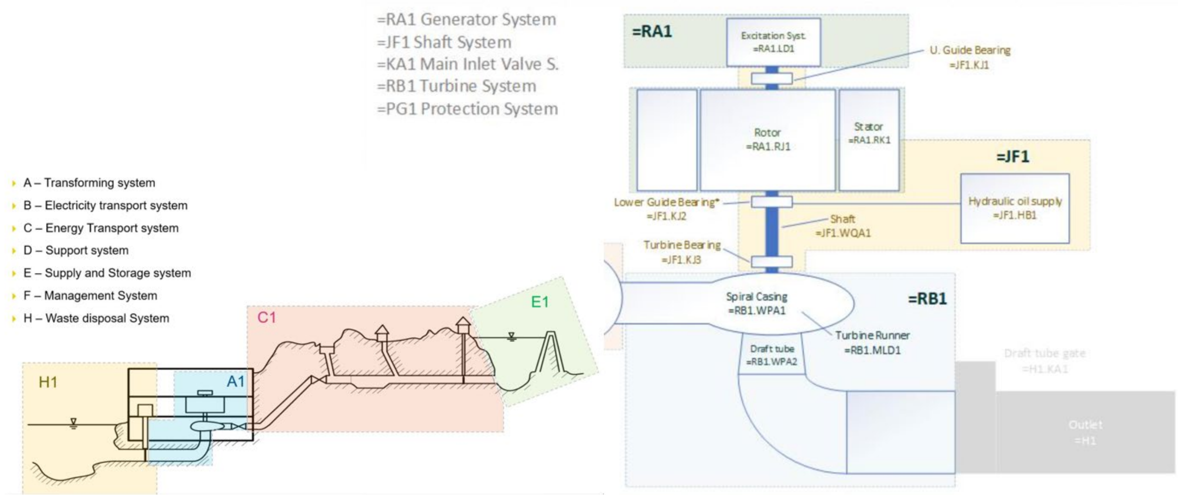

Figure 4: Following the RDS Hydro standard for signal names

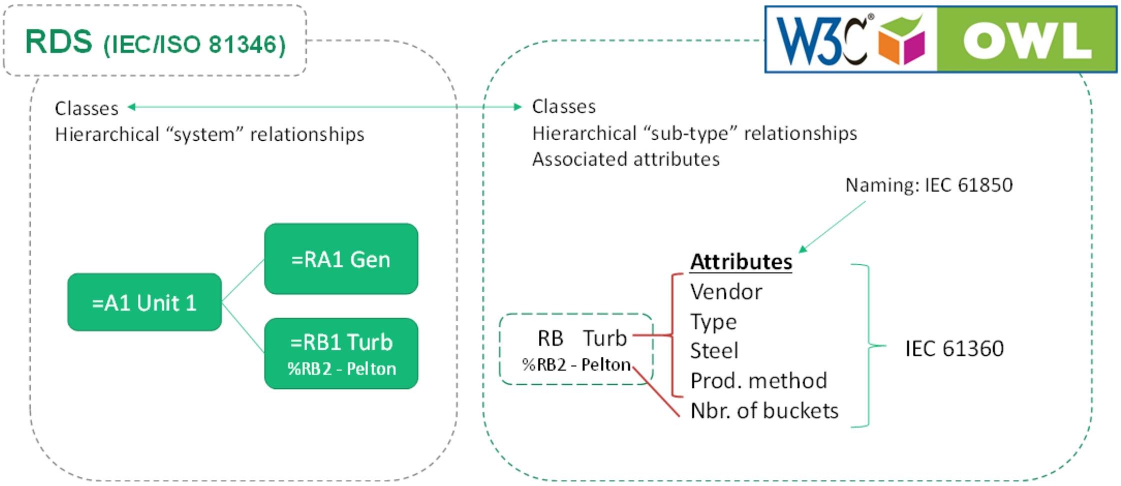

Figure 5: Overview of Asset Management Ontology.

3 Test cases

3.1 Real-time data from the Waterpower lab

In order to test solutions for working with real-time data in TwinLab, a solution for receiving measurement data from the Waterpower Laboratory at NTNU was set up. The lab PC is located on a closed NTNU network. A dedicated fibre connection was set up from the Waterpower Lab to the SINTEF network. The lab PC was equipped with a second network card to be able to publish measurement data from the logging program on an OPC UA server. An OPC UA client was then set up on the SINTEF network to collect data published the OPC UA server. Pushing data to TwinLab while still controlling access to the datastream was done by the use of Azure Event Hubs. This also enables live data sharing with parties external to TwinLab, such as US DoE and its National Laboratories.

The logging program in the Waterpower Laboratory is delivered by FDB and is based on the same solutions as the HydroCord monitoring system, which is installed at Grunnåi powerplant (FDB 2022).

3.2 Testing FMU/FMI format

Functional Mock-up Interface (FMI) is an open standard for exchanging dynamical simulation models between different tools. A Functional Mock-up Unit (FMU) is a file that contains a simulation model that follows the FMI standard.

Figure 6: Functional Mock-up Interface

In TwinLab, the FMI standard has been tested with a test case from Grunnåi. Tests revolved around the calculation of an estimated hydraulic efficiency based on the measurements available from Grunnåi. The calculations are based on the standard efficiency calculation seen in Equation 1 to 5.

$$\eta_h = \frac{P_m}{P_{hyd}} \tag{1}$$

$$P_{hyd} = \rho \cdot g \cdot Q \cdot H_e \tag{2}$$

$$P_m = P_g \cdot \eta_g \tag{3}$$

$$H_e = \frac{P_1}{\rho \cdot g} + \frac{v_1^2}{2 \cdot g} \quad (4)$$

$$v_1 = \frac{Q}{A_1} \quad (5)$$

The FMU for efficiency calculations was written based on the above equations, and the calculations were performed one time step at a time.
The tests were performed on a 30s long time series gathered from the Grunnåi power plant. The data was presented to the FMU one point at a time without any limiter on the time usage in order to investigate the feasibility of real time operation of the FMU.
The FMU was written in a separate python script and compiled using the PythonFMU module and the simulation of the FMU was conducted with the pyFMI module. The step calculations can be seen in Figure 7. The variables within the FMU were defined as a combination of *output, input and local*.

```
def do_step(self, current_time, step_size):

        self.A1 = math.pi * (self.D1/2)**2
        self.v = self.Q / self.A1
        self.He = self.P1 / (self.density * self.gravity) + 1 / (2 * self.
↪gravity) * (self.v)**2

        self.power_h = self.density * self.gravity * self.Q * self.He
        self.power_m = self.power_g / self.eta_g

        self.efficiency = self.power_m / self.power_h

        return True
```

Figure 7: Calculations of a step within the FMU

Execution of the FMU resulted in an average time spent per calculation in the order of 3ms, and Figure 8 which includes the calculation time for all 300 steps in the time series.

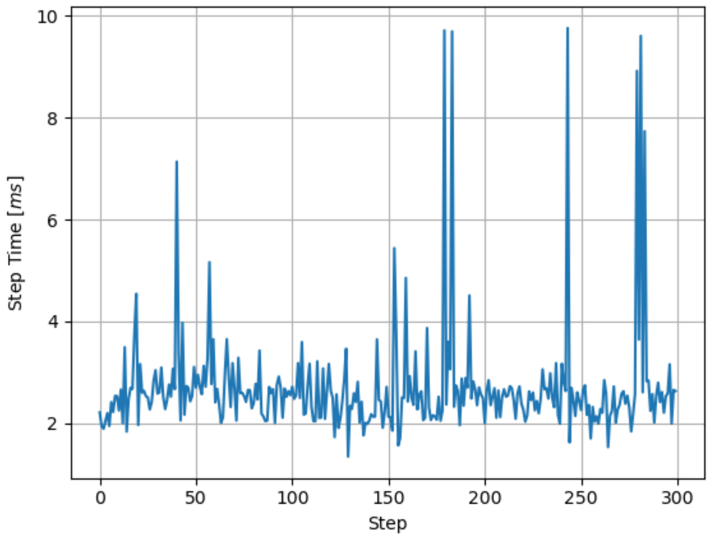

Figure 8: Time usage per calculation of efficiency

The input used in the calculations can be seen in Figure 9 where the measured Flow, Pressure, Power and Needle position are shown.

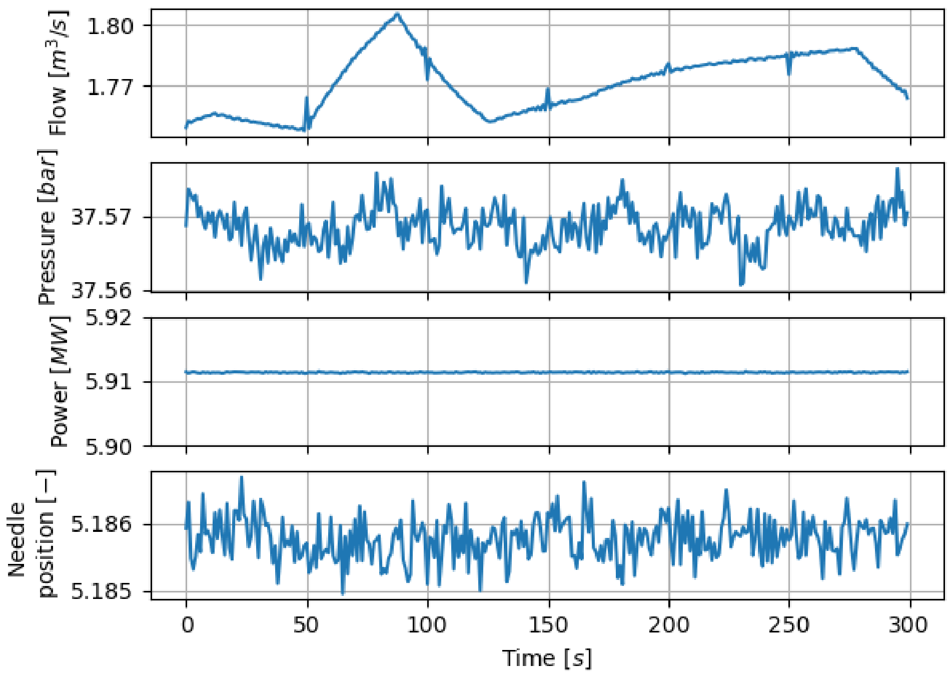

Figure 9: Input to FMU from time series

As seen in the Figure 9 some discrepancies in the measurements exist, mainly the independent behaviour of the Flow relative to the Needle position, in addition to the close to constant Power. The effects of these discrepancies are also visible in the output from the FMU seen in Figure 10 where the Hydraulic Power (P_{hyd}) exhibits a large change while the Mechanical Power (P_{mech}) remains near constant for the whole period.

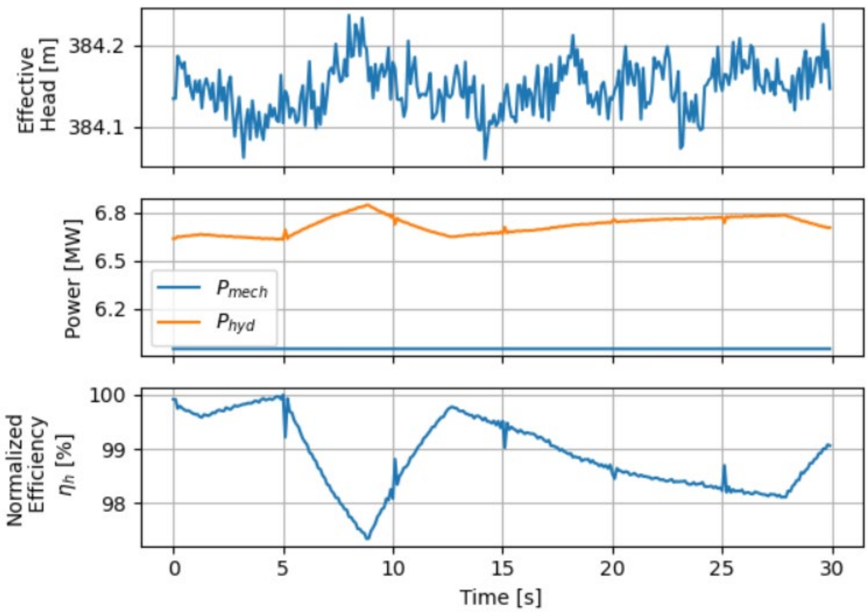

Figure 10: FMU Output

Viewing the efficiency calculated by the FMU in colour-based Hill-diagram, seen in Figure 11, the discrepancies become even more evident, where the inverse relation between the flow and efficiency is evident.

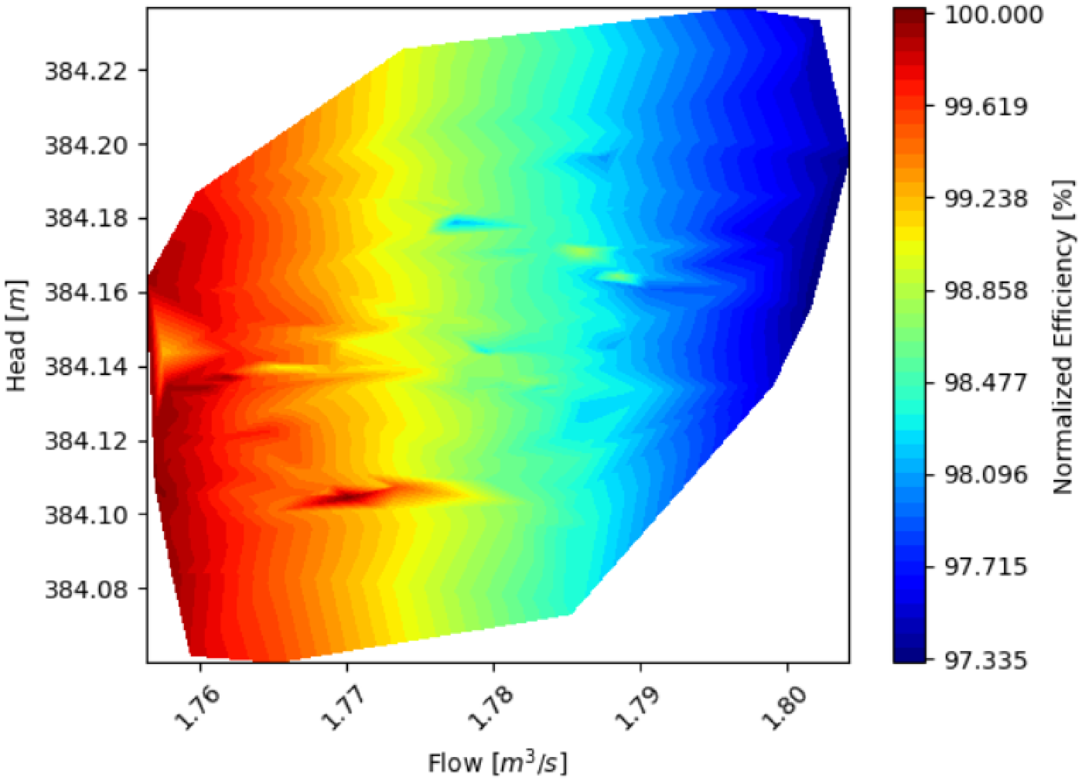

Figure 11: Efficiency calculated with FMU

The relationship between Needle opening and Flow can also be seen to be non-correlated in Figure 12.

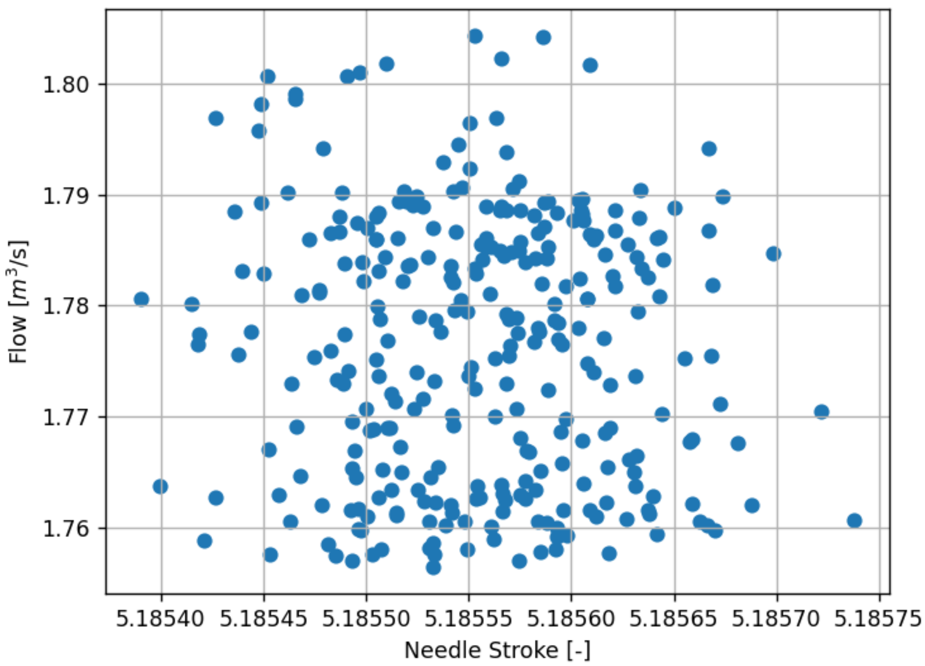

Figure 12: Flow relative to Needle position

Generally, the utilization of an FMU to calculate an efficiency estimate in a real time environment shows promise but can be seen to be highly dependent on the data quality and internal uniformity in update rate. The actual calculation of the efficiency requires in the order of 3ms to execute, and hence a logging frequency of 1Hz would be possible to process real-time. The creation of an FMU for efficiency estimates is also found to be easy, and the standard shows great promise for further use.

3.3 Hydraulic models in TwinLab

Several hydraulic models were reviewed for the possibility of integration in TwinLab, in order to establish a proof-of-concept for digital twins of rivers. The open-source software TELEMAC was found to be most promising for this application. It runs on Linux and has a Python interface.

TELEMAC-MASCARET is an integrated suite of solvers for use in the field of free-surface flow. Having been used in the context of many studies throughout the world, it has become one of the major standards in its field (Open TELEMAC 2022). This will be tested during the next phases of TwinLab.

4 Conclusion

Through the project TwinLab has been established as an open digitalization platform based on industry standards. The project will be continued with more test cases and applications implemented in TwinLab. The main activities in the following TwinLab II project will be:

- Implementing research results and operational data from HydroCen and partners
- Real-time measurement data from powerplants
- Francis shark bite detection with AI
- Hydraulic models for river ecosystems

Several digitalization activities are going in parallel and the activities in TwinLab need to be coordinated and aligned with the ongoing projects and initiatives. Some of these have already confirmed that they will be using Twinlab in their work and we expect all of these to have interaction with TwinLab during the next year.

- Digitalization activities in USA through the agreement with DoE
- Collaboration with Skagerak Energi Vattenfall for implementing real-time data from powerplants
- NTNU Bachelor program for Electrification and Digitalization
- SmartKraft pilot projects
- USN projects for Grunnåi digital twin
- AssetLife and GenericLife project initiatives

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