Applying Design of Experiments Method for the Verification of a Hydropower System

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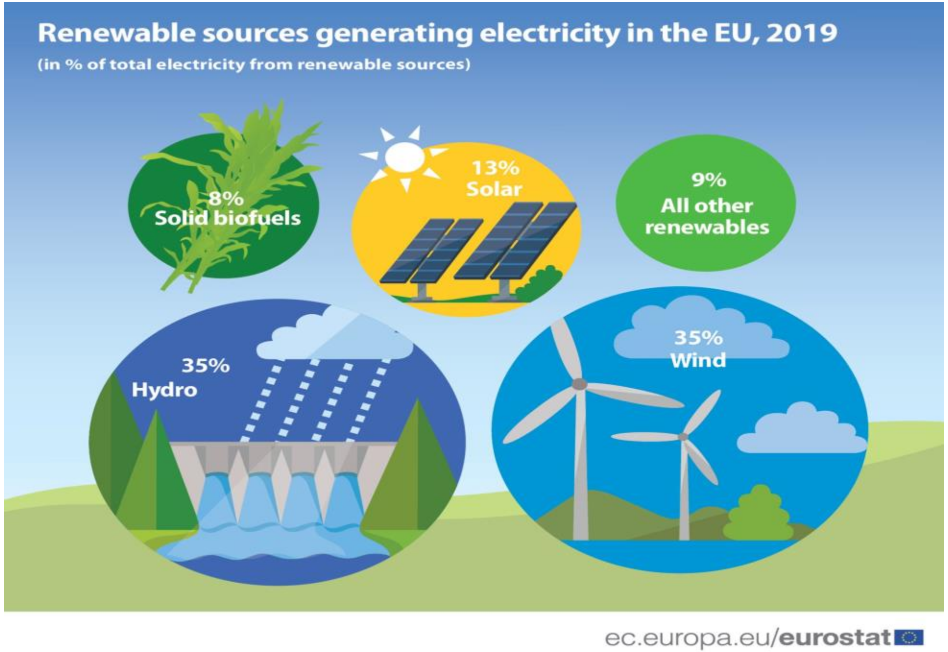
Outline

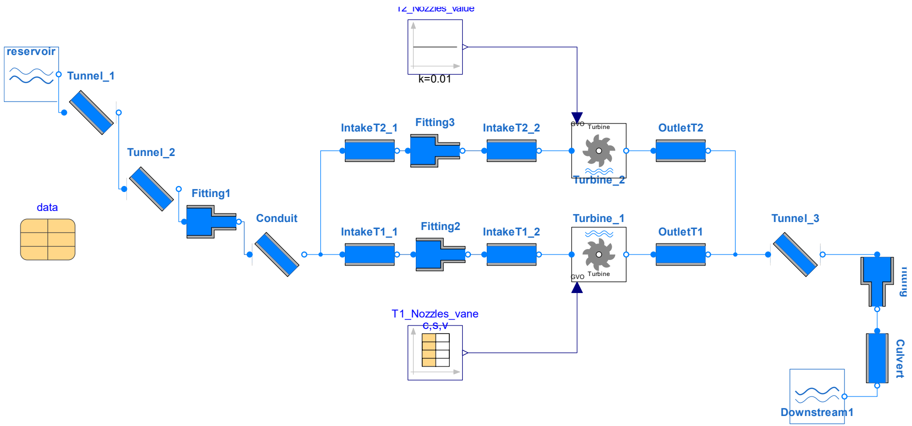
1. Introduction

- In 2019, wind and hydropower accounted for the total electricity generated from renewable sources (35% each) [1].
- There are many hydropower plant simulation models.

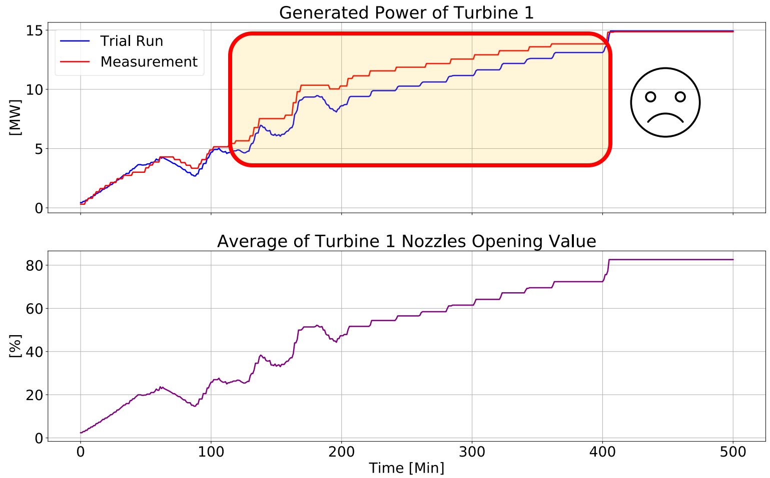


[1] Wind and water provide most renewable electricity - Products Eurostat News - Eurostat (europa.eu)

1. Introduction



Example of simple simulation model of hydropower plant



Trial run

The simulation model needs to be verified

Design of Experiments Method

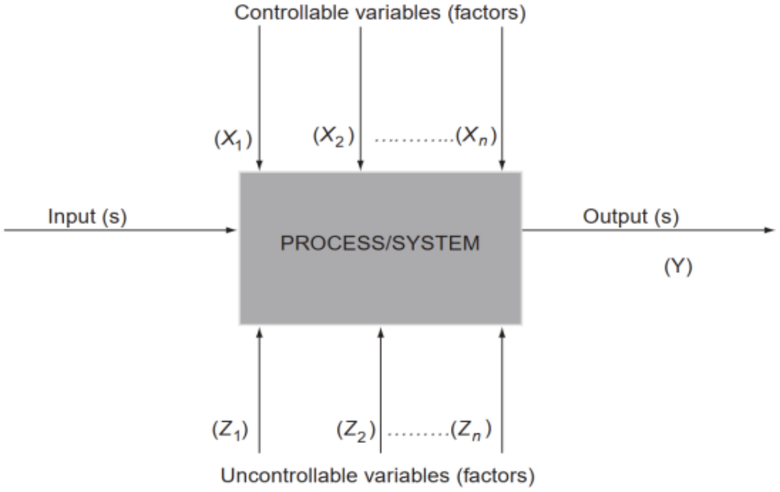
2. Design of Experiments (DoE)

Design of Experiments (DoE) is a systematic, efficient methodology that can be used for:

- System Optimization
- Transfer function
- Comparison

Statistical background of DoE:

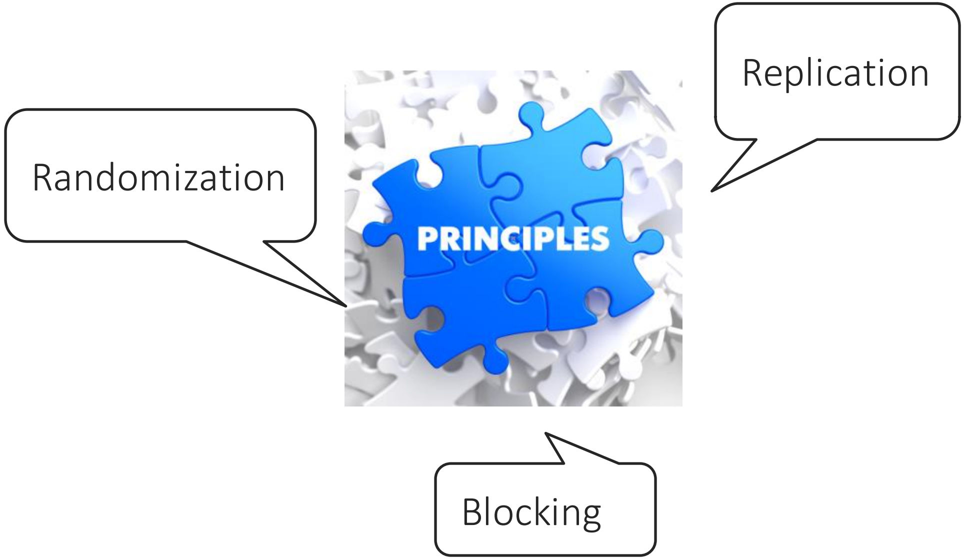
$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_i x_i$$



2. Design of Experiments (DoE)

Design of Experiments (DoE) has three main principles:

- Randomization
- Replication
- Blocking



2. Design of Experiments (DoE)

Key steps of DoE:

1. Objective recognition
2. Selection of response
3. Selection of process variables
4. Performing the experiment
5. Interpreting experimental results and conclusions

3. Modelling Grunnåi Power Plant

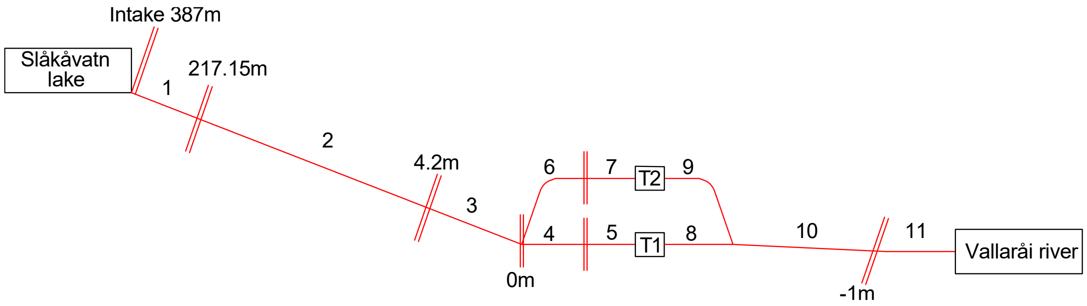
Location

Grunnåi Power Plant is located in Seljord municipality, Telemark, Norway [1]

Dam of the hydropower plant

[1] www.skagerakkraft.no/grunnai_2/

3. Modelling Grunnåi Power Plant



Overview of hydropower plant structure

The waterway geometry

Elements	*Index*	*Length [m]*	*Diameter [m]*
Tunnel_1	1	203	5.8
Tunnel_2	2	1455	5.8
Conduit	3	30	1.2
IntakeT1_1	4	20	1.2
IntakeT1_2	5	1.5	0.8
IntakeT2_1	6	25	1.2
IntakeT2_2	7	1.5	0.6
Outlet T1	8	1.5	0.8
Outlet T2	9	1.5	0.6
Tunnel_3	10	460	3
Culvert	11	58	2

3. Modelling Grunnåi Power Plant

Turbine 1 (T1) Pelton type

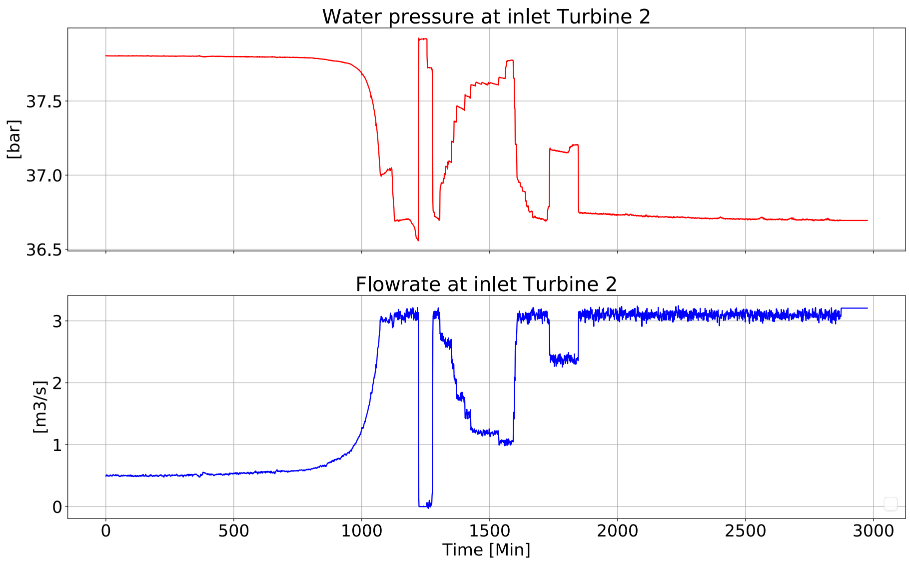
Property	Value
Number of nozzles	5
Nominal head	385 [m]
Nominal flowrate	4.42 [m^3/s]
Nominal power	15 MW
Turbine efficiency	90%

Turbine 2 (T2) Pelton type

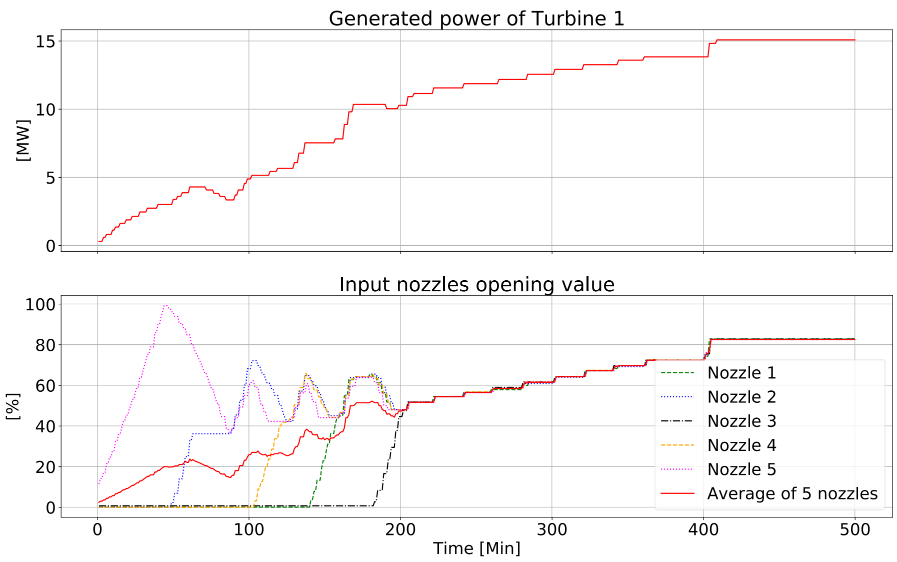
Property	Value
Number of nozzles	5
Nominal head	389 [m]
Nominal flowrate	3.08 [m^3/s]
Nominal power	10.76 MW
Turbine efficiency	91%

3. Modelling Grunnåi Power Plant

Measurement data

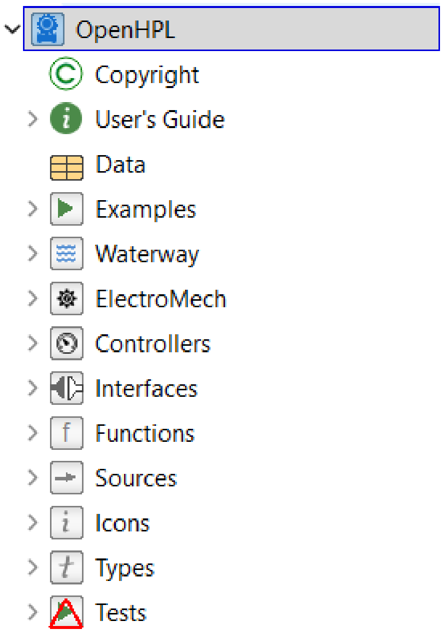


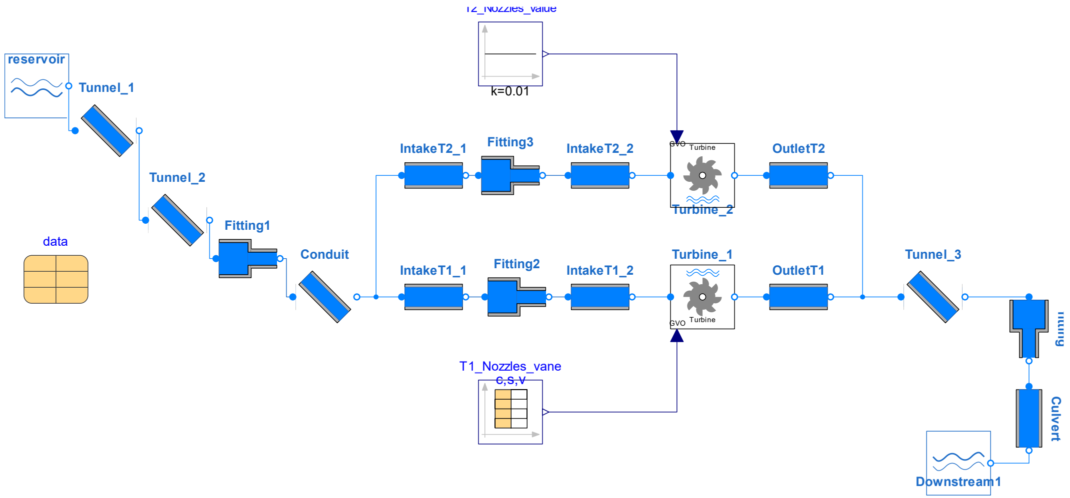
Dataset 1



Dataset 2

3. Modelling Grunnåi Power Plant





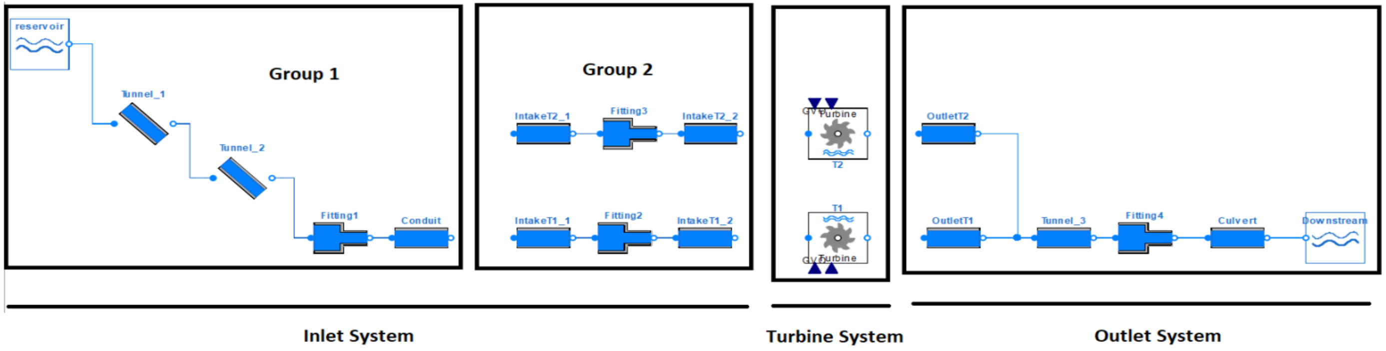
The simulation model of hydropower is created by using OpenHPL (an open-source hydropower library consisting of hydropower units that are modelled in Modelica)

4. Applying DoE for Model Verification

Randomization

Replication

Blocking



Experiment subject

Experiments

Experiment: The following are objectives of experiment:

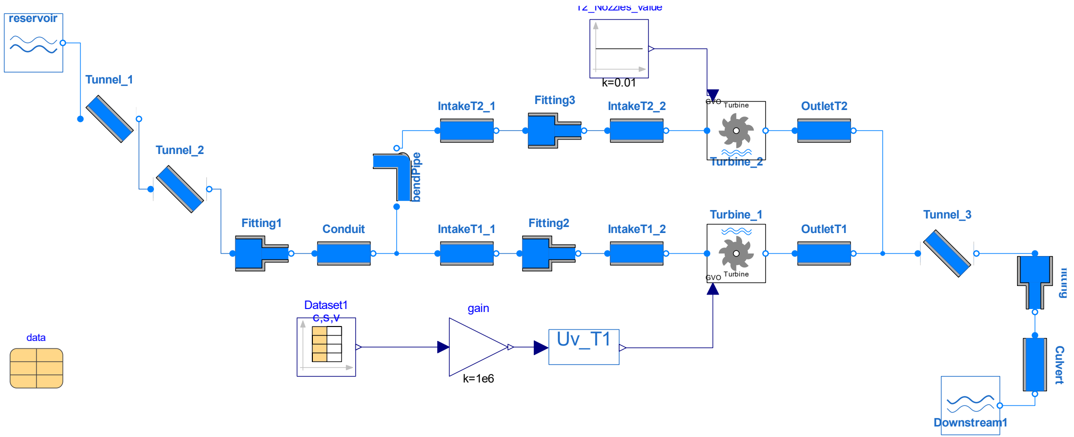
- Develop a mathematical model which relates generated power of turbine and the input signal value of turbine block, the main vane opening value.
- Verify the mathematical model built.

Input:

- Main vane opening value of turbines.

Output:

- Generated power of turbines.



Experiments

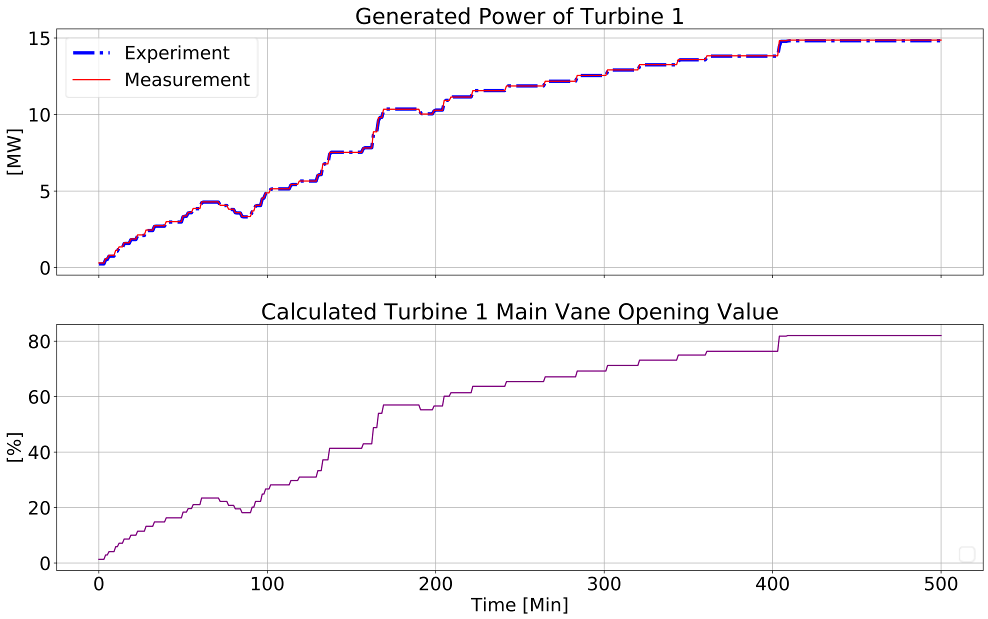
Mathematical models

T1: $y = -0.0036 + 5.54 \times 10^{-8}x$

T2: $y = -0.0049 + 9.48 \times 10^{-8}x$

x: Generated power (W)

y: Main vane opening value (%)



Conclusions

1. DoE is a distinct method in order to simplify the optimal solution for simulation model design due to the difficulties in the process of setting up simulation model.
2. Under available measurement data as prerequisites, each portion of the model was experimental in turn to verify and optimize the design as well as eliminate noise factors.
3. The results of the series of experiment and the completed simulation model will be used for research and further study cases.
4. This paper contributed a simple solution to verify and optimize various type of simulation models in many complex systems with complicated chain of parts.

Thank you for your attention!

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