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Digital Twin for Hydropower System Object Modeling

Alder Dam - FY2023

February 2023

Hongfei Hou
Osman Ahmed

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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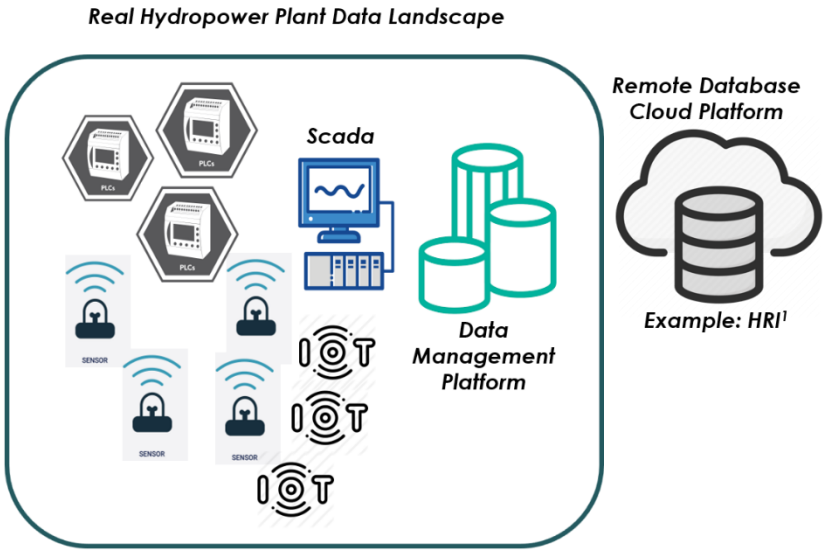
Abstract

Hydropower is the world's largest source of renewable electricity, and hydropower plants are distributed all over the world. Typical major components of a hydropower plant are the governor, excitation, generator, thrust bearing, hydraulic turbine, transformer, the main lead, metering and control, tailwater depression, and dissolved oxygen. For each component, various measures are taken. The measurements are acquired by various heterogeneous systems, including standalone sensors, programmable logic controllers (PLC), Supervisory control and data acquisition (SCADA), Internet of Things (IoT), and data acquisition and integration platforms such as OSI/PI. The measured data are often archived within the plant by a data management platform, and many institutions have cloud-based archive systems, such as Hydropower Research Institution (HRI), U.S. Army Corps of Engineers (USACE), and Columbia River Data Access in Real Time (DART).

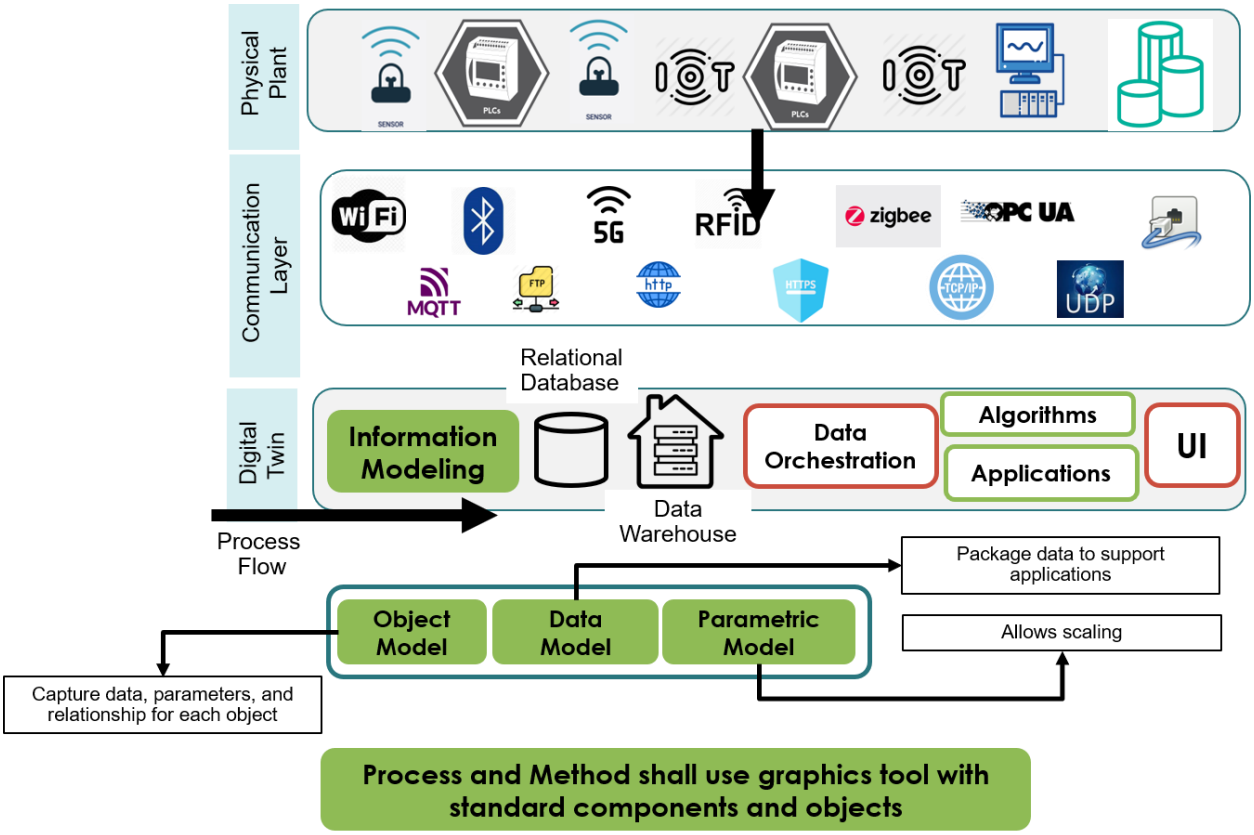


Object Modeling is a general framework for designing information systems. It focuses on objects, the actions they perform, and the messages they send to one another to cause those actions to be taken. The major differences among object modeling, network modeling, data modeling, and process modeling are that in the first we focus on the actions in response to information, objects which form the system, the actions they perform, and how they pass information to one another, while in the second we concentrate on where, when and how much information is moved, while in the third we focus on what information is moved and where it is moved, while in the last we focus on how it is moved and when it is moved.

Object modeling was developed basically as a method to develop object-oriented systems and to support object-oriented programming. It describes the static structure of the system. The object Modeling Technique is easy to draw and use. That is why we choose object modeling to connect physical hydropower plants to Digital Twin. It recognizes the objects and the relationship between them. It identifies the attributes and functions of each class. Dynamic Modeling: It explains how objects respond to events. Functional Modeling indicates the processes executed in an object and how data changes when it moves to objects. It has been used in many applications like telecommunication, transportation, etc.

Summary

Digital Twin faces several challenges. The first one is to obtain all real-time measured data, which is critical in decision-making for a market demanding changes or events handling. Real-time monitoring is one of the main features of Digital Twin, and it can efficiently prevent disasters and minimize potential damages. The second one is to create a database that captures the relationship between data and knowledge of how data is physically distributed. In other words, it is challenging to create a database that knows the physical topology and hierarchical distribution of data.



However, current practices show that hydropower data is located everywhere and in various formats. Data sources are heterogeneous and distributed. They can range from a single sensor or new IoT platform to a data management platform. For Digital Twin, data have to be real-time, and data needs are extensive. To well present physical hydropower plants, various types of data will be acquired, including weather data, meta-data, topological data, physical dimensional data, camera data for 3D visualization, operational records, location data, etc.

That is why we propose Digital Twin Hydropower System Open Platform Framework (DTHS-OPF). The goals of DTHS-OPF will be open system architecture, open sourcing, open data integration platform, open interoperability, and easy custom configuration using a user graphical interface with object modeling and parametric modeling. DTHS-OPF is expected to be easy to configure, straightforward to use, and affordable to own and operate. It will be scalable to meet the market demand and be flexible and adaptable to any new technologies.

Acknowledgments

The study was funded by the U.S. Department of Energy Water Power Technologies Office.

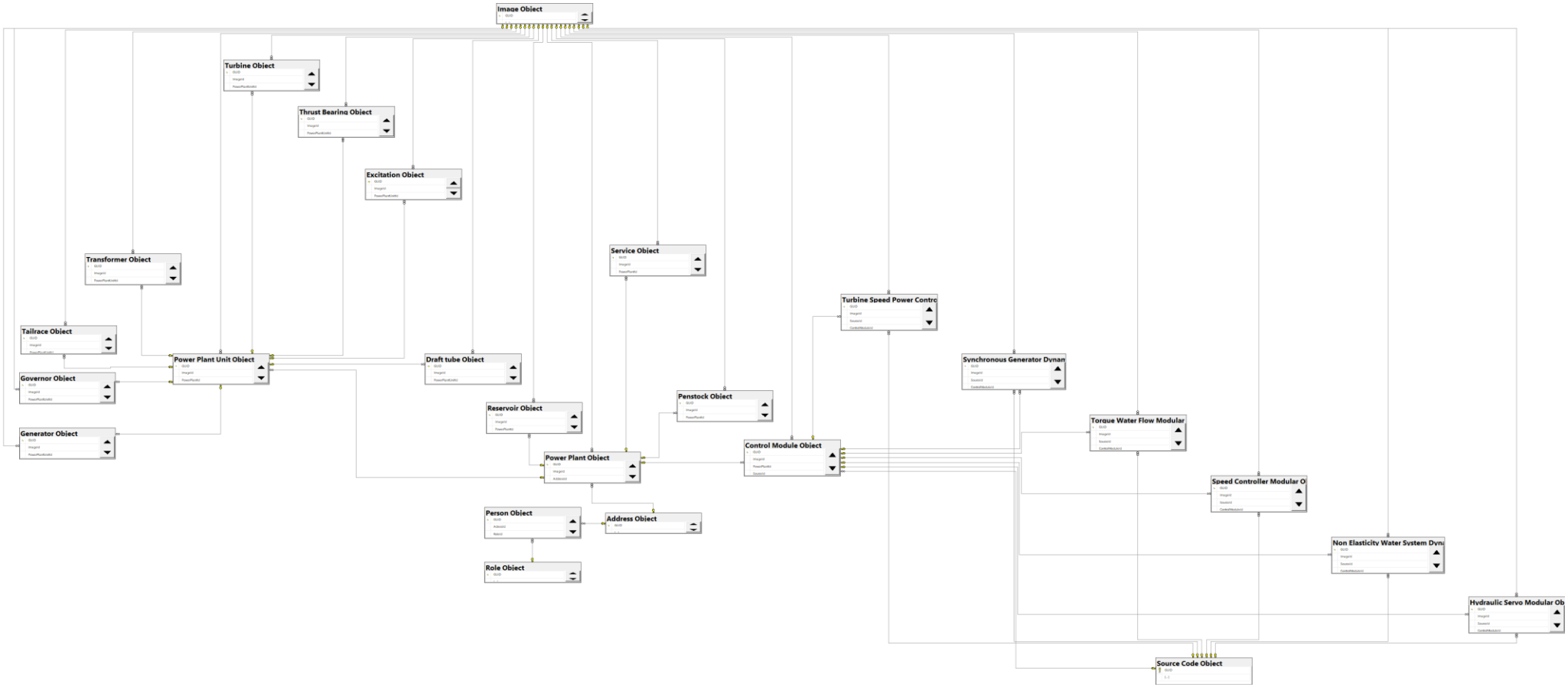
Acronyms and Abbreviations

2D	2 dimensional
3D	3 dimensional
KCFS	Kilo cubic feet per second
mm	Millimeter
Mils	Thousandths of an inch
m/s	Meter per second
MW	Megawatts
Nm	Feet/pound
RPM	Revolution per minute

Contents

1.0 Diagram

The relationships among the objects are shown in the following diagram.



2.0 Objects

Those objects contain physical components of the hydropower plants, such as an address, dimensions, and so on, and the virtual components, such as service logs, control modules, and so on.

2.1 Address object

Address objects represent the location information of the associated entities, and can be associated with multiple person-objects and hydropower plant objects.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	Office/Dam
Street	Street number, street name
City	City of the location of the associated object.
State/Province	State/province of the location of the associated object.
Zip code	Zip code of the location of the associated object.
Country	Country of the location of the associated object.
Website	Website of the associated object.
Phone	The phone number of the associated object.
Fax	The fax number of the associated object.

2.2 Role object

Role objects group together one or more privileges that can be assigned to users, for example, manager, technician, operators, and so on,

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	Name of the roles.
Description	Describing the privileges and duties of the role.

2.3 Person object

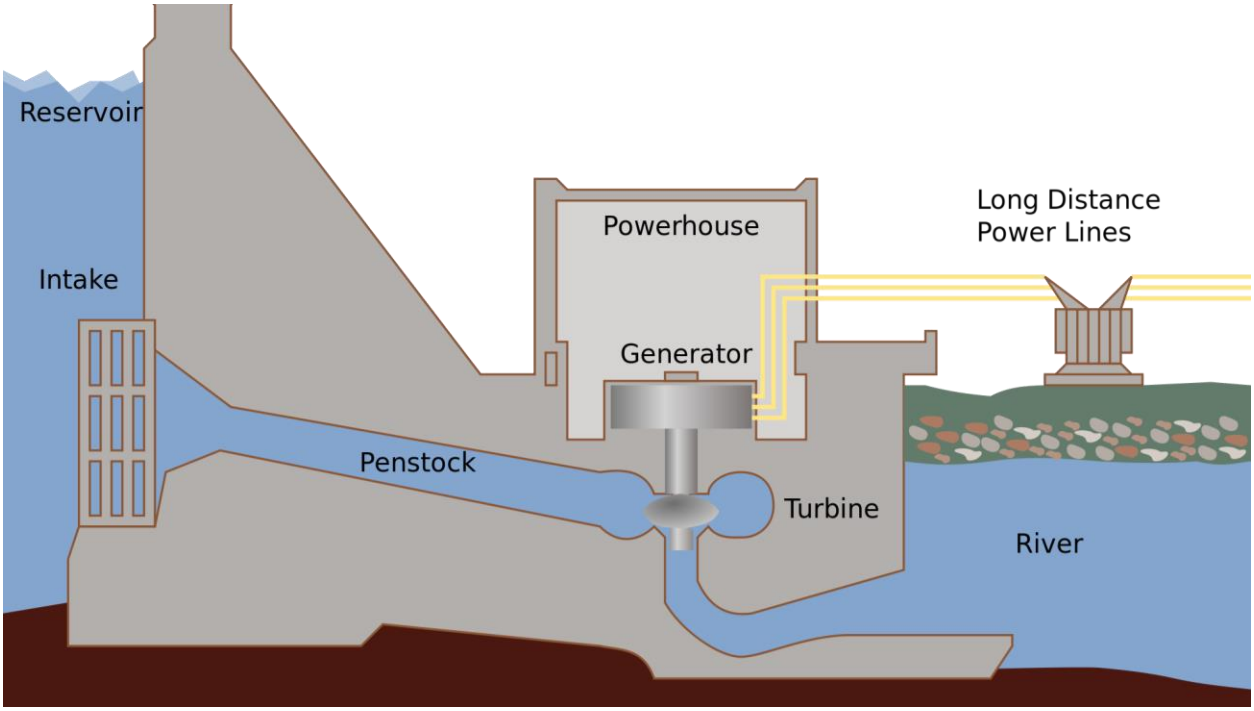
Person objects represent the personal information of the managers, operators, technicians, and so on for the associated hydropower plants.

Attribute	Note
Unique Id	Prefer to be a GUID.
First Name	The first name of the associated person.
Last Name	The last name of the associated person.
Role Ids	Each person could have more than one role. The relationship can be stored in a separate table/object
Email	The email address of the associated person.
Employee Id	The employee Id of the associated person.
Work Phone	The work phone of the associated person.

2.4 Image object

Image objects represent the images of the associated components of the hydropower plants. The image can be in the format of either 2D or 3D. If it is a 2D image, the width, height, and DPI would be required.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of the image. Can be the image file name.
Type	2D/3D
URL	Location of the 2D/3D image.
Width	Only applicable to 2D images.
Height	Only applicable to 2D images.
DPI	Only applicable to 2D images.
Description	Describe the image information.



2.5 Power_Plant object

The power plant objects represent the information of the physical hydropower plants. Each hydropower plant should have at least one unit, a reservoir, intake, penstock, generator, turbine, and so on.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of the hydropower plant, such as Alder dam.
Starting Latitude	The latitude of one side of the dam
Starting Longitude	The longitude of one side of the dam
Ending Latitude	The latitude of the other side of the dam
Ending Longitude	The longitude of the other side of the dam
Built Date Time	The date time when the power plant was built
Start Serving Date Time	The date time when the power plant started serving
Number of Units	The number of installed units of the associated hydropower plant.
Installed Capacity	The installed capacity of the associated hydropower plant.

Height	The height of the associated hydropower plant.
Length	The length of the associated hydropower plant.
Normal Elevation	The normal elevation of the associated hydropower plant.
Surface Area	The surface area of the associated hydropower plant.
Address Id	Foreign key of Address object
Id of Person of Contact	Foreign key of the Person's object
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0
Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.

2.6 Reservoir object

Reservoir objects represent the reservoir component of the hydropower plants.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of the reservoir.
Power Plant Id	Foreign key of the Power_Plant object
Type	The type of reservoir, such as valley-dammed, bank-side, and service reservoirs.
Volume	The volume of the reservoir.
Surface area	The surface area of the reservoir.
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0
Y scale of the image	0.0 ~ 1.0

Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.

2.7 Intake object

The intake objects represent the intake component of the hydropower plants.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of the intake.
Power Plant Id	Foreign key of the Power Plant object
Type	The type of intake.
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0
Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.

2.8 Penstock object

The penstock objects represent the penstock component of the hydropower plants.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of the penstock.
Power Plant Id	Foreign key of the Power_Plant object
Type	The type of penstock.
Id of Image	Foreign key of the Image object

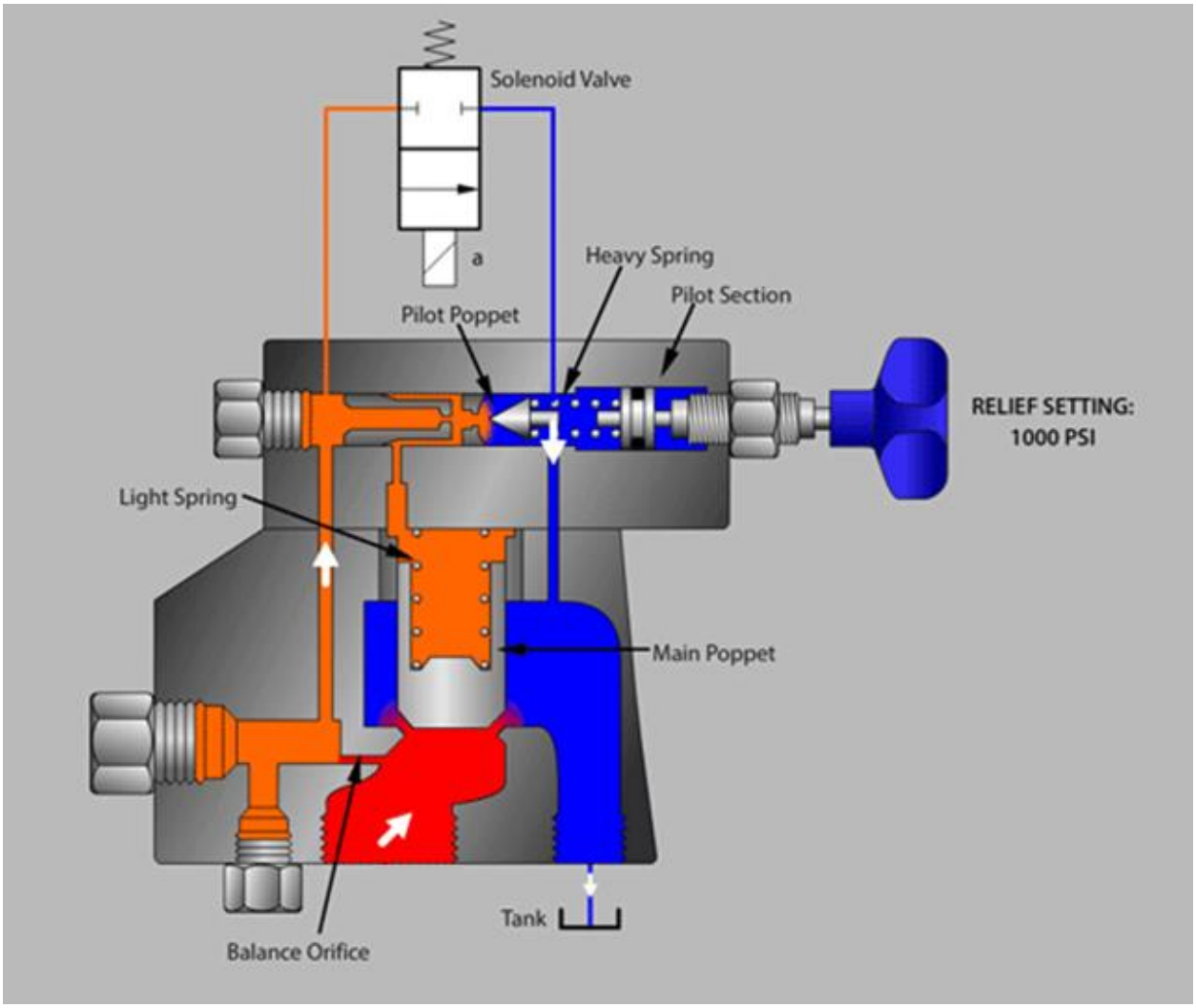
X scale of the image	0.0 ~ 1.0
Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.

2.9 PowerPlantUnit object

The power plant unit objects represent the installed units of the hydropower plants.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of the hydropower plant unit.
Power Plant Id	Foreign key of the Power_Plant object
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0
Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.
Display Parameters:	
Real-time power generated	*MW*
Real-time speed	*RPM*
Real-time temperature	*Fahrenheit*
Real-time flow	*KCFS*
Real-time head	*Feet*

Real-time atmospheric pressure	*kPa*
Real-time Wicket gate opening percentage	*%*
Real-time voltage	*Volts*
Real-time Generator Torque	*Nm*



2.10 Governor object

The governor objects represent the governor components of the hydropower plant units.

Attribute	Note
Unique Id	Prefer to be a GUID.

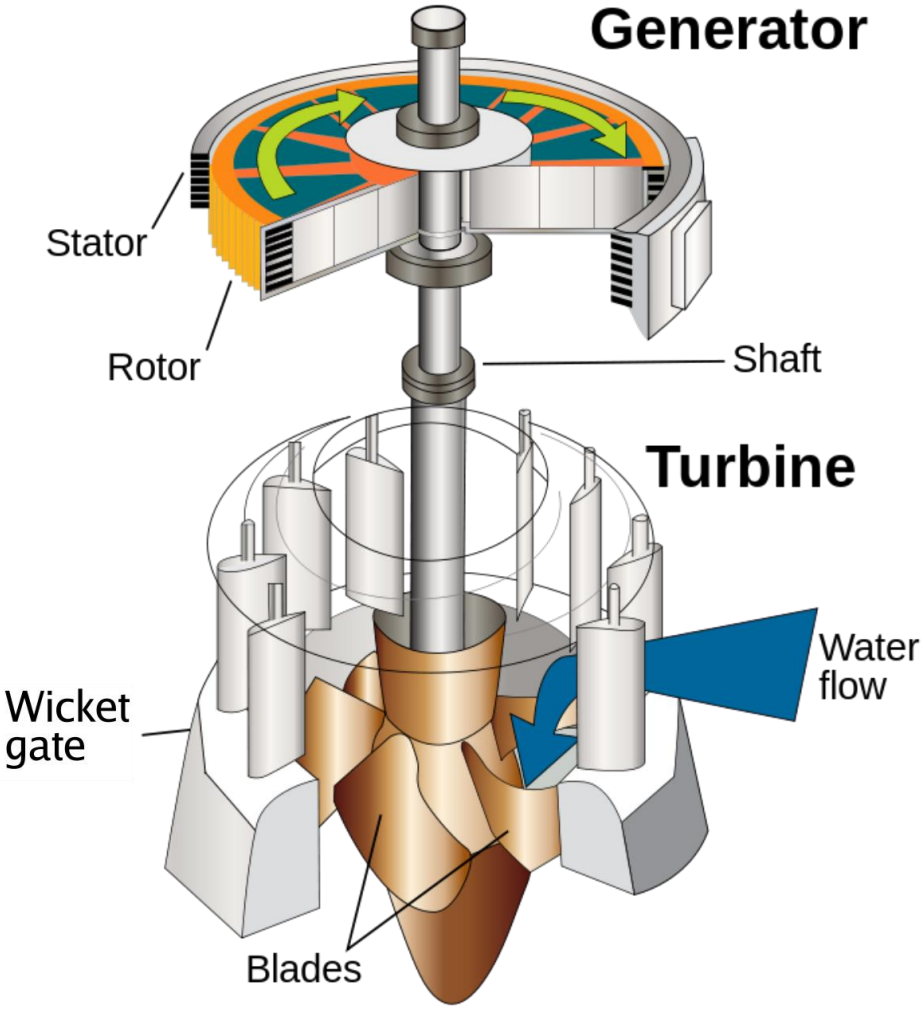
Name	The name of the governor.
PowerPlantUnit Id	Foreign key of the PowerPlantUnit object
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0
Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.
Parameters:	
Distance – vertical	*mm*
Flow	*KCFS*
Frequency	*Hertz*
Position (relative)	*degrees*
Pressure	*Pascals*
Speed	*RPM*
Temperature	*Fahrenheit*

2.11 Excitation object

The excitation objects represent the excitation component of the hydropower plant units.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of the excitation.
PowerPlantUnit Id	Foreign key of the PowerPlantUnit object
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0

Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.
Parameters:	
Vibration – Magnitude of displacement	*Mils (thousandths of an inch)*



2.12 Generator object

The generator objects represent the generator component of the hydropower plant units.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of the generator.
PowerPlantUnit Id	Foreign key of the PowerPlantUnit object
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0
Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.
Parameters:	
Air gap	*mm*
Current	*amps*
Distance – vertical	*mm*
Flow	*KCFS*
Flux	*Gaus*
Frequency	*Hertz*
Position (relative)	*degrees*
Pressure	*Pascals*
Reactive Power	*MW*
Real Power	*MW*
Temperature	*Fahrenheit*

Vibration – Magnitude of displacement	*Mils*
Vibration – Velocity	*m/s*
Voltage	*Volts*
Generator Torque	*Nm*

2.13 Thrust Bearing object

The thrust-bearing objects represent the thrust-bearing components of the hydropower plant units.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of the thrust-bearing.
PowerPlantUnit Id	Foreign key of the PowerPlantUnit object
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0
Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.
Parameters:	
Distance – vertical	*mm*
Flow	*KCFS*
Pressure	*Pascals*
Temperature	*Fahrenheit*
Vibration – Magnitude of displacement	*Mils*

2.14 Turbine object

The turbine objects represent the turbines of the hydropower plant units.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of the turbine.
PowerPlantUnit Id	Foreign key of the PowerPlantUnit object
Type	Kaplan/Francis, etc.
Capacity	The capacity of the turbine.
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0
Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.
Parameters:	
Cavitation	*None*
Distance – vertical	*mm*
Flow	*KCFS*
Position (relative)	*degrees*
Pressure	*Pascals*
Temperature	*Fahrenheit*
Vibration – Magnitude of displacement	*Mils*

2.15 Draft tube object

The draft tube objects represent the draft tubes of the connected turbines.

Attribute	Note

Unique Id	Prefer to be a GUID.
Name	The name of the draft tube.
PowerPlantUnit Id	Foreign key of the PowerPlantUnit object
Type	Conical draft tube, Simple elbow draft tube, Moody spreading draft tube, and Elbow draft tube with a varying cross-section.
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0
Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.
Parameters:	
Flow	*KCFS*
Pressure	*Pascals*
Temperature	*Fahrenheit*

2.16 Tailrace object

The tailrace objects represent the tailrace of the hydropower plant unit.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of the tailrace.
PowerPlantUnit Id	Foreign key of the PowerPlantUnit object
Type	Kaplan/Francis, etc.
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0

Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.
Parameters:	
Elevation	*feet*
Flow	*KCFS*
Temperature	*Fahrenheit*

2.17 Transformer object

The transfer objects represent the transformers of the hydropower plant unit.

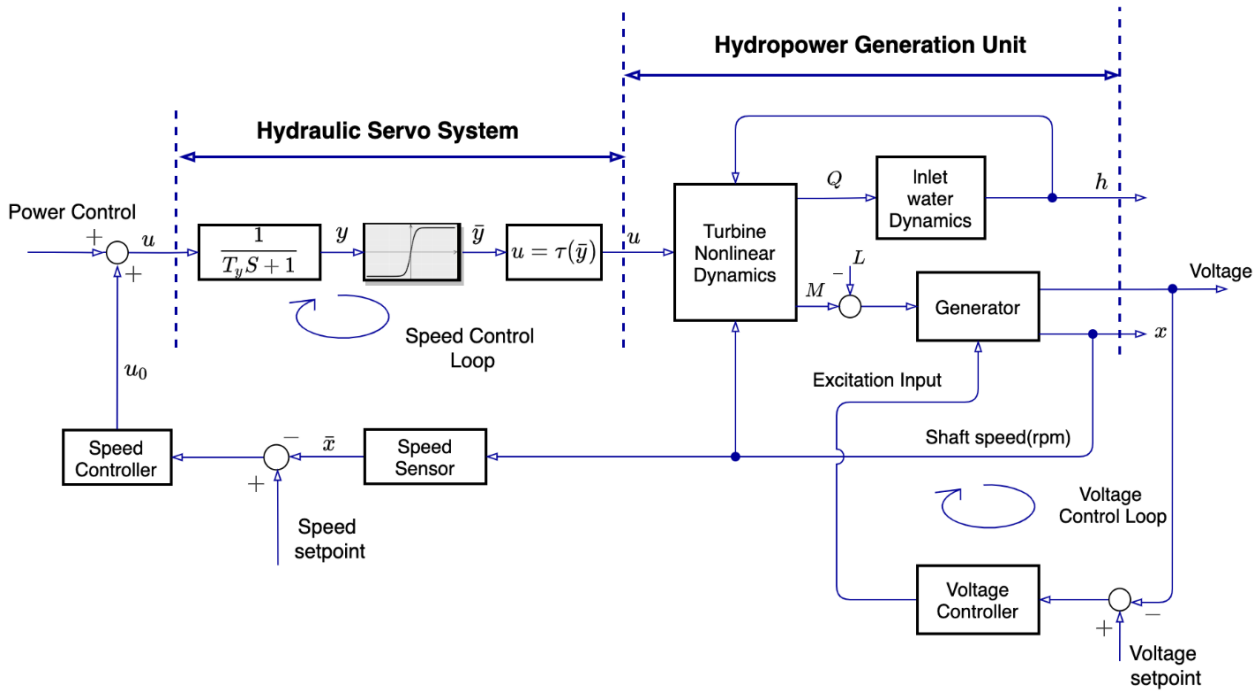
Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of the transformer.
PowerPlantUnit Id	Foreign key of the PowerPlantUnit object
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0
Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.
Parameters:	
Distance – vertical	*mm*
Flow	*KCFS*

Frequency	*Hertz*
Position (relative)	*degrees*
Pressure	*Pascals*
Speed	*RPM*
Temperature	*Fahrenheit*

2.18 Service object

The service objects represent the service/maintenance log of the hydropower plant units.

Attribute	Note
Unique Id	Prefer to be a GUID.
Title	The title of the service.
Service starting Date	The starting date of the service.
Service ending Date	The ending date of the service.
Description	The description of the service.
Comments	The notes of the service.
Service person Ids	The person Id is the foreign key of the person object. The person Ids and service Ids can be stored in a separate table/object.
Power Plant Id	Foreign key of the Power_Plant object



2.19 Source_Code object

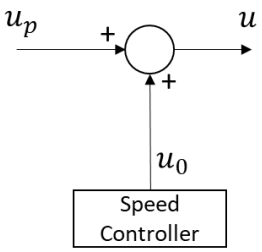
The source code objects represent the source code information for each control module.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of the source code.
Programming Language	The programming language used to develop the source code.
Programming Language Version	The version of the programming language used to develop the source code.
Code	The source code.
Source Code Version	The version of the source code.
Execution Order	The sequence number to execute the source code.
Comments	The notes of the source code.

2.20 Control_Module object

The control module object contains modules of simulations, such as a closed-loop Hydropower Turbine Speed Control System.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of the control module.
Description	The description of the control module.
Power Plant Id	Foreign key of the Power_Plant object
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0
Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.
Source Code Id	Foreign key of Source Code object

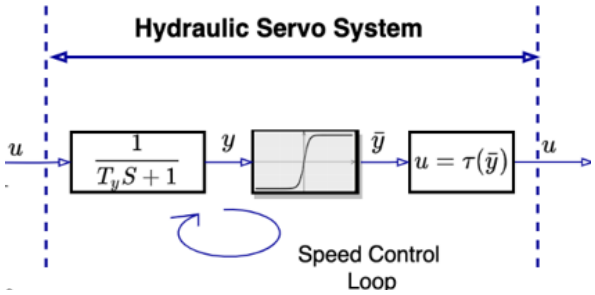


2.21 Turbine_Speed_Power_Control_Modular object

Take the guided vane opening for inlet water which is generated based on the opening variable from the speed controller and the setpoint of active power for the power flow control to the grid to generate the output for the Hydraulic Servo System.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of the modular.
Control Module Id	Foreign key of Control Module object
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0
Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.
Source Code Id	Foreign key of Source Code object

Inputs		
u_0	*Time-varying variable*	*The output of the speed controller*
u_p	*Time-varying variable*	*The setpoint of active power which reflects the power demand from the grid*
Outputs		
u	*Time-varying variable*	*The setpoint to the hydraulic servo for the guided vane opening*



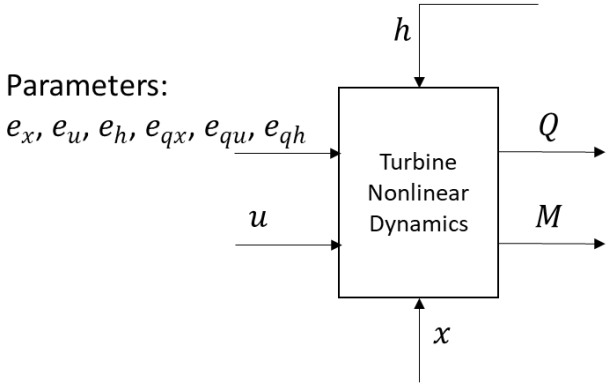
2.22 Hydraulic_Servo_Modular object

The Hydraulic Servo System is used to amplify the control signals and provide mechanical power to operate the guided vane opening.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of the modular.
Control Module Id	Foreign key of Control Module object
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0
Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.
Source Code Id	Foreign key of Source Code object

Inputs		
u	*Time-varying variable*	*The output from turbine speed (frequency) and power controller in-taker. This is also the input to the servo system*
Ty	*Parameter*	*The equivalent time constant of the hydraulic servo system that*

		depends on the specification of the hydraulic servo
s	*Complex Laplace variable*	
Outputs		
u	*Time-varying variable*	*The output from turbine speed (frequency) and power controller in-taker. This is also the input to the servo system*

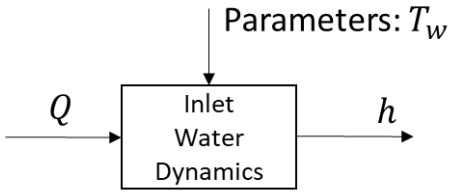


2.23 Torque_Water_Flow_Modular object

Take the guided vane opening, the shaft speed, and the water height to generate the output as the turbine torque and water flow rate.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of the modular.
Control Module Id	Foreign key of Control Module object
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0
Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen

Z index	The layer on Z direction.	
Source Code Id	Foreign key of Source Code object	
Inputs		
u	*Time-varying variable*	*The incremental guided vane opening which is also the output from the hydraulic servo*
h	*Time-varying variable*	*The incremental water pressure*
x	*Time-varying variable*	*The incremental turbine speed*
e_x, e_h, e_u	*Torque parameters*	*Linearized coefficients for the torque generation calculated at a fixed operating point O*
e_{qx}, e_{qh}, e_{qu}	*Water flow parameters*	*Linearized coefficients for the water flow calculated at a fixed operating point O*
$O = \{\omega_0, H_0, Q_0, u_0\}$	*Parameters*	*The definition of a selected and fixed operating point for the hydropower generation unit connected to the grid*
$\omega = 2\pi f$	*Time-varying variable*	*Turbine speed in rad/sed*
f	*Time-varying variable*	*Turbine-generator frequency. This frequency is fixed at 60Hz when the hydropower generation unit is connected to the grid*
Q, H, ω	*Time-varying variables*	*Water flow rate, water head, and turbine speed/frequency. These variables can be calculated using O and the incremental variables, q, h, and x*
Outputs		
M	*Time-varying variable*	*turbine torque*
Q		*water flow-rate*

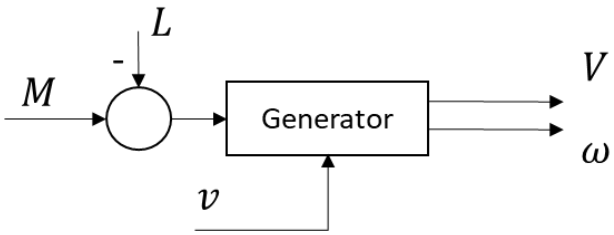


2.24 Non_Elasticity_Water_System_Dynamics_Modular object

The low-water head penstock system takes the normalized water head as input and generates outputs as the normalized water flow rate.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of modular.
Control Module Id	Foreign key of Control Module object
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0
Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.
Source Code Id	Foreign key of Source Code object

Inputs		
q	*Time-varying variable*	*The incremental variable for the water flow-rate*
Tw	*Parameter*	*The water starting time constant which can be calculated using the equations*
Outputs		
h	*Time-varying variable*	*The incremental variable for water head*



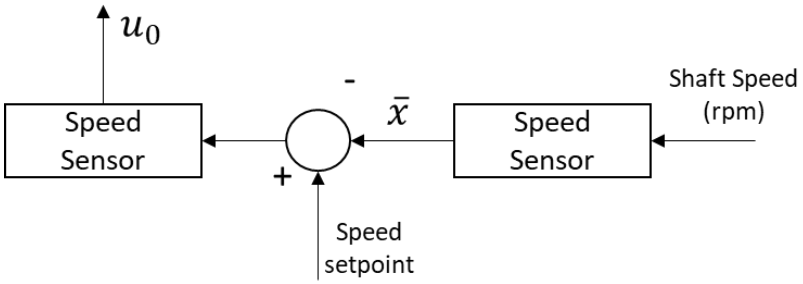
2.25 Synchronous_Generator _Dynamics_Modular object

The Synchronous generator modular represents the dynamic relationship between the turbine shaft frequency in rad/s, the torque, and the load (when connected to the grid).

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	The name of the modular.
Control Module Id	Foreign key of Control Module object
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0
Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.
Source Code Id	Foreign key of Source Code object

Inputs		
M	*Time-varying variable*	*Mechanical torque as a result of water flow to the turbine chamber*
L	*Time-varying variable*	*Equivalent load when connected to the grid*
Outputs		

J	*Parameter*	*Equivalent inertia for all the rotational parts with the shaft of the hydropower generation unit*



2.26 Speed_Controller_Modular object

The speed controller modular generates the time-varying variable as the speed controller.

Attribute	Note
Unique Id	Prefer to be a GUID.
Name	
Control Module Id	Foreign key of Control Module object
Id of Image	Foreign key of the Image object
X scale of the image	0.0 ~ 1.0
Y scale of the image	0.0 ~ 1.0
Z scale of the image	0.0 ~ 1.0
X screen position in percentage	The starting X position in percentage on the screen
Y screen position in percentage	The starting Y position in percentage on the screen
Z index	The layer on Z direction.
Source Code Id	Foreign key of Source Code object
Inputs	

e_{speed}	*Time-varying variable*	*The tracking error of the incremental speed control for the incremental shaft speed*
K_p	*Parameter*	*The proportional gain*
K_I	*Parameter*	*The integral gain*
Outputs		
u_0	*Time-varying variable*	*The output of the speed controller*

3.0 References

Water Power Technologies Office, US DOE. Types of Hydropower Plants. Retrieved March 23, 2021, from http://energy.gov/eere/water/types-hydropower-plants.

Thomas Publishing Company. Sensors - A Complete Guide (Types, Applications, and Suppliers). Retrieved March 23, 2021, from https://www.thomasnet.com/articles/instruments-controls/sensors/.

K. Shafique, B. A. Khawaja, F. Sabir, S. Qazi, and M. Mustaqim, "Internet of Things (IoT) for Next-Generation Smart Systems: A Review of Current Challenges, Future Trends and Prospects for Emerging 5G-IoT Scenarios," in IEEE Access, vol. 8, pp. 23022-23040, 2020, doi: 10.1109/ACCESS.2020.2970118.

Luigi Atzori, Antonio Iera, Giacomo Morabito, The Internet of Things: A survey, Computer Networks, Volume 54, Issue 15,2010, Pages 2787-2805, ISSN 1389-1286, https://doi.org/10.1016/j.comnet.2010.05.010.

Google LLC. Google Cloud IoT solutions. Retrieved on March 23, 2021, from https://cloud.google.com/solutions/iot.

Amazon.com, Inc.AWS IoT Core, Retrieved March 23, 2021, from https://aws.amazon.com/iot-core.

Microsoft Corporation. Azure IoT Hub, Retrieved on March 23, 2021, from https://azure.microsoft.com/en-us/services/iot-hub/.

J. M. Lynch, “An Internet Based SCADA System”, BSc Project Report, University of Southern Queensland, Queensland, Oct. 2005.

S. Wahyudi. MODERN SCADA PHILOSOPHY IN POWER SYSTEM OPERATION, August 12, 2012, http://sswahyudi.blogspot.com/2012/08/modern-scada-philosophy-in-power-system.html.

Hydropower Research Institute. Mission. Retrieved on March 23, 2021, from https://www.hridata.org.

Columbia Basin Research. Columbia River DART (Data Access in Real Time)Retrieved on March 23, 2021, from http://www.cbr.washington.edu/dart.

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