HAI SECURITY DATASET

HIL-BASED AUGMENTED ICS (HAI) SECURITY DATASET WAS COLLECTED FROM A REALISTIC ICS TESTBED AUGMENTED WITH A HARDWARE-IN-THE-LOOP SIMULATOR THAT EMULATES STEAM-TURBINE POWER GENERATION AND PUMPED-STORAGE HYDROPOWER GENERATION

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HIL-BASED AUGMENTED ICS (HAI) SECURITY DATASET WAS COLLECTED FROM A REALISTIC ICS TESTBED AUGMENTED WITH A HARDWARE-IN-THE-LOOP SIMULATOR THAT EMULATES STEAM-TURBINE POWER GENERATION AND PUMPED-STORAGE HYDROPOWER GENERATION

BACKGROUND

This dataset was developed for research on anomaly detection in cyber-physical systems (CPSs) such as railways, water-treatment, and power plants. In 2017, we initially launched three laboratory-scale CPS testbeds: GE's turbine testbed, Emerson's boiler testbed, and FESTO's MPS water-treatment testbed. These consisted of relatively simple processes and were operated independently of each other. Next, in 2018, we built a complex process system that combined the three systems with a hardware-in-the-loop (HIL) simulator that emulates thermal power generation and pumped-storage hydropower generation, thus ensuring that their variables were highly coupled and correlated for a richer dataset. In addition, an OPC-UA gateway was installed to allow for data collection from heterogeneous devices. Finally, at the end of 2019, we released a dataset that included data from both normal and anomalous situations corresponding to 38 attacks.

TESTBED

The testbed consists of a boiler, a turbine, a water-treatment component, and an HIL simulator. The boiler process is a water-to-water heat-transfer process involving low pressures and moderate temperatures. The turbine process involves the use of a rotor kit testbed that closely simulates the behavior of an actual rotating machine. Both processes are interconnected with the HIL simulator in order to ensure they remain synchronous with the rotating speed of the steam-power generator. The water-treatment process includes the pumping of water to the upper reservoir and releasing it into the lower reservoir using a pumped-storage hydropower generation model during the HIL simulation.
The real-world processes are controlled by three different types of controllers. The boiler process is controlled by Emerson's Ovation distributed control system (DCS) for the water level, flow rate, pressure, temperature, water feed pump, and heater control. The turbine process is controlled by GE's Mark VIe DCS for speed control and vibration monitoring. The water-treatment process is controlled by a Siemens S7-300 PLC for the water level and pump control. A dSPACE® SCALEXIO system is used for the HIL simulations and is interconnected with the real-world processes using a Siemens S7-1500 PLC and ET200 remote IO devices.

DATASET

The dataset was built by collecting 59 points every second from the testbed. The dataset for the normal situation was collected continuously for almost 7 days and the attack dataset was collected with 38 attack scenarios on the six control loops in the PLCs and DCSs. The attack dataset consists of one day's worth of data for 28 attack scenarios on each control loop and two days' worth of data for 14 attacks on multiple control loops. Here, a control loop refers to a system comprising all the software functions needed for measuring and adjusting the variable that controls a given process.

TESTBED OVERVIEW

PROCESS ARCHITECTURE

The process flow of the testbed is shown in Figure 1 and can be divided into four primary processes: the boiler process (P1), the turbine process (P2), the water-treatment process (P3), and the HIL simulation (P4). The HIL simulation enhances the correlation between the three real-world processes at the signal level by simulating thermal power generation and pumped-storage hydropower generation scenarios.

The boiler and turbine processes are used to simulate the thermal power plant, while the water-treatment process is used to simulate the pumped-storage hydropower plant.

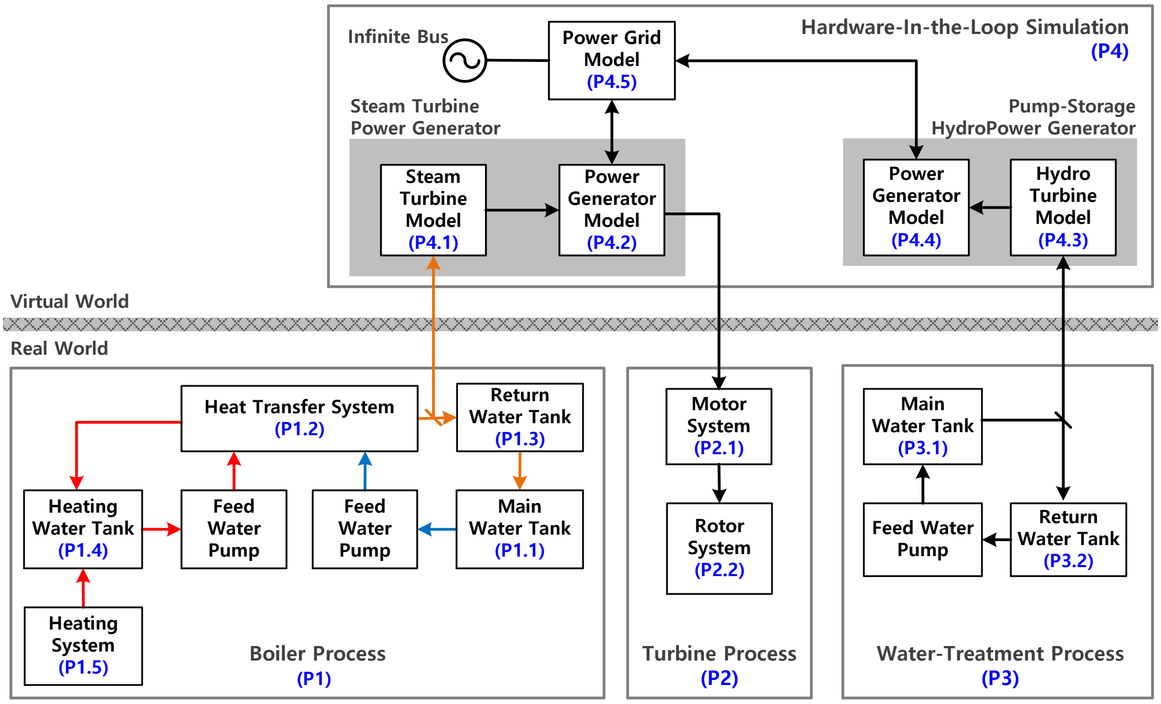

FIGURE 1. PROCESS FLOW DIAGRAM

P1: Boiler Process

The boiler process is a water-to-water heat-transfer process with low pressures and moderate temperatures. The boiler process controls the boiler pressure, temperature, and water level. It also controls the opening and closing rates of the main valve based on the opening rate of the steam valve of the thermal power plant in the HIL simulator. The pressure and temperature of the main pipe and the water level are transmitted to the HIL simulator in real time to determine the amount of power generated.

Water in the main water tank is pumped and supplied to the heat-transfer system (P1.2), which subsequently sends the water at a constant temperature and pressure to the return water system (P1.3). The water temperature and pressure are then converted into the current steam temperature and pressure values for the HIL simulator's steam-turbine power generator (P4.1).

Finally, the water is returned to the main water tank, thus ensuring that the water level in the return water tank remains constant (P1.3).

The boiler system consists of eleven sensors, three actuators (two pumps and a heater), and six valves for keeping the water temperature, water pressure, water level, and flow rate constant. The operator can control five setpoints via the OWS (Operator Workstation).

P2: Turbine Process

We used a GE Rotor Kit (Bently Nevada Asset Condition Monitoring) that closely simulates the behavior of an actual rotating machine. It consists of a motor system with a direct current motor speed control device and a rotor system that allows for coupling and includes a rotor shaft, two balance wheels, two journal bearings, and a bearing block. The motor speed remains synchronous with the rotating speed of the thermal power generator model in the HIL simulator.

The turbine system consists of a speedometer and four vibration-monitoring proximity probes to keep the motor speed constant. The operator sets the turbine RPM setpoint through the OWS and can control the motor turbine with precision.

P3: Water-Treatment Process

The water-treatment process includes the pumping of water to the upper reservoir and releasing it back into the lower reservoir using the hydropower turbine model in HIL simulation.

The water-treatment system uses seven sensors, two actuators (a pump and a heater), and an outflow control valve to control the flow and pressure from the return water tank (P3.2) to the main water tank (P3.1) as well as the water level in the main water tank (P3.1).

The hydraulic pressure, flow rate, and water level of the upper water tank are transmitted to the HIL simulator in real time to determine the amount of power generated.

P4: Hardware-In-the-Loop Simulation

This simulation system consists of two synchronous generator models (steam-turbine power generator and pumped-storage hydropower generator) and one power grid model that includes the local load demand and is connected to an infinite bus.

An HIL-based simulator was developed to combine the three control systems (boiler, turbine, and water treatment) to form a combined power generation system.

The temperature and pressure of the boiler system are used to determine the pressure and temperature of the steam entering the steam turbine model (P4.1, STM). The output power of the STM is controlled with an internal steam governor. The power generator model (P4.2) then generates the corresponding electrical power. Meanwhile, the hydro turbine model (P4.3, HTM) and power generator model (P4.4) calculate the amount of output power generated based on the discharge from the water-treatment system. Both power generator models are controlled to ensure that the frequency of the microgrid load is 60 Hz (P4.5).

To control the amount of power generated based on the input load, it is necessary to determine the opening/closing rates of the valves of the thermal power plant and pumped-storage power plant. This allows one to determine the valve opening/closing rates for each control system (i.e., the boiler and water treatment systems).

TESTBED COMPONENTS

The real-world processes are controlled by three different types of controllers. The boiler process is controlled by Emerson's Ovation DCS for the water level, flow rate, pressure, temperature, water feed pump, and heater control. The turbine process is controlled by GE's Mark VIe DCS for speed control and vibration monitoring. The water-treatment process is controlled by a Siemens S7-300 PLC for the water level and pump control. The HIL simulator, which is a dSPACE modular simulator, is interconnected with the real-world processes through a Siemens S7-1500 PLC and ET200 remote IO devices.

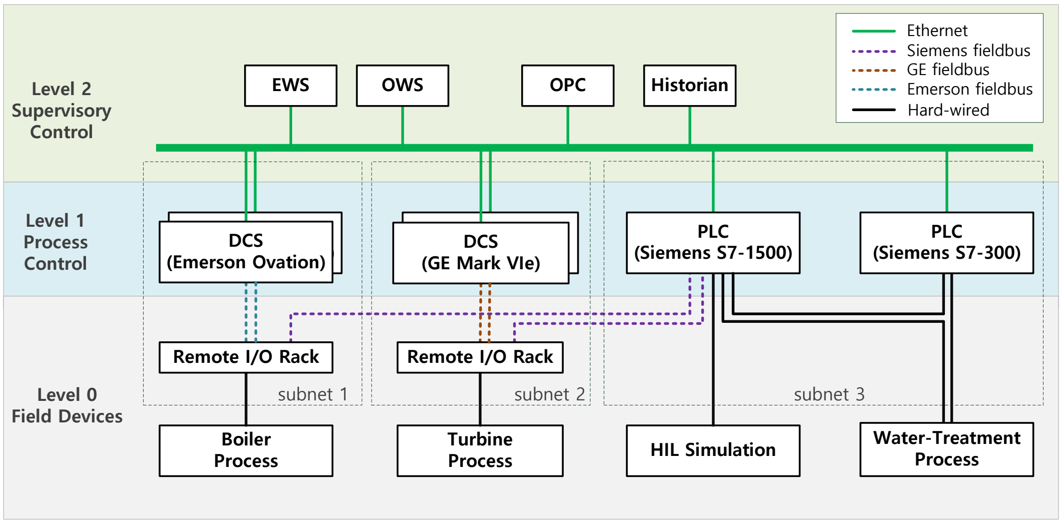

FIGURE 2. TESTBED COMPONENTS AND DATA FLOW

PROCESS CONTROLLERS

Boiler (P1) Controllers

Emerson's Ovation DCS has four feedback loops to control the water level, pressure, temperature, and outflow:

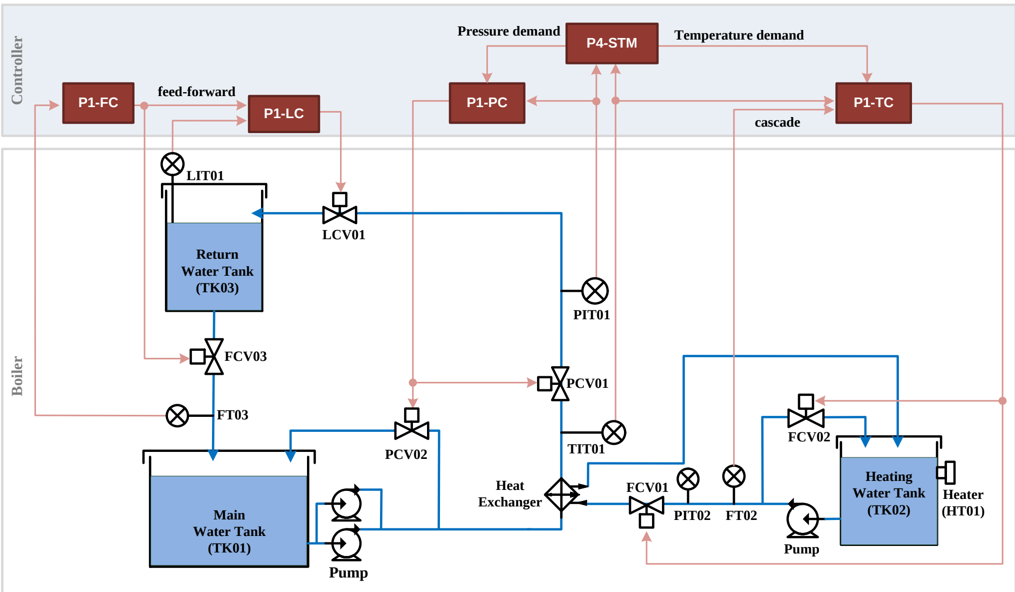

FIGURE 3. ARCHITECTURE OF BOILER PROCESS.

P1-PC: Pressure Control

P1-PC is a feedback controller that controls two pressure-control valves (PCV01D and PCV02D) to maintain the pressure (PIT01) between the main and return water tanks as per the operator's setpoint command (B2016).

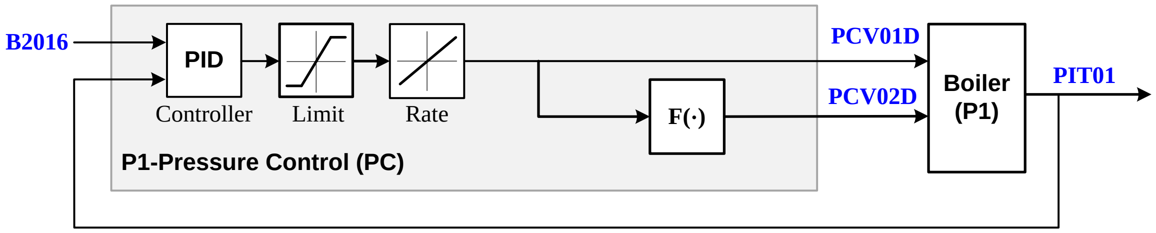

FIGURE 4. PRESSURE CONTROL OF BOILER.

P1-LC: Level Control

P1-LC is a feedback controller that controls a level-control valve (LCV01D) to maintain the water level (LIT01) of the return water tank as per the operator's setpoint command (B3004). In addition, feed-forward control is used to rapidly suppress any disturbances in the outflow rate (FCV03D).

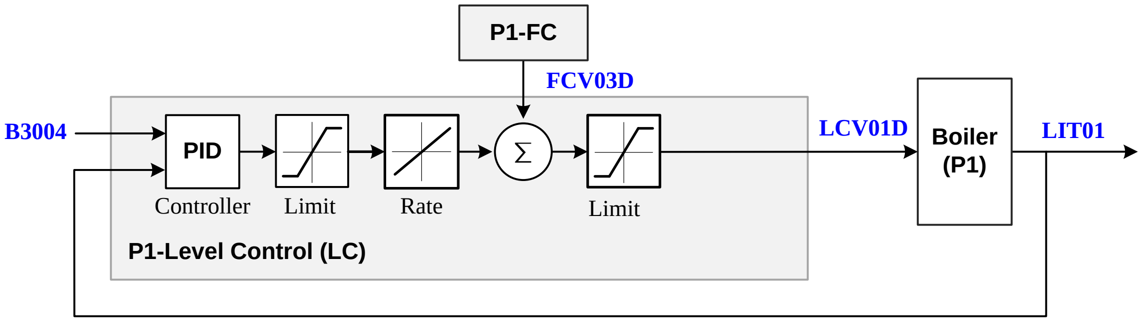

FIGURE 5. LEVEL CONTROL OF BOILER.

P1-FC: Flow Rate Control

P1-FC is a feedback controller that controls a flow-control valve (FCV03D) to maintain the outflow rate (FT03) for the return water tank as per the operator's setpoint command (B3005).

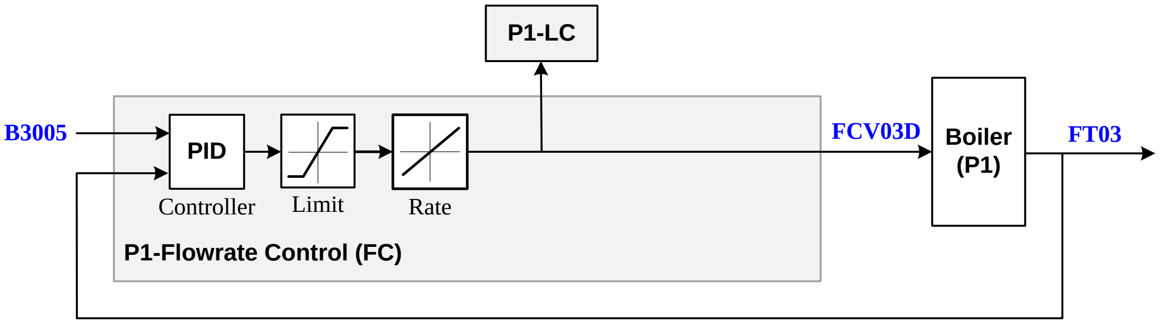

FIGURE 6. FLOW RATE CONTROL OF BOILER.

P1-TC: Temperature Control

P1-TC is a feedback controller that controls two flow-control valves (FCV01D and FCV02D) in the heat-transfer system to maintain the temperature (TIT01) of the main vessel as per the operator's setpoint command (B4022). Cascade control with feedforward compensation to the flow controller (inner loop) based on the water flow is used to improve the speed of response to fluctuations in the water flow.

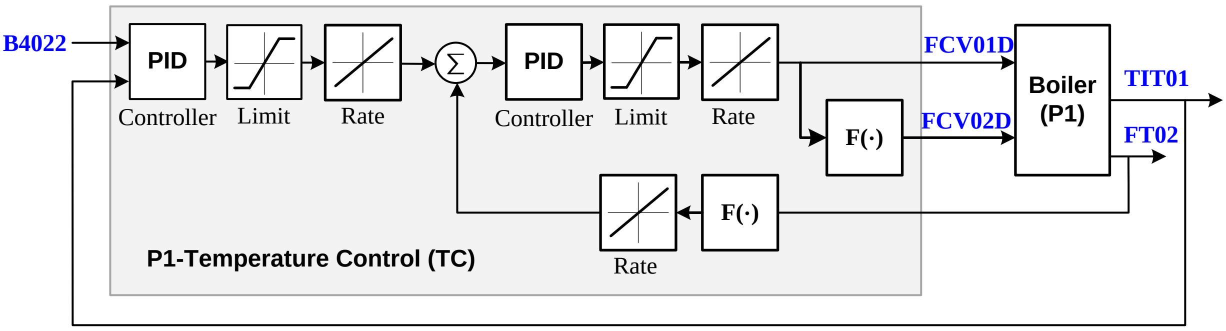

FIGURE 7. TEMPERATURE CONTROL OF BOILER.

Turbine (P2) Controllers

GE's Mark VIe DCS has only one feedback loop for controlling the motor speed. The HIL simulator (P4-STM) generates the setpoint trajectories for speed control (P2-SC).

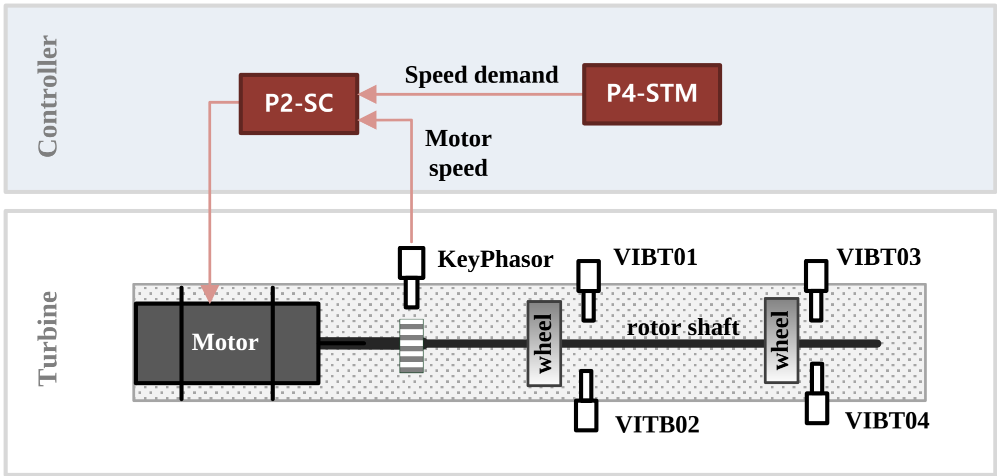

FIGURE 8. PROCESS ARCHITECTURE OF TURBINE.

P2-SC: Speed Control

P2-SC starts ramping the motor speed from zero to the minimum controlling speed at a constant rate and then enables engagement control with a PI controller to regulate the motor speed (SIT01) to be as close as possible to the speed setpoint (SD01).

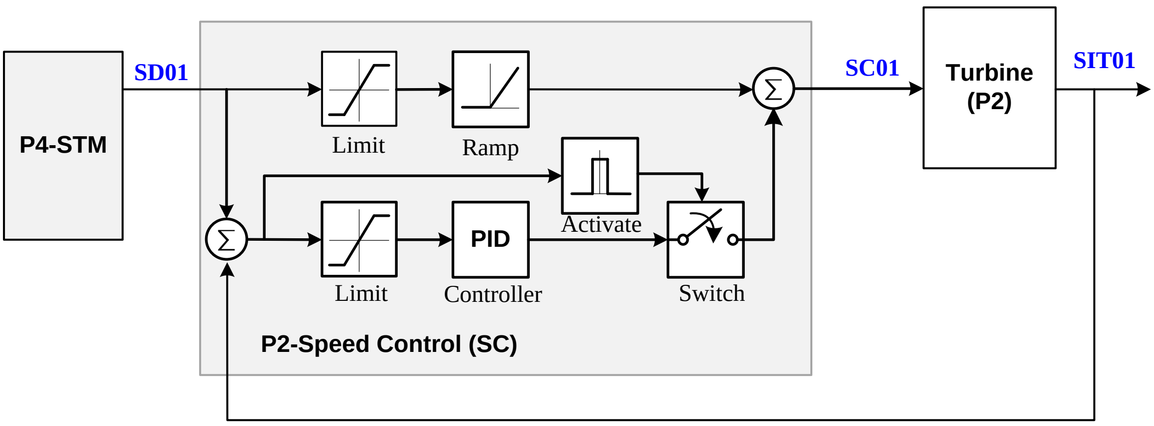

FIGURE 9. SPEED CONTROL OF TURBINE.

Water-Treatment (P3) Controllers

Siemens's SIMATIC S7 PCL has only one feedback loop to control the water level of the upper reservoir:

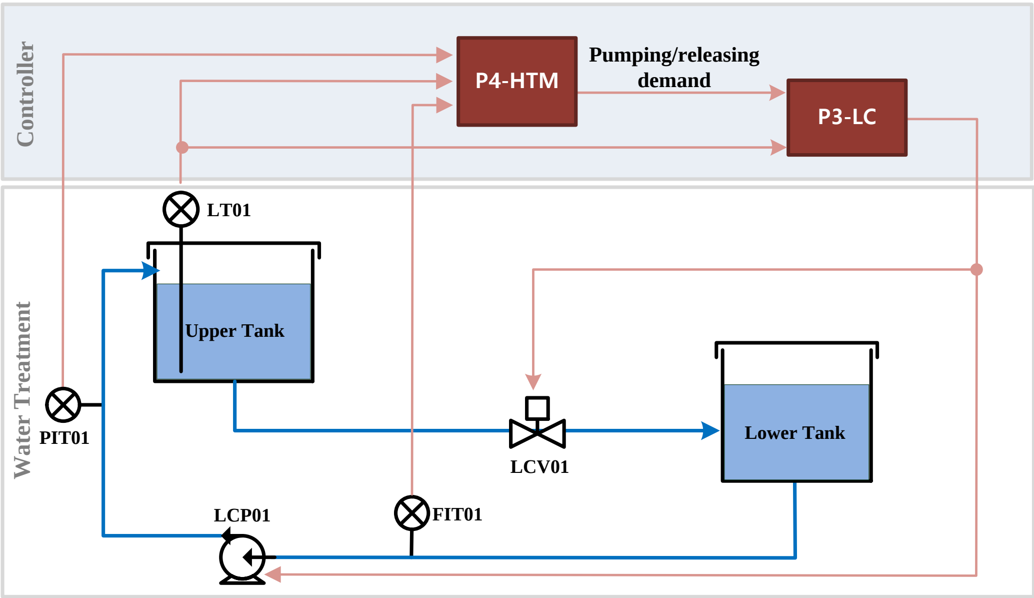

FIGURE 10. PROCESS ARCHITECTURE OF WATER-TREATMENT PLANT.

P3-LC: Level Control

P3-LC controls the level-control valve (LCV01) and the pump (PP01) by adjusting the discharge and pumping demands of the HIL simulator (P4.HTM).

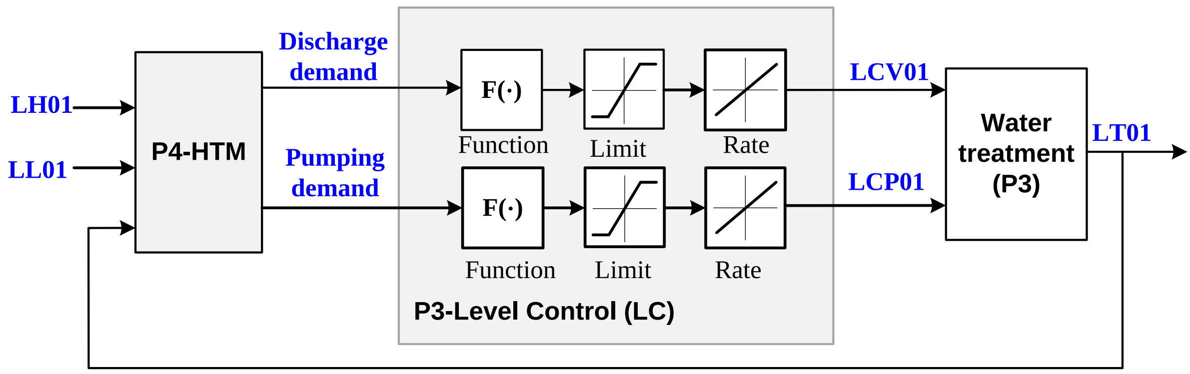

FIGURE 11. LEVEL CONTROL OF WATER-TREATMENT PLANT.

DATA POINTS

Our SCADA system has 59 data points listed in the table shown below. SCADA systems typically consist of data elements called points (or tags), with each point representing a single variable measured or controlled by the system.

No	Point Name	Range	Unit	Description
1	P1_B2004	0 ~ 10	Bar	Heat-exchanger outlet pressure setpoint
2	P1_B2016	0 ~ 10	bar	Pressure demand to follow P1_B2004 and electrical load from steam turbine model
3	P1_B3004	0 ~ 720	mm	Water level setpoint in return water tank
4	P1_B3005	0 ~ 2,500	L/H	Water outflow rate setpoint from return water tank
5	P1_B4002	0 ~ 100	°C	Heat-exchanger outlet temperature setpoint
6	P1_B4005	0 ~ 100	-	Temperature cascade control (On: 1, Off: 0)
7	P1_B400B	0 ~ 3,000	L/H	Water outflow rate setpoint from heating water tank
8	P1_B4022	0 ~ 100	°C	Temperature demand to follow P1. B4005 and electrical load from steam-turbine model
9	P1_FCV01D	0 ~ 100	%	Position command for FCV01 valve
10	P1_FCV01Z	0 ~ 100	%	Current position of FCV01 valve
11	P1_FCV02D	0 ~ 100	%	Position command for FCV02 valve
12	P1_FCV02Z	0 ~ 100	%	Current position of FCV02 valve
13	P1_FCV03D	0 ~ 100	%	Position command for FCV03 valve
14	P1_FCV03Z	0 ~ 100	%	Current position of FCV03 valve
15	P1_FT01	0 ~ 2500	mmH_2O	Digital value of FT01 flow transmitter
16	P1_FT01Z	0 ~ 3190	L/H	Water inflow rate into return water tank
17	P1_FT02	0 ~ 2500	mmH_2O	Digital value of FT02 flow transmitter
18	P1_FT02Z	0 ~ 3190	L/H	Conversion from P1_FT02 to outflow rate at heating water tank
19	P1_FT03	0 ~ 2500	mmH_2O	Digital value of FT03 flow transmitter
20	P1_FT03Z	0 ~ 3190	L/H	Conversion from P1_FT03 to outflow rate at return water tank
21	P1_LCV01D	0 ~ 100	%	Position command for LCV01 valve
22	P1_LCV01Z	0 ~ 100	%	Current position of LCV01 valve
23	P1_LIT01	0 ~ 720		Water level of return water tank
24	P1_PCV01D	0 ~ 100	%	Position command for PCV01 valve
25	P1_PCV01Z	0 ~ 100	%	Current position of PCV01 valve
26	P1_PCV02D	0 ~ 100	%	Position command for PCV2 valve
27	P1_PCV02Z	0 ~ 100	%	Current position of PCV02 valve
28	P1_PIT01	0 ~ 10	bar	Heat-exchanger outlet pressure
29	P1_PIT02	0 ~ 10	bar	Water supply pressure of heating water pump

No	Point Name	Range	Unit	Description
30	P1_TIT01	-10 ~ 100	℃	Heat-exchanger outlet temperature
31	P1_TIT02	-10 ~ 100	℃	Temperature of heating water tank
32	P2_SIT01	0 ~ 3600	RPM	Current motor speed
33	P2_SD01	0 ~ 3600	RPM	User speed demand
34	P2_VT01	0 ~ 15	V	Phase lag signal of key phasor probe near motor
35	P2_VYT02	-10 ~ 10	μm	Shaft-vibration-related Y-axis displacement near the first mass wheel
36	P2_VXT02	-10 ~ 10	μm	Shaft-vibration-related X-axis displacement near the first mass wheel
37	P2_VYT03	-10 ~ 10	μm	Shaft-vibration-related Y-axis displacement near the second mass wheel
38	P2_VXT03	-10 ~ 10	μm	Shaft-vibration-related X-axis displacement near the second mass wheel
39	P2_24Vdc	0 ~ 30	V	DCS power supply
40	P2_Auto	0 or 1	-	System auto/manual mode
41	P2_Emgy	0 or 1	-	Emergency-stop input
42	P2_On	0 or 1	-	System on/off input
43	P2_TripEx	0 or 1	-	Trip exit input
44	P3_LT01	0 ~ 100	%	Water level in upper tank
45	P3_LH01	0 ~ 100	%	High water level setpoint
46	P3_LL01	0 ~ 100	%	Low water level setpoint
47	P3_LCP01D	0 ~ 27648	-	Speed command for feed water pump
48	P3_LCV01D	0 ~ 27648	-	Position command for LCV01 valve
49	P4_LD	0 ~ 600	MW	Total electrical load demand
50	P4_ST_FD	-0.1 ~ 0.1	mHz	Frequency deviation of steam-turbine model
51	P4_ST_PO	0 ~ 500	MW	Output power of steam-turbine model
52	P4_ST_PT01	0 ~ 27648	-	Digital value of steam pressure in steam-turbine model
53	P4_ST_TT01	0 ~ 27648	-	Digital value of steam temperature in steam-turbine model
54	P4_ST_LD	0 ~ 500	MW	Electrical load demand for steam-turbine model
55	P4_ST_PS	0 ~ 500	MW	Scheduled power demand of steam-turbine model
56	P4_HT_FD	-0.1 ~ 0.1	mHz	Frequency deviation of hydropower-turbine model
57	P4_HT_PO	0 ~ 100	MW	Output power of hydropower-turbine model
58	P4_HT_LD	0 ~ 100	MW	Electrical load demand for steam-turbine model
59	P4_HT_PS	0 ~ 100	MW	Scheduled power demand of hydropower-turbine model

ATTACK OVERVIEW

SCENARIO CONFIGURATION

All scenarios were configured using the four variables of a closed-control loop, namely, the setpoints (SPs), process variables (PVs), control variables (CVs), and control parameters (CPs).

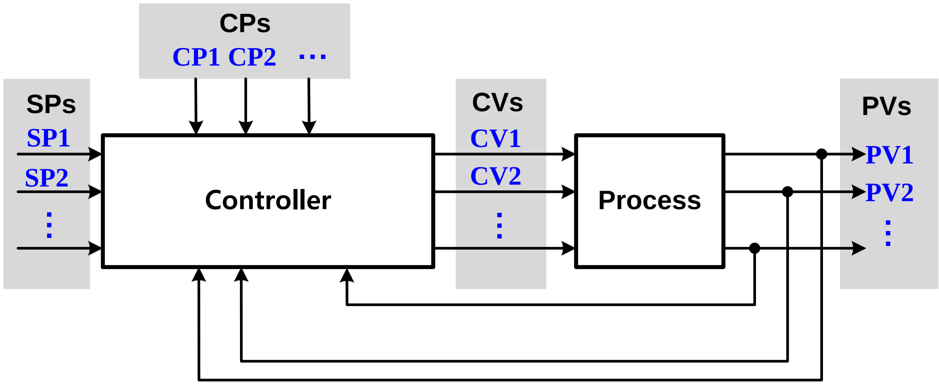

FIGURE 12. ATTACK MODEL BASED ON CONTROL LOOP

NORMAL SITUATION

During normal operation, it is assumed that the operator operates the control facility in a routine manner via the HMI. The operator monitors the PV value of the current sensor displayed on the HMI and changes the SPs of the various control devices to operate the control facility. When the control process moves out of the normal range, the values of the physical parameters, such as the pressure and water level, change abnormally, and the hybrid control system enters an abnormal operating state.

Through experiments, we confirmed the normal range of the SPs for which the entire process was stable by changing the value of each SP. We used the HMI operation task scheduler to periodically set the SPs to random values within the normal range to simulate the benign scenario.

No	Point	Unit	Min/max	Normal range
1	P1_B2004	bar	0 ~ 10	0.03 ~ 0.1
2	P1_B3004	mm	0 ~ 720	300 ~ 500
3	P1_B3005	L/H	0 ~ 2500	900 ~ 1,100
4	P1_B4002	℃	0 ~ 100	31 ~ 32
5	P2_SD01	rpm	0 ~ 3600	0 ~ 1,000
6	P3_LH01	%	0 ~ 100	70
7	P3_LL01	%	0 ~ 100	10

ATTACK SCENARIO

An abnormal operating condition is one where some of control facilities are out of the normal range and operate in an unpredictable state owing to an attack or a device malfunction.

Firstly, we simulated several single attacks (SA) and evaluated their effects on control while considering the attack target, attack time, and method for each control loop:

Attack Name	Attack Target			Description
	Loop	Var	Point	
SA1	P1-PC	SP1	P1_B2016	Decrease SP value of P1-PC and then restore in form of trapezoidal profile (hiding SP changes in HMI)
SA2	P1-PC	SP1	P1_B2016	Decrease SP value of P1-PC and then restore in form of trapezoidal profile (hiding SP changes in HMI
		PV1	P1_PIT01	Try to maintain previous sensor value
SA3	P1-PC	CV1	P1_PCV01D	Close press control valve of P1-PC and then restore to normal.
SA4	P1-PC	CV1	P1_PCV01D	Close press control valve of P1-PC and then restore to normal.
		PV1	P1_PIT01	Try to maintain previous sensor value
SA5	P1-FC	SP1	P1_B3005	Decrease SP value of P1-FC and then restore in form of trapezoidal profile (hiding SP changes in HMI)
SA6	P1-FC	SP1	P1_B3005	Decrease SP value of P1-FC and then restore in form of trapezoidal profile (hiding SP changes in HMI)
		PV1	P1_FT03	Try to replay previous sensor value
SA7	P1-LC	SP1	P1_B3004	Increase SP value of P1-LC and then restore in form of trapezoidal profile (hiding SP changes in HMI)
SA8	P1-LC	SP1	P1_B3004	Increase SP value of P1-LC and then restore in form of trapezoidal profile (hiding SP changes in HMI)
		PV1	P1_LIT01	Try to replay previous sensor value
SA9	P1-LC	CV1	P1_LCV01D	Open level control valve of P1-LC and then restore in form of trapezoidal profile
SA10	P1-LC	CV1	P1_LCV01D	Open level control valve of P1-LC and then restore in form of trapezoidal profile
		PV1	P1_LIT01	Try to replay previous sensor value
SA11	P2-SC	SP1	P2_SD01	Decrease SP value of P2-SC and then restore to normal (hiding SP changes in HMI)
SA12	P2-SC	SP1	P2_SD01	Decrease SP value of P2-SC and then restore to normal (hiding SP changes in HMI)
		PV1	P2_SIT01	Try to replay previous sensor value
SA13	P3-LC	SP2	P3_LL01	Decrease SP value of P3-LC and then restore to normal (hiding SP changes in HMI)
		CV2	P3_LCV01	Increase opening rate of level-control valve (P3-LC) and then restore to normal
SA14	P3-LC	SP1	P3_LH01	Increase SP value of P3-LC and then restore to normal (hiding SP changes in HMI)
		CV1	P3_LCP01	Increase pump drive rate of level-control pump (P3-LC) and then restore to normal

Subsequently, the attack scenarios were extended to consider 19 multiple attacks (MA) at the same time by simultaneously executing a combination of SAs.

Attack Name	Single attacks		
	Name	**Variables**	**Points**
MA01	**SA12**	P2-SC-SP1PV1	P2_SP01, P2_SIT01
	SA02	P1-PC-SP1PV1	P1_B2016, P1_PIT01
MA02	**SA11**	P2-SC-SP1	P2_SD01
	SA03	P1-PC-CV1	P1_PCV01D
MA03	**SA12**	P2-SC-SP1PV1	P2_SD01, P2_SIT01
	SA10	P1-LC-CV1PV1	P1_LCV01D, P1_LIT01
MA04	**SA11**	P2-SC-SP1	P2_SD01
	SA05	P1-FC-SP1	P1_B3005
MA05	**SA14**	P3-LC-SP1CV1	P3_LH01, P3_LCP01
	SA01	P1-PC-SP1	P1_B2016
MA06	**SA14**	P3-LC-SP1CV1	P3_LH01, P3_LCP01
	SA08	P1-LC-SP1PV1	P1_B3004, P1_LIT01
MA07	**SA14**	P3-LC-SP1CV1	P3_LH01, P3_LCP01
	SA09	P1-LC-CV1	P1_LCV01D
MA08	**SA07**	P1-LC-SP1	P1_B3004
	SA06	P1-FC-SP1PV1	P1_B3005, P1_FT03
MA09	**SA03**	P1-PC-CV1	P1_PCV01D
	SA06	P1-FC-SP1PV1	P1_B3005, P1_FT03
MA10	**SA02**	P1-PC-SP1PV1	P1_B2016, P1_PIT01
	SA05	P1-FC-SP1	P1_B3005
MA11	**SA13**	P3-LC-SP2CV2	P3_SP02, P3_LCV01
	SA02	P1-PC-SP1PV1	P1_B2016, P1_PIT01
MA12	**SA01**	P1-PC-SP1	P1_B2016
	SA05	P1-FC-SP1	P1_B3005
MA13	**SA13**	P3-LC-SP2CV2	P3_LL01, P3_LCV01
	SA01	P1-PC-SP1	P1_B2016
MA14	**SA13**	P3-LC-SP2CV2	P3_LL01, P3_LCV01
	SA09	P1-LC-CV1	P1_LCV01D
MA15	**SA13**	P3-LC-SP2CV2	P3_SP02, P3_LCV01
	SA05	P1-FC-SP1	P1_B3005
MA16	**SA11**	P2-SC-SP1	P2_SD01
	SA13	P3-LC-SP2CV2	P3_LL01, P3_LCV01
MA17	**SA11**	P2-SC-SP1	P2_SD01
	SA07	P1-LC-SP1	P1_B3004
MA18	**SA07**	P1-LC-SP1	P1_B3004
	SA01	P1-PC-SP1	P1_B2016
MA19	**SA09**	P1-LC-CV1	P1_LCV01D
	SA03	P1-PC-CV1	P1_PCV01D

DATASET

DATA FILES

The dataset are presented in four CVS files for two sets of the normal and abnormal situations.

DATA FIELDS

The data are listed in 63 columns. The first column represents the local time in the form “yyyy-MM-dd hh:mm:ss,” while the remaining 59 columns show the recordings of the SCADA points. The last four columns are labels whether any attack occurred or not. Here the column “attack” is for all process, while the remaining columns are for the corresponding process.

ATTACK TIMETABLE

	Attack Name	Attack Variables	Attack Points	Start Time		Duration (sec)
1	SA08	P1-LC-SP1PV1	P1_B3004, P1.LIT01	19-10-29	13:40	370
2	SA09	P1-LC-CV1	P1_LCV01D		14:35	312
3	SA10	P1-LC-CV1PV1	P1_LCV01D, P1_LIT01		15:45	868
4	SA05	P1-FC-SP1	P1_B3005		16:30	262
5	SA07	P1-LC-SP1	P1_B3004	19-10-30	8:50	371
6	SA01	P1-PC-SP1	P1_B2016		9:40	334
7	SA02	P1-PC-SP1PV1	P1_B2016, P1_PIT01		10:35	504
8	SA03	P1-PC-CV1	P1_PCV01D		11:37	268
9	SA04	P1-PC-CV1PV1	P1_PCV01D, P1_PIT01		12:30	518
10	SA12	P2-SC-SP1PV1	P2_SD01, P2_SIT01		14:30	370
11	SA14	P3-LC-SP1CV1	P3_LH01, P3_LCP01		15:35	180
12	SA13	P3-LC-SP2CV2	P3_LL01, P3_LCV01		16:33	154
13	SA11	P2-SC-SP1	P2_SD01	19-10-31	8:42	348
14	MA01	P2-SC-SP1PV1	P2_SD01, P2_SIT01		10:30	518
		P1-PC-SP1PV1	P1_B2016, P1_PIT01			
15	MA02	P2-SC-SP1	P2_SD01		11:33	346
		P1-PC-CV1	P1_PCV01D			
16	SA12	P2-SC-SP1PV1	P2_SD01, P2SIT01		13:25	368
17	MA03	P2-SC-SP1PV1	P2_SD01, P2SIT01		14:30	396
		P1-LC-CV1PV1	P1_LCV01D, P1.LIT01			
18	MA04	P2-SC-SP1	P2_SD01		15:41	348
		P1-FC-SP1	P1_B3005			

	Attack Name	Attack Variables	Attack Points	Start Time		Duration (sec)
19	MA05	P3-LC-SP1CV1	P3_LH01, P3_LCP01		16:29	398
		P1-PC-SP1	P1_B2016			
20	MA06	P3-LC-SP1CV1	P3_LH01, P3_LCP01	19-11-01	9:29	560
		P1-LC-SP1PV1	P1_B3004, P1_LIT01			
21	MA07	P3-LC-SP1CV1	P3_LH01, P3_LCP01		10:41	310
		P1-LC-CV1	P1_LCV01D			
22	SA14	P3-LC-SP1CV1	P3_LH01, P3_LCP01		11:23	180
23	MA08	P1-LC-SP1	P1_B3004		12:31	580 506
		P1-FC-SP1PV1	P1_B3005, P1_FT03			
24	MA09	P1-PC-CV1	P1_PCV01D		13:41	580
		P1-FC-SP1PV1	P1_B3005, P1_FT03			
25	SA01	P1-PC-SP1	P1_B2016		14:23	310
26	MA10	P1-PC-SP1PV1	P1_B2016, P1_PIT01		15:31	560 520
		P1-FC-SP1	P1_B3005			
27	SA06	P1-FC-SP1PV1	P1_B3005, P1_FT03		16:18	560
28	MA11	P3-LC-SP2CV2	P3_LL01, P3_LCV01		17:20	410 520
		P1-PC-SP1PV1	P1_B2016, P1_PIT01			
29	MA12	P1-PC-SP1	P1_B2016	19-11-04	15:31	410
		P1-FC-SP1	P1_B3005			
30	MA13	P3-LC-SP2CV2	P3_SP02, P3_LCV01		17:20	520
		P1-PC-SP1	P1_B2016			
31	MA14	P3-LC-SP2CV2	P3_SP02, P3_LCV01	19-11-05	9:30	380
		P1-LC-CV1	P1_LCV01D			
32	MA15	P3-LC-SP2CV2	P3_SP02, P3_LCV01		10:20	290
		P1-FC-SP1	P1_B3005			
33	SA11	P2-SC-SP1	P2_SD01		11:23	340
34	MA16	P2-SC-SP1	P2_SD01		12:30	2880 340
		P3-LC-SP2CV2	P3_LL01, P3_LCV01			
35	MA17	P2-SC-SP1	P2_SD01		14:45	2880
		P1-LC-SP1	P1_B3004			
36	MA18	P1-LC-SP1	P1_B3004		16:20	330
		P1-PC-SP1	P1_B2016			
37	SA09	P1-LC-CV1	P1_LCV01D		17:23	310
38	MA19	P1-LC-CV1	P1_LCV01D	19-11-06	8:58	310
		P1-PC-CV1	P1_PCV01D			

ABBREVIATIONS

C

CV	Control Variable

D

DCS	Distributed Control System

F

FC	Flow Controller
FCV	Flow Control Valve
FIT	Flow Indicator Transmitter
FT	Flow Transmitter

H

HMI	Human Machine Interface

L

LC	Level Controller
LCV	Level Control Valve
LIT	Level Indicator Transmitter
LLH	Liquid Level [High]
LLL	Liquid Level [Low]
LLN	Liquid Level [Normal]
LSH	Level Switch [High]
LSHL	Level Switch [High/Low]
LSL	Level Switch [Low]
LT	Level Transmitter

P

PC	Pressure Controller
PCL	Process Control Loop
PCV	Pressure Control Valve
PIT	Pressure Indicator Transmitter
PLC	Programmable Logic Controller
PV	Process Variable

S

SC	Speed Controller
SI	Speed Indicator
SIT	Speed-Indicator Transmitter
SP	Setpoint
SS	Steam Supply

T

TCV	Temperature Control Valve
TIT	Temperature Indicator Transmitter
TT	Temperature Transmitter

V

VT	Vibration Transmitter