Four-Tank Batch Process in Smart Automation

Description of Fault Types in an Industrial Application

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1 Four-Tank Batch Process in Smart Automation Karlsruhe

1.1 Research Plant Smart Automation

The research plant Smart Automation (SmA) is operated by Siemens at site Karlsruhe, Germany. SmA is a process plant for research topics in the field of engineering, operation, security, digital twin, cloud services, industrial IoT, edge, virtual and augmented reality. As medium water is used. Figure 1 shows a photograph of the research plant Smart Automation. The research plant features four tanks as part of the infrastructure backbone which has been used to simulate several fault types.

Figure 1: Research plant Smart Automation

1.2 Description of Four-Tank Batch Process

A four-tank batch process pumps water from a reservoir tank to three small tanks. The plant is controlled using a sequential flow chart (SFC) simulating a batch process according to ISA-88. In order to identify the current SFC step, a step identifier (StepID) is introduced.

A reservoir vessel (VE1000) contains water. In step 1 (StepID 1), vessel VE2100 is filled. The valves between the vessels of the three-tank system (VE2100, VE2200, VE2300) and the valve between vessel VE2300 and vessel VE1000 (outflow valve) are closed. A pump fills water into vessel VE2100 till it contains 14 liters. In step 2, (StepID 7), the valve to vessel VE2100 is closed. The valves between the tanks and the outflow valve are set to 75 %. Step 2 ends when vessel VE2100 contains 5 liters. In step 3 (StepID 8), the valves to vessels VE2100 and VE2300 are opened. Thereby, the pump fills water in VE2100 and VE2300. Step 3 ends when vessel VE2300 contains 10 liters. In step 4 (StepID 3), the three inlet valves to the three vessels (YS21001, YS22001, YS23001) are closed. The valves between the vessels and the outflow valve are fully opened. Step 4 ends when all three vessels have been emptied containing less than 2 liters. Next, the sequential flow chart starts step 1 again.

In the following figure a flow chart of the process summarizes the steps.

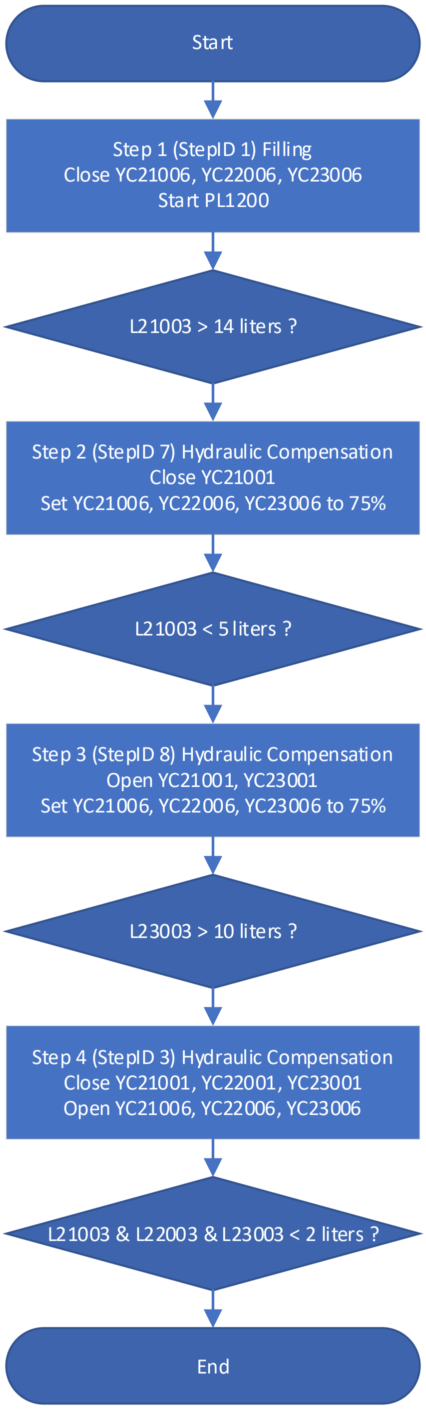

Figure 2: Flow chart of process steps

1.3 Fault Types and P&ID

The four-tank batch process has been operated in normal operation and in 9 fault types. The operational state is indicated by the Deviation ID.

Table 1 describes the fault types and the introduced changes. The location of the fault types in the plant is marked in Figure 3.

Figure 4 shows a simplified piping and instrument diagram (P&ID) of the plant.

Table 1: Fault types

#	Failure type	Deviation in StepID	PL1200/ DriveSpeed Contr	PL1100/ DriveSpeed Contr	YC21006/ Valve $Analog	YC22006/ Valve $Analog	YC23006/ Valve $Analog	YS14005/ Valve (Spray-Ball)	PL2150/ DriveSpeed Contr	YS14004	YS10004	Deviation ID
1	normal operation	-	2600 1/min	0 1/min	75%	75%	75%	0%	0 Hz	0%	100%	1
2	low drive speed	1 till 3	2300 1/min	0 1/min	75%	75%	75%	0%	0 Hz	0%	100%	2
3	high drive speed	1 till 3	2900 1/min	0 1/min	75%	75%	75%	0%	0 Hz	0%	100%	3
4	2nd pump	1 till 3	2600 1/min	2600 1/min	75%	75%	75%	0%	0 Hz	0%	100%	4
5	stuck valve	7 till 3	2600 1/min	0 1/min	100%	75%	75%	0%	0 Hz	0%	100%	5
6	stuck valve	7 till 3	2600 1/min	0 1/min	75%	100%	75%	0%	0 Hz	0%	100%	6
7	stuck valve	7 till 3	2600 1/min	0 1/min	75%	75%	100%	0%	0 Hz	0%	100%	7
8	short circuit	1 till 3	2600 1/min	0 1/min	75%	75%	75%	100%	0 Hz	0%	100%	8
9	leakage	1 till 7	2600 1/min	0 1/min	75%	75%	75%	0%	10 Hz	100%	100%	9
10	no venting	1 till 2	2600 1/min	0 1/min	75%	75%	75%	0%	0 Hz	0%	0%	10

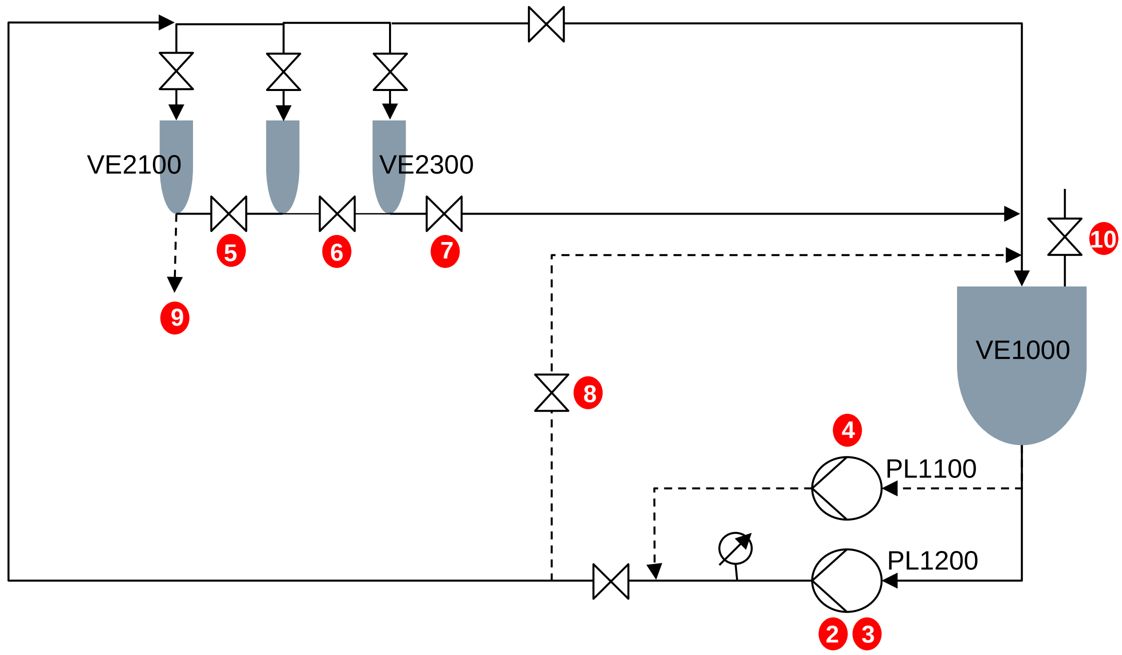

Figure 3: Schematic overview of fault types

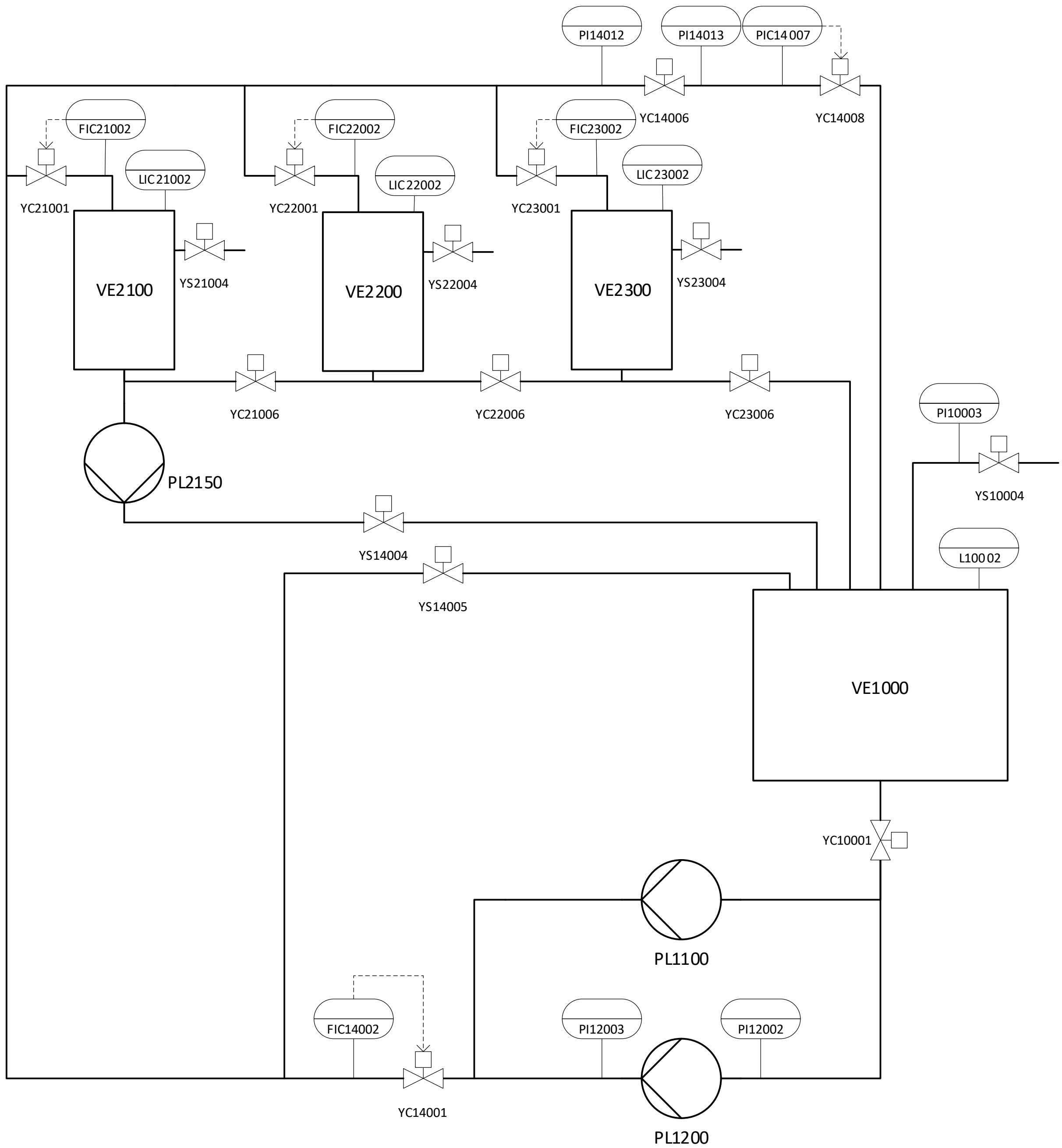

Figure 4: Simplified P&ID of SmA

1.4 Data points

In this section, the measurement variables (data points) are listed.

The data set consists of the Deviation ID, which indicates the fault type, the current step number of the sequential flow chart and 40 time series of different measurement variables and covers about 180 batches. The batches are not of equal length as some faults influence the batch runtime. The data corresponds to the original measurement from the distributed control system with measurement noise and without any preprocessing.

Table 2: Data points 1 out of 2

#	column	description	include in evaluation
1	DeviationID ValueY	deviation ID; indicates the fault type	
2	CuStepNo ValueY	current step number	x
3	LevelMainTank ValueY	level of main vessel (VE1000), measured by L10002	x
4	YC10001_MV ValueY	control valve YC10001	x
5	PI12002_PV_Out ValueY	inlet pressure pump PL1200	x
6	PI12003_PV_Out ValueY	outlet pressure pump PL1200	x
7	YC14001_MV ValueY	control valve YC14001	x
8	FIC14002_MV ValueY	manipulated value for controller for flow out of vessel VE1000	x
9	FIC14002_PV_Out ValueY	measurement value for controller for flow out of vessel VE1000	x
10	FIC14002_SP ValueY	set point for controller for flow out of vessel VE1000	x
11	PI14013_PV_Out ValueY	pressure after control valve YC14006	x
12	YC14006_MV ValueY	control valve YC14006	x
13	PI14012_PV_Out ValueY	pressure before control valve YC14006	x
14	YC23001_MV ValueY	control valve for inlet of vessel VE2300	x
15	YC22001_MV ValueY	control valve for inlet of vessel VE2200	x
16	YC21001_MV ValueY	control valve for inlet of vessel VE2100	x
17	FIC23002_PV_Out ValueY	measurement value for controller for volume flow into vessel VE2300	x
18	FIC23002_MV ValueY	manipulated value for controller for volume flow into vessel VE2300	x
19	FIC23002_SP ValueY	set point for controller for volume flow into vessel VE2300	x
20	FIC22002_MV ValueY	manipulated value for controller for volume flow into vessel VE2200	x
21	FIC22002_PV_Out ValueY	measurement value for controller for volume flow into vessel VE2200	x
22	FIC22002_SP ValueY	set point for controller for volume flow into vessel VE2200	x
23	FIC21002_MV ValueY	manipulated value for controller for volume flow into vessel VE2100	x

Table 3: Data points 2 out of 2

24	FIC21002_PV_Out ValueY	measurement value for controller for volume flow into vessel VE2100	x
25	FIC21002_SP ValueY	set point for controller for volume flow into vessel VE2100	x
26	YS23004_Ctrl ValueY	valve connecting vessel VE2300 to ambient	x
27	YS22004_Ctrl ValueY	valve connecting vessel VE2200 to ambient	x
28	YS21004_Ctrl ValueY	valve connecting vessel VE2100 to ambient	x
29	LIC23002_MV ValueY	manipulated value for controller for level of vessel VE2300	x
30	LIC23002_PV_Out ValueY	measurement value for controller for level of vessel VE2300	x
31	LIC23002_SP ValueY	set point for controller for level of vessel VE2300	x
32	LIC22002_MV ValueY	manipulated value for controller for level of vessel VE2200	x
33	LIC22002_PV_Out ValueY	measurement value for controller for level of vessel VE2200	x
34	LIC22002_SP ValueY	set point for controller for level of vessel VE2200	x
35	LIC21002_MV ValueY	manipulated value for controller for level of vessel VE2100	x
36	LIC21002_PV_Out ValueY	measurement value for controller for level of vessel VE2100	x
37	LIC21002_SP ValueY	set point for controller for level of vessel VE2100	x
38	PIC14007_MV ValueY	manipulated value for controller for pressure in pipe between vessel VE2300 and VE1000	x
39	PIC14007_PV_Out ValueY	measurement value for controller for pressure in pipe between vessel VE2300 and VE1000	x
40	PIC14007_SP ValueY	set point for controller for pressure in pipe between vessel VE2300 and VE1000	x
41	YC14008_Ctrl ValueY	control valve between vessel VE2300 and vessel VE1000	x
42	PI10003_PV_Out ValueY	pressure in vessel VE1000	x

2 Description of Classification Goal

The different fault types should be classified, ideally also normal operation. As for a real production process neither the number of different faults nor fault labels are available, these information must not be used for training.

The application of a suitable classification algorithm would be as follows:

- The algorithm is trained with available historical data. If necessary, the algorithm could just be trained with faults. In this case, it is assumed, that an anomaly detection is running in parallel and only the detected faults need to be classified.
- After training the classification is performed with every new dataset or, in case of the anomaly detection, with every new abnormal dataset. The algorithm should find the corresponding cluster, and therefore, could identify historical datasets with the same failure. Ideally, this is possible even when the failure only has occurred once.
- Afterwards the new dataset could be used as additionally training data.

It would be also beneficial, if it’s not possible to clearly identify the correct cluster, to compute possible clusters together with a measure or probability for the respective membership.

In addition, an algorithm with the ability of analyzing the production even before it was finished enables faster reaction of the operators. A reliability measure is a prerequisite in this case.