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INTEGRATION OF HART AND FF H1 DEVICES INTO DISTRIBUTED CONTROL SYSTEM FOR FEEDFORWARD CONTROL IN REVAMPING EXISTING PLANTS

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Abstract. *To revamp existing process plants that use Highway Addressable Remote Transducer (HART) communication technology, reusing the existing instruments which are still available in the market to combine with new Foundation Fieldbus (FF) H1 instruments in the same control system can become a cost-effective strategy for digital modernization. This paper aims at presenting an engineering method based on IEC 61804 standard for integrating a HART field device and FF H1 devices into a distributed control system (DCS) to operate together in a feedforward control loop. To verify the performance of the proposed method, the feedforward on temperature control configured and handled on the DeltaV DCS is employed as an illustrative case study. Moreover, how different analog-input (AI) function block assignments to the HART and FF transmitters for measuring the controlled variable and disturbance input as well as how different proportional-integral-derivative (PID) function block allocations to the DCS controller and FF field devices affect the H1 segment macrocycle schedules and network traffic loads is also analyzed. Experimental results obtained from some control configuration schemes demonstrate that the combined HART-FF H1 technique can maintain the controlled variable at the setpoint in the presence of disturbances for feedforward control.*
Keywords: HART, FF H1, DCS, IEC 61804, Feedforward, Function block, Macrocycle

1. **Introduction.** In transition from traditional analog transmission, chemical plants constructed in last few decades are usually instrumented with field devices interfacing to host systems by using Highway Addressable Remote Transducer (HART) to monitor and control process parameters [1]. The unique aspect of HART is a hybrid of frequency-shift-keying digital communication and analog 4-20 mA signal. HART was designed to improve work procedures for configuration, calibration, diagnostics, and other device functions, while maintaining the compatibility with traditional control systems using 4-20 mA instruments. Because of its low baud rate, the HART analog signal continues to be utilized in point-to-point wiring for control applications. Thus, the capability of HART digital communications is only employed occasionally by connecting portable configuration tool in most plants [2]. In order to modernize existing process plants at the field level, Foundation Fieldbus (FF) H1 can be employed in bus and tree topologies [3]. The unique aspect of FF is a distribution of control function into field instruments to reduce the host controller and network traffic loads [4]. Moreover, the 'Control-in-the-Field' concept enables the enhancement of process safety and production availability [5,6]. Recently, a technique to combine analog 4-20 mA and FF H1 devices for creating a proportional-integral-derivative (PID) control loop in revamping projects has been introduced [7]. This

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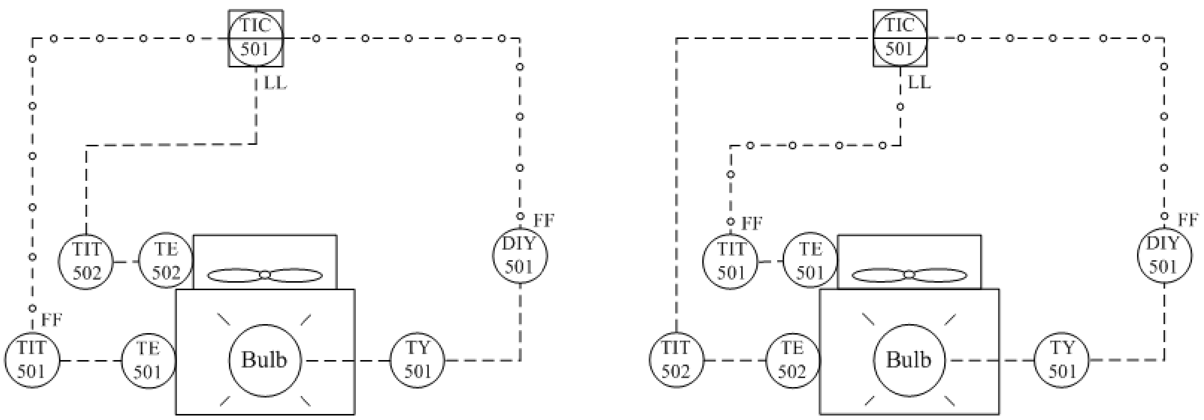
suggested technique is based on the employment of the PID instruction of a programmable logic controller (PLC) to regulate the measured process variable. Alternatively, a method to build the PID control loop by combining HART and FF H1 devices to work together in revamping projects has been presented [8]. This suggested method is based on the function block-type graphical language defined in IEC 68104 standard for integrating HART and FF H1 instruments into the DCS host. The purpose of this article is to present the similar integration method based on IEC 61804 standard to combine HART and FF H1 field devices in the same control loop. However, this integration technique is applied to feedforward control implemented with dynamic compensation. The feedforward on temperature control by modifying a laboratory-scale plant proposed in [9] for combination of HART and FF H1 devices as well as for configuration and operation on the DeltaV DCS host is employed as a case study to verify the effectiveness of the proposed integration.

This article is divided into five sections including this introduction. Section 2 and Section 3 describe the case study on temperature control and the proposed integration method, respectively. Section 4 provides experimental results, and Section 5 gives the conclusions and possible directions for future research.

2. **Case Study on Temperature Control.** The modified laboratory-scale plant to integrate HART and FF H1 instruments into the DeltaV DCS host for feedforward on temperature control is used as the case study. Figure 1 displays the piping and instrumentation diagrams (P&IDs) of the studied process control, when defining the temperature generated by an electric bulb rated 100 W at 220 Vac and the temperature generated by a fan operation as a controlled variable and a process disturbance, respectively. There are two interesting cases for device installation to combine the FF H1 temperature transmitter and fieldbus-to-current converter (TIT_501 and DIY_501) and the HART temperature transmitter (TIT_502) into the same feedforward control loop. The major details of field devices utilized are given in Table 1. The TIT_501 and TIT_502 transmitters are connected to measure the controlled parameter and the disturbance input by using the temperature sensing elements (TE_501 and TE_502), respectively, as shown in Figure 1(a). Otherwise, the TIT_501 and TIT_502 are used to measure the disturbance input and the controlled parameter, respectively, as shown in Figure 1(b). Before applying the measured disturbance input in feedforward path to combining with the feedback algorithm inside the temperature indicator controller (TIC_501), a lead/lag (LL) function is employed for dynamic compensation. The DIY_501 is installed for converting the controller output into



(a) Case 1 (b) Case 2

FIGURE 1. Two interesting cases for installing the HART and FF H1 devices

TABLE 1. Major details of field devices utilized in case study

Tag	Device Function	Manufacturer	Device Model
TIT_501	FF H1 Temperature Transmitter	Rosemount	3144P
TIT_502	HART Temperature Transmitter	Rosemount	644
DIY_501	FF H1 Fieldbus-to-Current Converter	Smar	FI302
TY_501	SCR-Based Power Regulator	Sangi Electric	SCR-1A030

the 4-20 mA signal for applying to the power regulator (TY_501), which is utilized to vary a power supply of the bulb.

3. **Proposed Integration Method.** Based on function blocks for process control and electronic device description language (EDDL) specified in IEC 61804 standard, the DCS manufacturers can create a single engineering platform to support field devices with diverse data transmission technologies [2,10]. Figure 2 shows the function block diagram for configuring the feedforward control with lead-lag dynamic compensation on the Control Studio application of the DeltaV DCS host. The AI1 and AI2 analog input blocks must be in the transmitters for measuring the controlled parameter and the disturbance input, respectively. The AI1 block output (OUT) is linked to the PID1 block input (IN), while the AI2 block output is linked to the LL1 block input. Since all two FF H1 devices used do not provide the lead/lag function block, the LL1 block is then allocated to the DCS host controller for compensating differences in process response to changes in measured disturbance and manipulated variable. The LL1 block output is linked to the additive feedforward input (FF_VAL) of the PID1 block, which can be alternatively assigned in

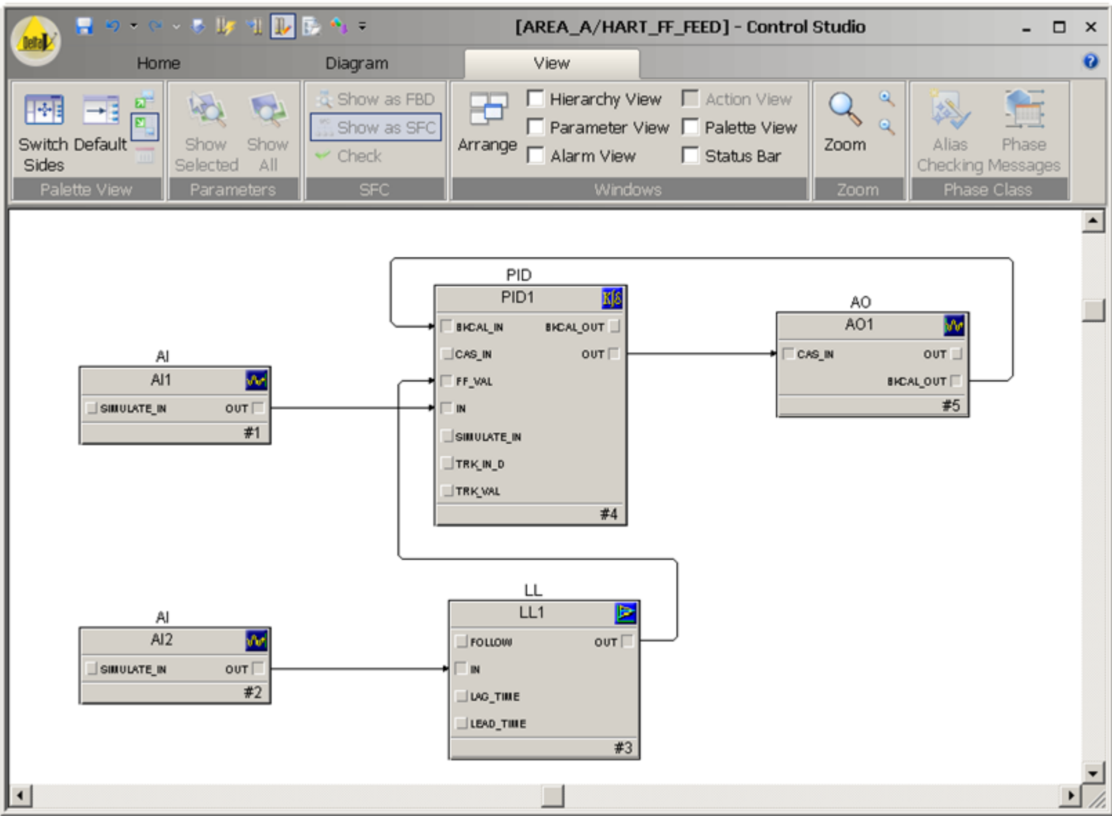


FIGURE 2. Function block diagram for configuring feedforward control on the DetlaV host

the DCS host controller or the FF H1 devices. The PID1 block output is linked to the cascade input (CAS_IN) of the AO1 analog output block that must be in the DIY_501 converter to produce the current control signal of the TY_501 power regulator for further adjustment of the bulb power supply. The back-calculation output (BKCAL_OUT) of the AO1 block is linked to the back-calculation input (BKCAL_IN) of the PID1 block for providing safety and bumpless transfer as well as for preventing integral windup. The internal links between function blocks in the same device do not require to be communicated over the network, whereas the external links between function blocks in different devices are communicated over the network. In order to examine how different function block placements affect the H1 segment macrocycle schedules and network traffic loads, the offline device and control configurations to create the control module named 'HART_FF_FEED' on the DeltaV host were performed. Based on the P&IDs of Figures 1(a) and 1(b), Table 2 summarizes all six possible configuration schemes to build the studied feedforward on temperature control as illustrated in Figure 2. In case of configuring the AI block to the FF H1 transmitter (TIT_501), the CHANNEL parameter is employed to set the transducer block from which the analog measurement value is taken. In case of configuring the AI block to the HART transmitter (TIT_502), the HART-Analog-Input-Channel type is selected, and the FIELD_VAL_PCT is its associated channel parameter. To save space, only the control configuration utilizing the Control Studio application for Scheme 1 is shown in Figure 3 for illustrating how to assign function blocks to the field devices and host controller. Figures 4(a)-4(f) show the H1 segment macrocycle schedules

Table 2. Possible configuration schemes for creating the feedforward loop of Figure 2

Scheme	AI1	AI2	PID1	LL1	AO1
1	TIT_501	TIT_502	Host Controller	Host Controller	DIY_501
2	TIT_501	TIT_502	TIT_501	Host Controller	DIY_501
3	TIT_501	TIT_502	DIY_501	Host Controller	DIY_501
4	TIT_502	TIT_501	Host Controller	Host Controller	DIY_501
5	TIT_502	TIT_501	TIT_501	Host Controller	DIY_501
6	TIT_502	TIT_501	DIY_501	Host Controller	DIY_501

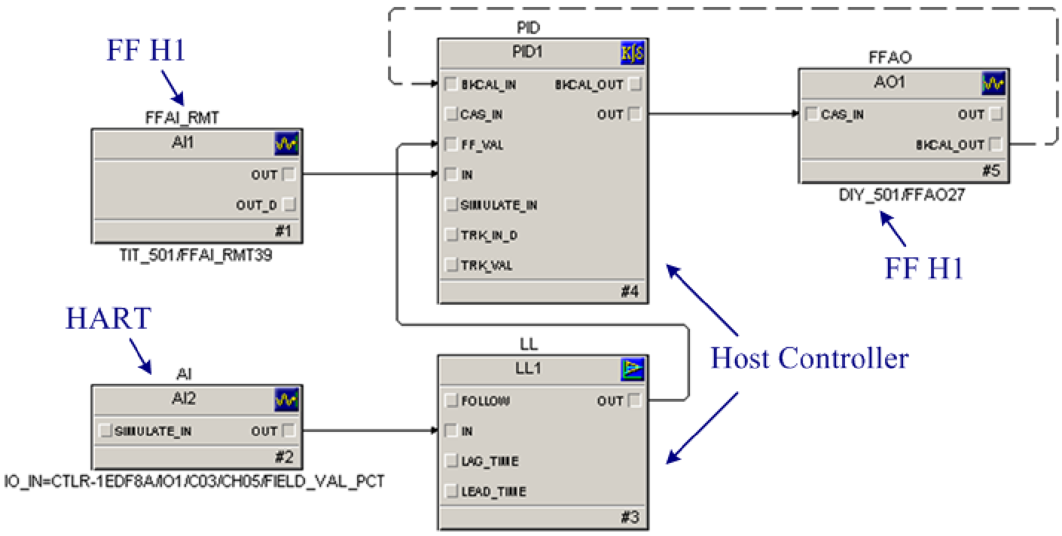
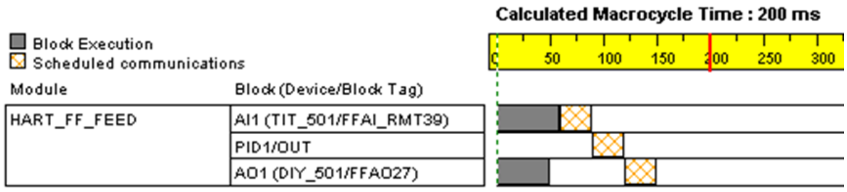
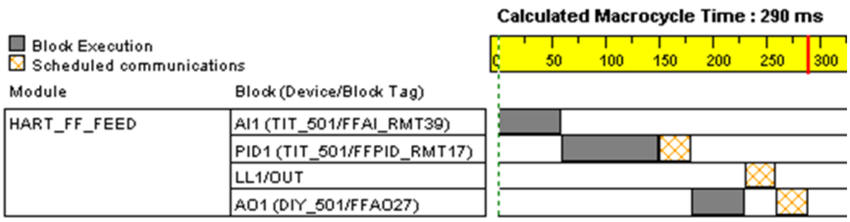


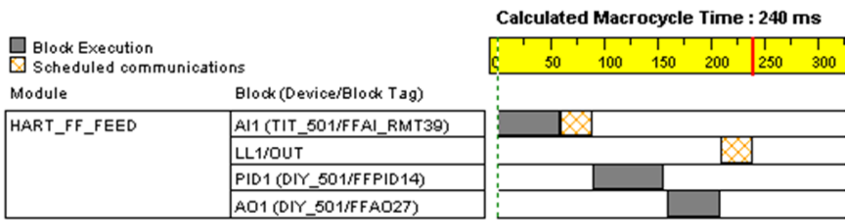
Figure 3. Example of function block assignment for configuring the Scheme 1



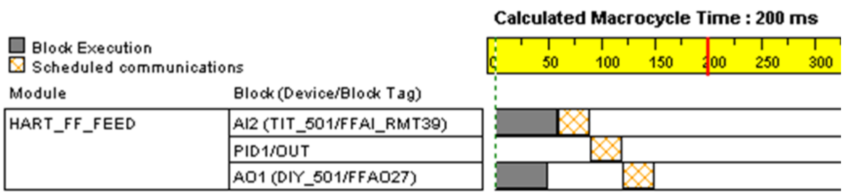
(a) Scheme 1



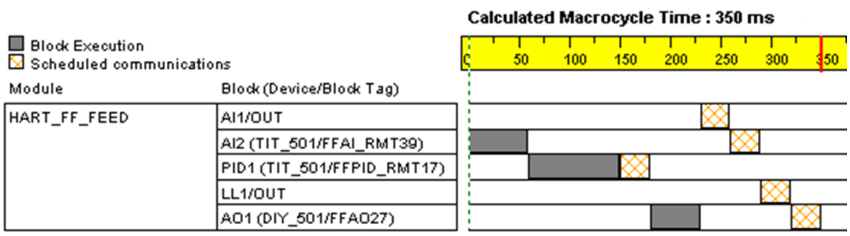
(b) Scheme 2



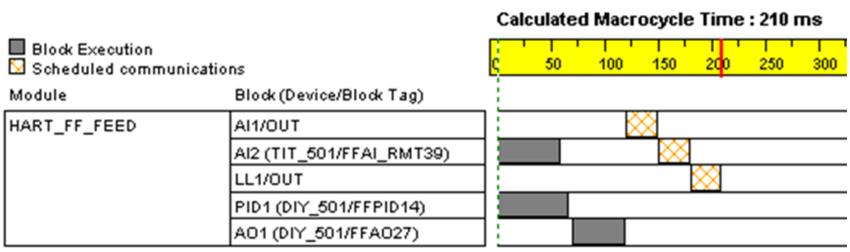
(c) Scheme 3



(d) Scheme 4



(e) Scheme 5



(f) Scheme 6

FIGURE 4. Macrocycle schedules generated for different configuration schemes of Table 2

for configuring Schemes 1-6, respectively. These schedules generated by the DeltaV host are used to specify the order of FF function block executions and the communication of the function block external links. The execution times of the function blocks running in the TIT_502 transmitter and the host controller are excluded in the macrocycle schedules. The execution times of the AI and PID blocks located in the TIT_501 transmitter are 60 ms and 90 ms, respectively. The execution times of the PID and AO blocks located in the DIY_501 converter are 67 ms and 50 ms, respectively. The time period required for each scheduled data transmission for external function block links is 30 ms. The network traffic loads for scheduled data communications during the calculated macrocycle schedules for Figures 4(a)-4(f) are summarized in Table 3. It is seen that configuring the feedforward loop by using Schemes 1 and 4 provides the shortest calculated macrocycle schedule and maximum network traffic load, while configuring the feedforward loop by using Scheme 3 provides the minimum network traffic load. Thus, the device installation of Case 1 is preferred for combining the HART transmitter and the FF H1 instruments into the same control strategy.

Table 3. Calculated macrocycle times and network traffic loads

Scheme	P&ID for Installation	Number of External Links	Time for External Links	Calculated Macrocycle	Network Load
1	Case 1	3	90 ms	200 ms	45.00%
2	Case 1	3	90 ms	290 ms	31.03%
3	Case 1	2	60 ms	240 ms	25.00%
4	Case 2	3	90 ms	200 ms	45.00%
5	Case 2	5	150 ms	350 ms	42.86%
6	Case 2	3	90 ms	210 ms	42.86%

4. **Experimental Results.** Figure 5 depicts the experimental setup to verify the proposed integration performance for the studied feedforward on temperature control in case of the HART and FF H1 device installation according to the P&ID of Case 1 and the control loop configuration by employing Schemes 1-3. Table 4 gives the major function block parameters used in experiments, and Table 5 summarizes the settling time values for 0-25% step response and recovery time values at the setpoint of 25% under disturbance caused by the fan operation. It is seen that the feedforward control configuration by using Scheme 1 to assign the PID1 function block to the DCS host controller offers the shortest settling time, whereas the feedforward control configuration by using Scheme 2 to allocate the PID1 function block to the FF H1 transmitter provides the shortest recovery time. Therefore, the function block allocation has impacts on the control performance. In order to save the space, only the step and disturbance responses recorded by the Process History View application for configuring the control loop with Scheme 2 are shown in Figures 6(a) and 6(b), respectively. It is apparent that the HART and FF H1 field instruments can be integrated into the DCS host to work together in the same loop for automatic feedforward control of the studied temperature process. The combined HART-FF H1 control loop enables users to decide for allocating the PID function block to run either in the DCS host controller or in the FF H1 devices to meet their requirements.

5. **Conclusions.** An engineering method based on IEC 61804 standard for creating the feedforward control with lead-lag dynamic compensation by integration of the HART and FF H1 field instruments into the DCS host to reuse the HART device in revamping existing plants has been presented. The feedforward on temperature control configured

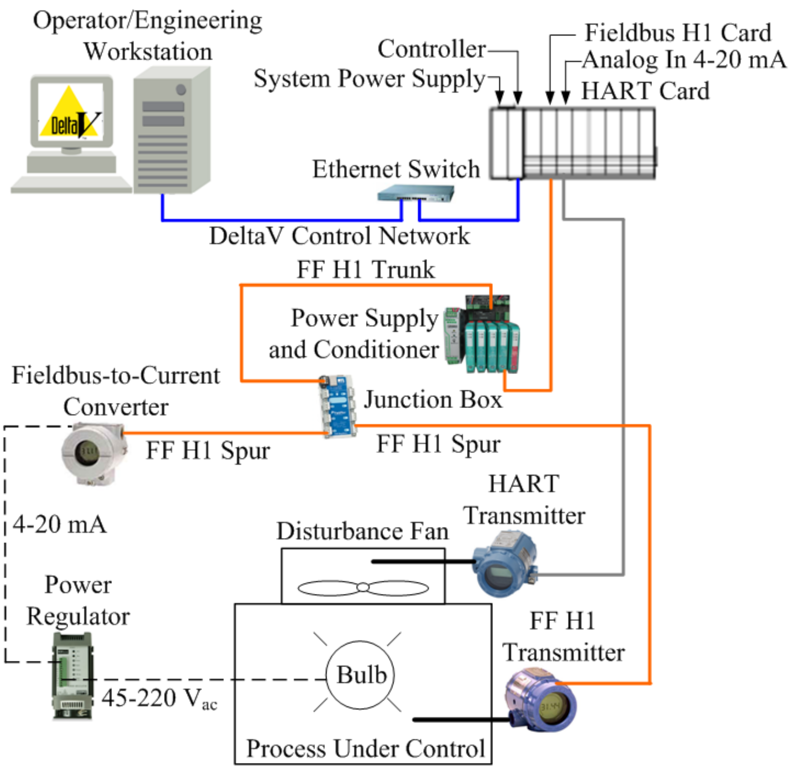


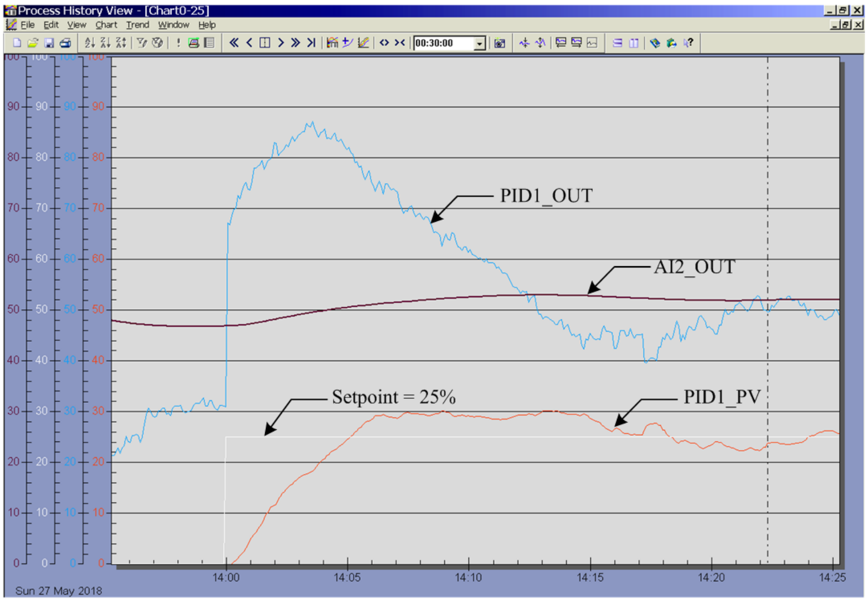
FIGURE 5. Experimental setup for feedforward control with device installation of Case 1

TABLE 4. Major function block parameters used in experiments

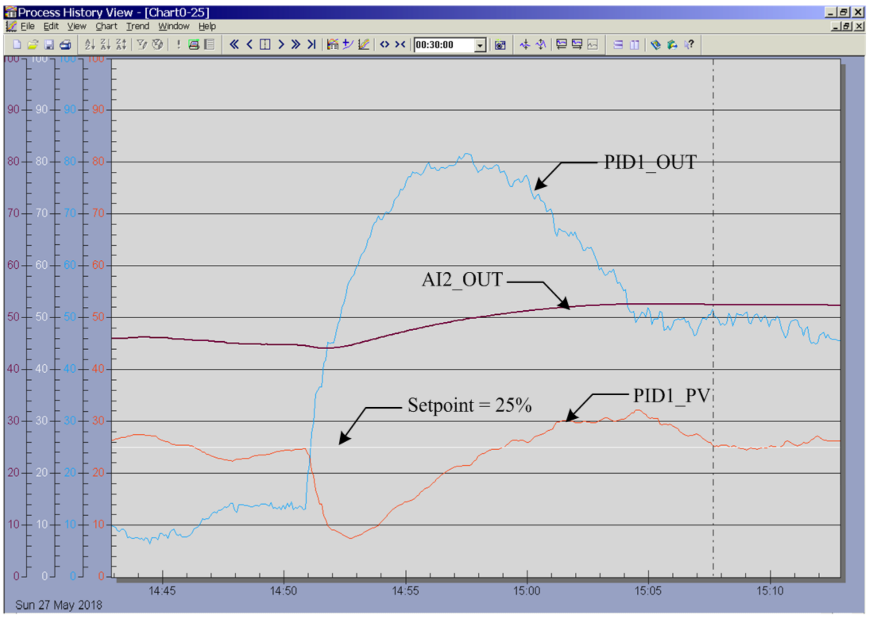
Function Block	Parameter	Configured Value
HART AI Block	IO_IN	TIT_502/FIELD_VAL_PCT
	XD_SCALE	0-100°C
	OUT_SCALE	0-100%
	L_TYPE	Indirect
FF AI Block	CHANNEL	1
	XD_SCALE	40-60°C
	OUT_SCALE	0-100%
	L_TYPE	Indirect
FF AO Block	CHANNEL	1
	PV_SCALE	0-100%
	XD_SCALE	4-20 mA
LL Block	GAIN	0.92
	LAG_TIME	198 s
	LEAD_TIME	616.8 s
PID Block	FF_GAIN	0.3
	FF_SCALE	0-100%
	PV_SCALE	0-100%
	OUT_SCALE	0-100%
	GAIN	1.4
	RESET	99.2 s
	RATE	18.5 s

Table 5. Experimental results from the control configurations of Schemes 1-3

Scheme	Settling time for 0-25% step response	Recovery time at setpoint of 25% under disturbance
1	20.23 min	18.13 min
2	23.23 min	16.48 min
3	23.29 min	19.46 min



(a) Step response



(b) Disturbance response

Figure 6. Step and disturbance responses from the control configuration of Scheme 2

and operated on the DetlaV has been utilized as the case study to confirm the proposed technique workability. Other function block parameters to be set for operating the control loop to obtain more benefits of smart field instruments are required to examine in the future work.

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