ICIC Express Letters
Part B: Applications
Volume **7**, Number **11**, November **2016**

ICIC International ©2016 ISSN 2185-2766
pp. 2339–2346

COMMUNICATION SCHEDULE OPTIMIZATION FOR FOUNDATION FIELDBUS H1 SEGMENT WITH DUAL CASCADE CONTROL LOOPS

Thaksin Sangsuwan, Sawai Pongswatd and Amphawan Julsereewong

Faculty of Engineering
King Mongkut's Institute of Technology Ladkrabang
Ladkrabang, Bangkok 10520, Thailand
sangsuwan.iee@gmail.com; { sawai.po; amphawan.ju }@kmitl.ac.th

Received April 2016; accepted July 2016

Abstract. *This paper proposes a method for optimizing communication schedules of dual cascade control loops within the same Foundation Fieldbus (FF) H1 segment. Integrated Harmonas-DEO host system is utilized as a configuration tool for building control strategy and scheduling macrocycle of the studied H1 segment, which consists of two level-to-flow cascade control loops. Communication schedule optimization of two different cases of assigning control functions to run in the field devices is described. Method validation is based on the use of three metrics: latency improvement, publication gap improvement, and macrocycle utilization improvement. Comparison results between the natural macrocycle and optimized macrocycle show that the proposed method can improve not only the latency of control loop but also the availability of communication bandwidth.*

Keywords: Foundation Fieldbus (FF), H1 segment, Cascade control, Communication schedule, Macrocycle, Optimization

1. **Introduction.** Nowadays, digital communications play the vital role for controlling industrial processes. The Foundation Fieldbus (FF) H1 is a well-known digital fieldbus technology widely used as the field-level network standard in process industry [1]. A unique feature of FF system ensuring device interoperability is its use of a standard user layer based on blocks and device descriptions. Several types of standard function blocks are available to perform various functions required in process automation. In addition, FF provides an optional control scheme known as 'Control in the Field' (CIF) by placing the control function to run in an H1 field instrument [2]. Using CIF approach for creating simple proportional-integral-derivative (PID) control loop or cascade control loop can not only reduce the network load for scheduled communications but also increase the network bandwidth for unscheduled communications [3-5]. In addition, it is possible to execute more than one control loops in an H1 segment and still meets fast control response requirement by implementing CIF architecture. Two or three separate control loops can be configured to run on one H1 segment. However, the optimization of communication schedules is still required for improving system performance. Interesting methods to optimize communication schedules for an H1 segment with dual PID control loops [6] and an H1 segment with single cascade control loop [7] have been suggested. Nevertheless, none of them focuses on the optimization of macrocycles generated for operating two cascade control loops on the same H1 segment.

The aim of this paper is then to present an effective method to optimize the communication schedules during system engineering phase for H1 segment with dual cascade control loops. This paper consists of six sections including this introduction. Section 2 and Section 3 describe the studied H1 segment for running two independent cascade control loops and cascade control strategy using FF function blocks, respectively. Section 4 and Section 5 provide the proposed optimization method and the comparison results between non-optimized and optimized communication schedules, respectively. Finally, Section 6 gives the conclusions.

2. Studied H1 Segment.

Figure 1 shows a system architecture of the studied H1 segment with dual cascade control loops. The integrated Harmonas-DEO host system from Azbil is used for building control strategy as well as scheduling segment macrocycle. The FF H1 devices are installed in two plant models of level-to-flow cascade control. The first control loop consists of a level transmitter (LIT_101), flow transmitter (FIT_101), and control valve (FCV_101), while the second control loop consists of a level transmitter (LIT_201), flow transmitter (FIT_201), and control valve (FCV_201). Table 1 gives the number of analog input (AI) function block, PID function block, and analog output (AO) function block as well as their block execution time of each H1 field device used for building control strategy.

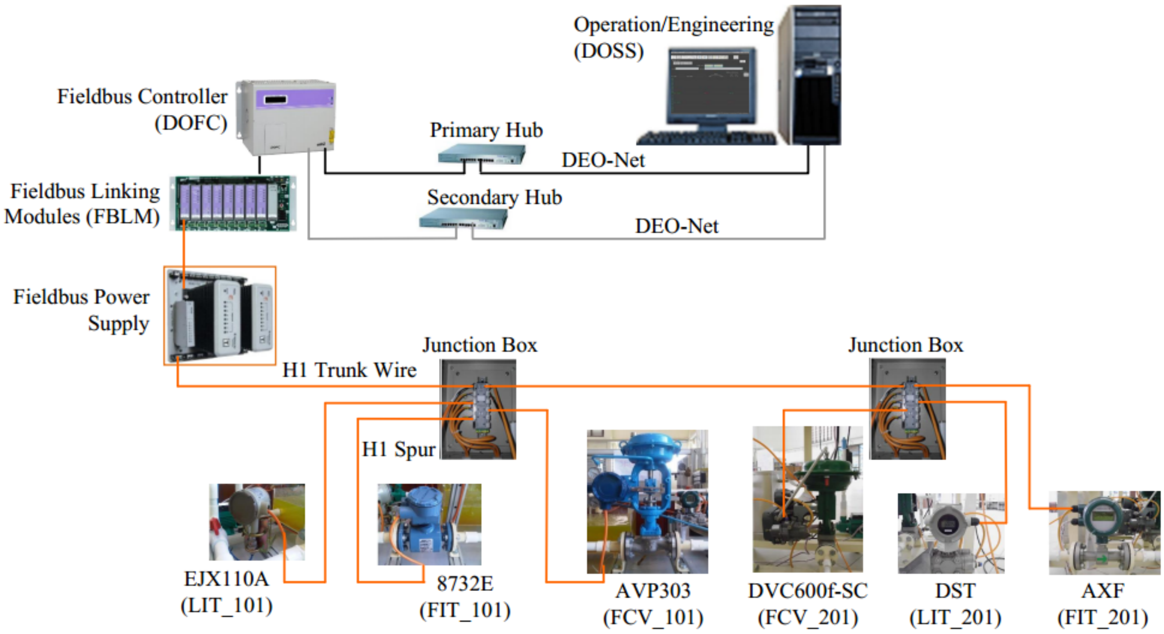


Figure 1. System architecture of the studied H1 segment with dual cascade control loops

Table 1. Number of function blocks and their execution time of H1 devices used

PD-Tag	AI Count	AI Time	PID Count	PID Time*	AO Count	AO Time*
LIT_101	3	30 ms	1	50 ms	N/A	N/A
FIT_101	1	10 ms	1	15 ms	N/A	N/A
FCV_101	N/A	N/A	2	130 ms	1	80 ms
LIT_201	2	80 ms	1	130 ms	N/A	N/A
FIT_201	1	30 ms	1	50 ms	N/A	N/A
FCV_201	1	25 ms	1	30 ms	1	30 ms

*Block execution time includes extra time required by the host system used of 5 ms.

3. Cascade Control Strategy Using FF Function Blocks.

The CIF control strategy based on FF technology can be created by selecting, linking, and parameterizing function blocks located in the H1 field devices within the same segment. The cascade control loop is configured by using five function blocks: primary and secondary AI blocks (AI1 and AI2), primary and secondary PID blocks (PID1 and PID2), and one AO block (AO1), as

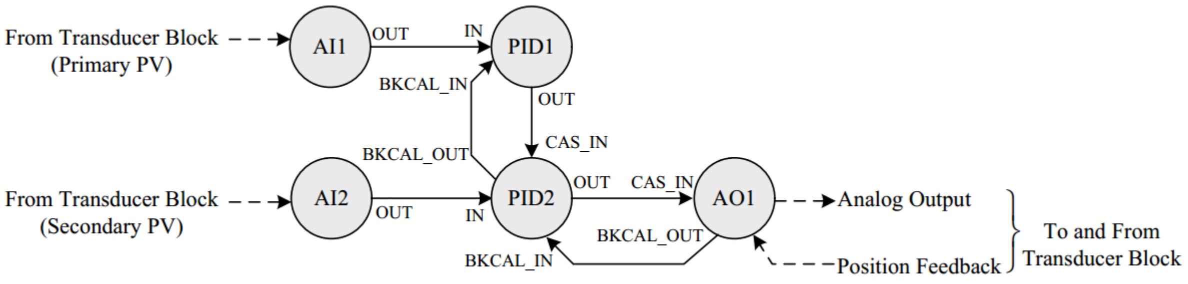
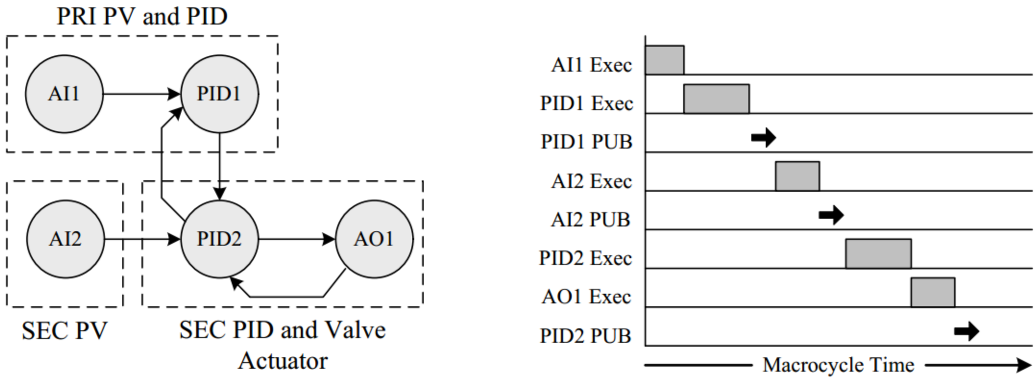
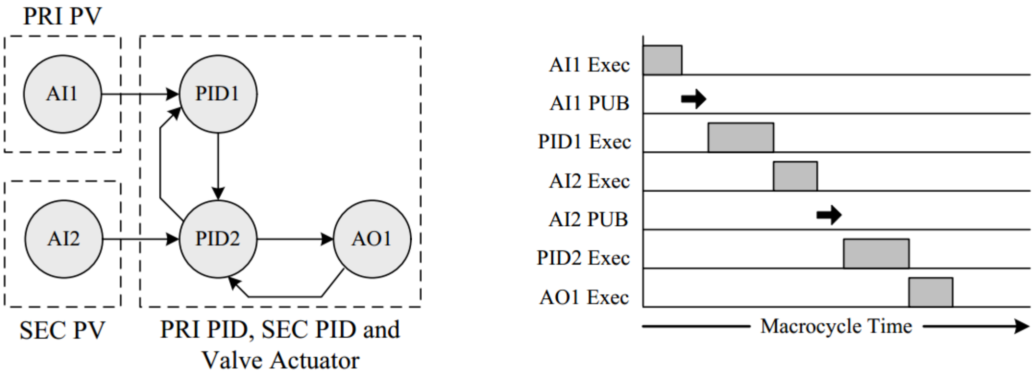


FIGURE 2. Cascade control loop blocks and links



(a) For locating PID1 in primary transmitter and PID2 in control valve



(b) For locating both PID1 and PID2 in control valve

FIGURE 3. Function block assignment and the natural communication schedules

depicted in Figure 2, and six links between blocks are required [1]. The function block receives inputs and executes its algorithm to generate an output, which is passed to the next block by the link. External links between function blocks in different devices are communicated over the network by using publisher-subscriber model, whereas internal links within the same device are not communicated over the network. This implies that the number of external links affects the network load [5]. Typically, the function blocks are executed according to the communication schedule (or segment macrocycle) created by the configuration tool. This schedule indicates the function block executions and external link publications. Two effective cases to assign the function blocks in the field devices for cascade control loop of Figure 2 with the CIF approach and the natural communication schedules are shown in Figure 3. The data transmissions occurred in the H1 segment are controlled by the link active scheduler (LAS). The LAS will issue a compel data (CD) message to the device requiring hard-periodical communication for external link to be communicated. During the function block execution, the LAS is transmitting the pass token (PT) message to all devices in the live list, so they can send soft-periodical communication data such as displaying information as well as aperiodic communication data such as alarm notification and operator setpoint changes.

4. **Proposed Optimization Method.** From function block details of the field devices installed in the studied H1 segment as shown in Table 1, there are two interested cases, Case 1 and Case 2, for implementing dual cascade control loops by block assignment as summarized in Table 2, where the subscripts 1 and 2 refer to the block used in the first control loop and the second control loop, respectively. There are two opportunities for optimizing the natural communication schedules of the studied H1 segment as follows.

- Minimizing loop control latency via parallel execution of the function blocks located in different devices by prioritized scheduling whenever possible.
- Maximizing the macrocycle availability for data communications over the network using client-server and report distribution models by consecutively scheduling publications for external links whenever possible.

Figure 4 and Figure 5 show the optimization of communication schedules generated for Case 1 and Case 2, respectively. The natural schedule of Case 1 in Figure 4 is optimized by assigning blocks $\mathrm{AI1}_1$, $\mathrm{AI1}_2$ and $\mathrm{PID1}_1$, $\mathrm{PID1}_2$ to be executed simultaneously as well as by grouping the scheduled communications CD2, CD1 and CD6, CD3 to publish the block outputs consecutively. Similarly, the natural schedule of Case 2 in Figure 5 is optimized by scheduling $\mathrm{AI1}_1$, $\mathrm{AI1}_2$ to be executed in parallel and by grouping two publications of CD1, CD2 and CD4, CD3.

Table 2. Function block assignment for building dual cascade loops in the same segment

Case	$\mathrm{AI1}_1$	$\mathrm{AI2}_1$	$\mathrm{AI1}_2$	$\mathrm{AI2}_2$	$\mathrm{PID1}_1$	$\mathrm{PID2}_1$	$\mathrm{PID1}_2$	$\mathrm{PID2}_2$	$\mathrm{AO1}_1$	$\mathrm{AO1}_2$
1	LIT 101	FIT 101	LIT 201	FIT 201	LIT 101	FCV 101	LIT 201	FCV 201	FCV 101	FCV 201
2	LIT 101	FIT 101	LIT 201	FIT 201	FCV 101	FCV 101	LIT 201	FCV 201	FCV 101	FCV 201

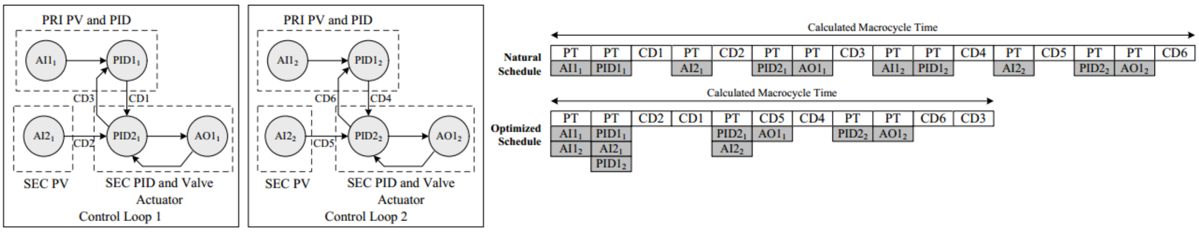


Figure 4. Optimizing the communication schedule generated for Case 1

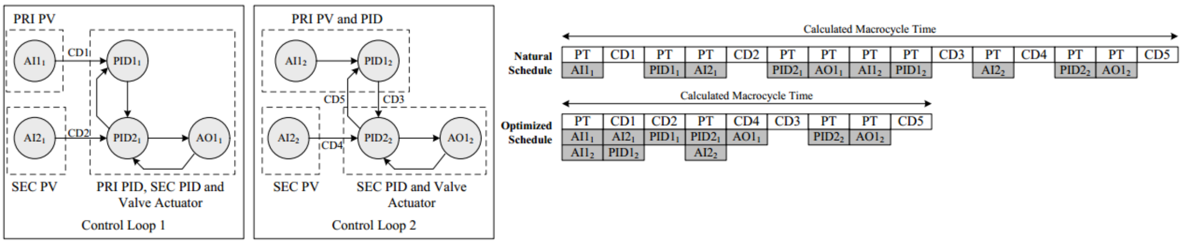


Figure 5. Optimizing the communication schedule generated for Case 2

5. **Results and Discussion.** Experimental results of the natural and optimized communication schedules of Case 1 and Case 2, which are obtained from using the Harmonas-DEO host as the configuration tool, are summarized in Table 3 and Table 4, respectively, where the time offsets are in milliseconds.

Table 3. Experimental results of the natural and optimized schedules of Case 1

	Natural Schedule					Optimized Schedule				
Function	Start	Length	End	Pub Gap	Usable Gap	Start	Length	End	Pub Gap	Usable Gap
AI1$_1$ Exec	0	30	30			0	30	30		
PID1$_1$ Exec	30	50	80			30	50	80		
PID1$_1$ PUB	80	30	110	300	270	80	30	110	0	0
AI2$_1$ Exec	110	10	120			40	10	50		
AI2$_1$ PUB	120	30	150	10	0	50	30	80	690	660
PID2$_1$ Exec	150	130	280			110	130	240		
AO1$_1$ Exec	280	80	360			240	80	320		
PID2$_1$ PUB	360	30	390	210	180	330	30	360	0	0
AI1$_2$ Exec	390	80	470			0	80	80		
PID1$_2$ Exec	470	130	600			80	130	210		
PID1$_2$ PUB	600	30	630	210	180	210	30	240	0	0
AI2$_2$ Exec	630	30	660			150	30	180		
AI2$_2$ PUB	660	30	690	30	0	180	30	210	70	40
PID2$_2$ Exec	690	30	720			240	30	270		
AO1$_2$ Exec	720	30	750			270	30	300		
PID2$_2$ PUB	750	30	780	60	30	300	30	330	60	30
				820	**660**				**820**	**730**

Table 4. Experimental results of the natural and optimized schedules of Case 2

	Natural Schedule					Optimized Schedule				
Function	Start	Length	End	Pub Gap	Usable Gap	Start	Length	End	Pub Gap	Usable Gap
AI1$_1$ Exec	0	30	30			0	30	30		
AI1$_1$ PUB	30	30	60	200	170	30	30	60	700	670
PID1$_1$ Exec	60	130	190			60	130	190		
AI2$_1$ Exec	190	10	200			50	10	60		
AI2$_1$ PUB	200	30	230	140	110	60	30	90	0	0
PID2$_1$ Exec	230	130	360			190	130	320		
AO1$_1$ Exec	360	80	440			320	80	400		
AI1$_2$Exec	440	80	520			0	80	80		
PID1$_2$ Exec	520	130	650			80	130	210		
PID1$_2$ PUB	650	30	680	420	390	210	30	240	0	0
AI2$_2$ Exec	680	30	710			150	30	180		
AI2$_2$ PUB	710	30	740	30	0	180	30	210	90	60
PID2$_2$ Exec	740	30	770			240	30	270		
AO1$_2$ Exec	770	30	800			270	30	300		
PID2$_2$ PUB	800	30	830	60	30	300	30	330	60	30
				850	**700**				**850**	**760**

For evaluating the proposed method validation, three following metrics are applied [6,7].

Latency Improvement (LI) – Loop latency is the time that elapses between the process sampling of the input function block until the final control element is commanded to correct a setpoint deviation by the output function block. The LI metric can be given by

$$LI = \left(1 - \left(\frac{optimized\_control\_sequence\_duration}{natural\_control\_sequence\_duration}\right)\right) \times 100\% \tag{1}$$

Publication Gap Improvement (PGI) – Publication gap is the time between the end of scheduled publication to the start of the next publication. The PGI metric can be written as

$$PGI = \left(1 - \left(\frac{\sum(length\_natural\_usable\_gap)}{\sum(length\_optimized\_usable\_gap)}\right)\right) \times 100\% \tag{2}$$

Macrocycle Utilization Improvement (MUI) – Macrocycle utilization is ratio of the optimized macrocycle time to the natural or non-optimized macrocycle time, expressed as a percentage. The MUI metric can be stated as

$$MUI = \left(1 - \left(\frac{\sum(optimized\_macrocycle\_time)}{\sum(natural\_macrocycle\_time)}\right)\right) \times 100\% \tag{3}$$

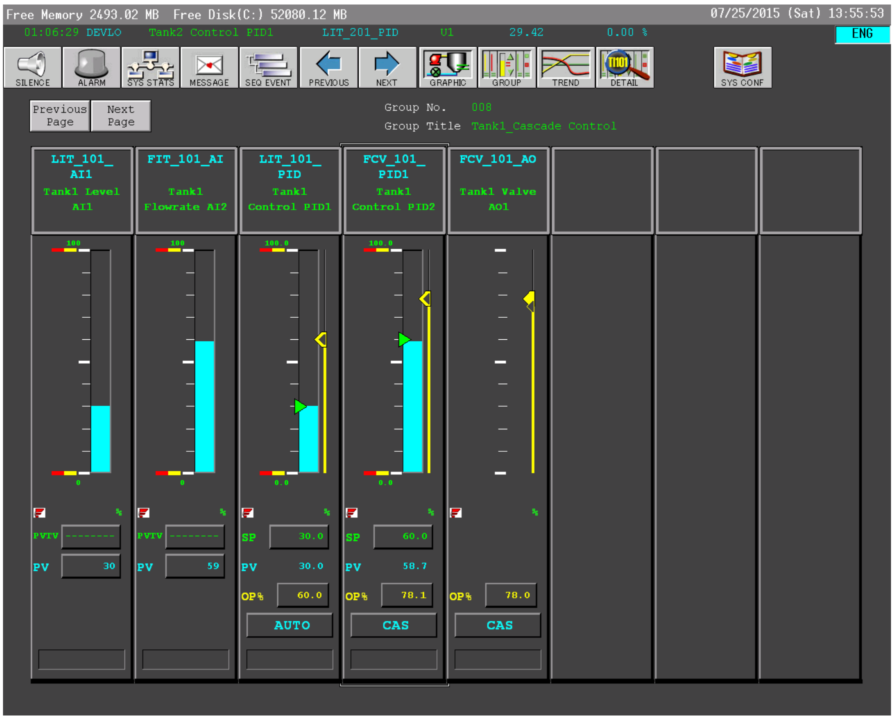
Based on the proposed method, Table 5 gives the improvement results from optimizing the communication schedules of Case 1 and Case 2. One of the goals for schedule optimization is to reduce the control loop latencies, and unneeded delays occurring between the input processing and the output processing of a control sequence. It is seen that the latency improvement can be obtained. Moreover, another goal is to locate the publication in communication schedule for increasing the gaps between publications so that larger gaps are available for soft-periodical and aperiodic communications to support other needs such as trend information, diagnostic information, and configuration downloads. It is evident that the publication gap improvement as well as the macrocycle utilization improvement can be achieved. Figure 6 shows the graphic user interface (GUI) from the host for operating the studied H1 segment with two cascade control loops by using the optimized schedule of Case 1. It is clearly seen that the preferred communication schedule can be used to maintain the process of both control loops within acceptable operating range.

Table 5. Improvement results from optimizing the schedules of two different cases

Item	Case 1	Case 2
Calculated Macrocycle of Natural Schedule	780 ms	830 ms
Calculated Macrocycle of Optimized Schedule	360 ms	400 ms
Usable Publication Gap of Natural Schedule	660 ms	700 ms
Usable Publication Gap of Optimized Schedule	730 ms	760 ms
Loop Latency Improvement	11.111%	9.091%
Publication Gap Improvement	9.589%	7.895%
Macrocycle Utilization Improvement	53.846%	51.807%

6. **Conclusions.**

A method to improve the communication schedules of FF-based two separate cascade control loops within the same H1 segment has been introduced. Optimization method for two different cases of control function block allocation has been described. Experimental results verify that the communication schedules can be improved by scheduling parallel execution and grouping data transmission for external function block links whenever possible. Accordingly, advantages such as latency reduction, and

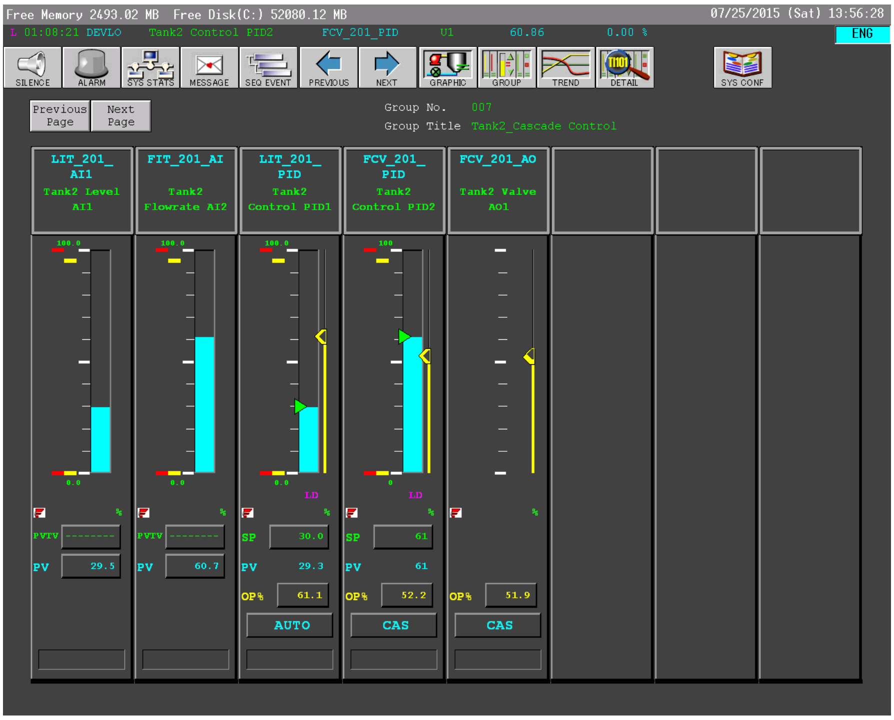


Free Memory 2493.02 MB Free Disk(C:) 52080.12 MB 07/25/2015 (Sat) 13:55:53
01:06:29 DEVLO Tank2 Control PID1 LIT_201_PID U1 29.42 0.00 %

Group No. 008
Group Title Tank1_Cascade_Control

LIT_101_AI1 Tank1 Level AI1: PVTV --------; PV 30
FIT_101_AI Tank1 Flowrate AI2: PVTV --------; PV 59
LIT_101_PID Tank1 Control PID1: SP 30.0; PV 30.0; OP% 60.0; AUTO
FCV_101_PID1 Tank1 Control PID2: SP 60.0; PV 58.7; OP% 78.1; CAS
FCV_101_AO Tank1 Valve AO1: OP% 78.0; CAS

(a) For the first control loop



Free Memory 2493.02 MB Free Disk(C:) 52080.12 MB 07/25/2015 (Sat) 13:56:28
L 01:08:21 DEVLO Tank2 Control PID2 FCV_201_PID U1 60.86 0.00 %

Group No. 007
Group Title Tank2_Cascade_Control

LIT_201_AI1 Tank2 Level AI1: PVTV --------; PV 29.5
FIT_201_AI Tank2 Flowrate AI2: PVTV --------; PV 60.7
LIT_201_PID Tank2 Control PID1: LD; SP 30.0; PV 29.3; OP% 61.1; AUTO
FCV_201_PID Tank2 Control PID2: LD; SP 61; PV 61; OP% 52.2; CAS
FCV_201_AO Tank2 Valve AO1: OP% 51.9; CAS

(b) For the second control loop

Figure 6. GUI for operating control loops using optimized schedule of Case 1

improved communication schedule capacity have been gained. In addition, the communication schedule for a hybrid control strategy that incorporates function blocks running in both field devices and host controller will be focused in the future work.

Acknowledgment. This work is supported by FieldComm Group Thai and Azbil Co-operation. The authors also would like to thank the reviewers for helpful comments and suggestions.

REFERENCES

[1] J. Berge, *Fieldbuses for Process Control: Engineering, Operation and Maintenance*, ISA, USA, 2004.

[2] Fieldbus Foundation, *System Engineering Guidelines*, USA, 2012.

[3] I. Verhappen and A. Pereira, *Foundation Fieldbus*, ISA, USA, 2009.

[4] A. Julsereewong, P. Julsereewong and T. Dejsiriphant, Study on field control locations for Foundation Fieldbus-based cascade control loop, *SICE Annual Conference*, pp.1706-1711, 2012.

[5] A. Julsereewong, P. Julsereewong and P. Harntujit, Foundation Fieldbus segment scheduling for fast loop controls, *ICIC Express Letters*, vol.7, no.4, pp.1201-1207, 2013.

[6] W. R. Hodson, Method for optimizing a link schedule, *U.S. Patent 2008/0229317 A1*, 2008.

[7] T. Sangsuwan, S. Pongswatd, A. Julsereewong, Y. Morioka and Y. Amano, Communication schedule optimization of cascade control using Foundation Fieldbus, *ICIC Express Letters*, vol.10, no.1, pp.197-204, 2016.