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WINCC-BASED PROCESS SIMULATION FOR VIRTUAL COMMISSIONING OF SCADA SYSTEM INTEGRATION

Teerawat Thepmanee, Adisak Tantaweenulak and Krit Smerpitak

Faculty of Engineering
King Mongkut's Institute of Technology Ladkrabang
Ladkrabang, Bangkok 10520, Thailand
{ teerawat.th; 60601030; krit.sm }@kmitl.ac.th

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Abstract. *In order to provide possibility for system integrators to verify the correctness and effectiveness of functions of a supervisory control and data acquisition (SCADA) system before on-site installation and actual commissioning, this paper presents a process simulation based on software-in-the-loop technique by using VBScript in WinCC for virtual commissioning. Design of integrating an existing control loop in water tank process of pharmaceutical manufacturing plant into a new SCADA is used as a case study. The interested process, which consists of inlet water pump, inlet control valve, level transmitter, and outlet water pump, is controlled by proportional-integral-derivative (PID) algorithm in a programmable logic controller (PLC) to maintain hydrostatic pressure in the water tank. Operations of the simulated process can be controlled in either manual mode or automatic mode. Moreover, the proposed simulation provides an option to imitate device failures that could not be done in real process due to damages for ensuring SCADA fault notification based on failure modes and effects analysis (FMEA). Experimental results of using the proposed process simulation for testing whether the created human machine interface (HMI) screens of the SCADA system integration fulfill functional design specifications are also included.*

Keywords: PID control, PLC, Process simulation, SCADA, Software-in-the-loop simulation, System integration, Virtual commissioning, WinCC

1. **Introduction.** Efforts to enhance the manufacturing competitiveness demand rapid improvements in automated production systems and engineering tools. During plant development process, simulation is an essential technique for testing the design and implementation of industrial automation systems not only to minimize the impact of potential risks but also to ensure the accomplishment of project goals [1]. For engineering project execution, commissioning is one of the most important tasks to prepare a system prior to verifying that it meets its specified requirements. However, this task has been known as time-consuming and cost-consuming stage in practice. To minimize the required time and cost for the on-site commissioning, virtual commissioning has been widely accepted to simulate a virtual system within virtual operating environment for early error detection and functionality verification [2]. There are two concepts for performing virtual commissioning: hardware-in-the-loop simulation and software-in-the-loop simulation. The first involves a virtual plant model and a real control system, while the latter involves a virtual plant model and a virtual control system. In case of hardware-in-the-loop concept, a real hardware controller is required to implement virtual commissioning. On the other hand, virtual commissioning using software-in-the-loop concept can be applied on an emulated controller. Therefore, no hardware controller is required, which is one of major benefits of software-in-the-loop simulation. In addition, the virtual commissioning can also be utilized for system integration field to validate operations of the designed system before

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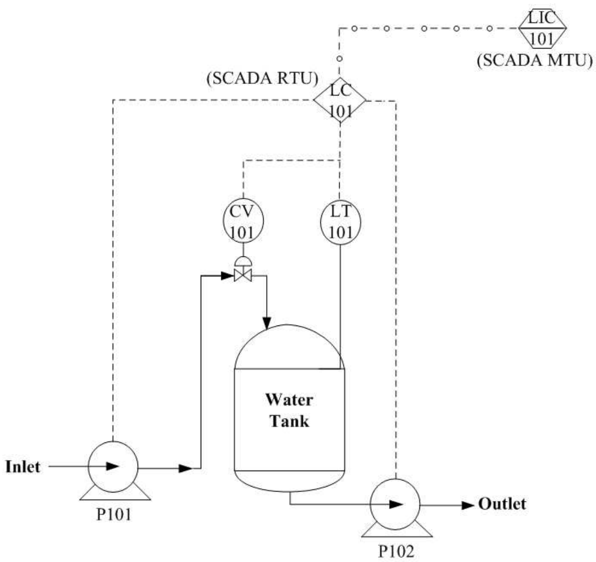
it is implemented in the physical plant [3]. However, this approach focuses on using DELMIA software for creating virtual environment to develop and validate a three-axis assembly cell. Application of virtual commissioning based on SIMULINK process simulator for design and verification of PID control of nonlinear continuous process has also been suggested [4]. Nevertheless, the purpose of this proposed application is to perform virtual commissioning using hardware-in-the-loop method. Recently, a simulation platform based on WinCC software for simulating a level control of coupled-tank system for study purpose has been proposed [5]. However, we develop this idea in the different way to simulate the continuous process without the use of real controller for speeding up the commissioning stage. The aim of this paper is to present a process simulation based on the use of VBScript in WinCC for virtual commissioning of system integration of SCADA, which is one of dominant automation systems for plant monitoring and virtualization [6-8]. The integration of new SCADA into existing PID control loop in water tank process for purified water system of a pharmaceutical manufacturing plant in Thailand is specified as a case study to demonstrate effectiveness of the proposed simulation.

The remainder of this paper is structured as follows. The case study and description of the proposed process simulation are detailed in Section 2 and Section 3, respectively. The experimental results are shown in Section 4. Lastly, the conclusions and possible future work are given in Section 5.

2. **Case Study for Proposed Process Simulation.** Figure 1(a) depicts a piping and instrumentation diagram (P&ID) of the SCADA designed for integrating with the existing control loop in the real water tank process as illustrated in Figure 1(b). At the field site, the control loop consists of a P101 inlet pump for pumping water from the storage to the tank, a CV101 control valve for adjusting the inlet flowrate, an LT101 transmitter for detecting the water level in the tank by measuring hydrostatic pressure, an LC101 controller (PLC) for regulating the controlled water level to be as close to a desired setpoint, and a P102 outlet pump for supplying the water to the next stage. At the control center, an LIC101 host computer performs as the master terminal unit (MTU) of the SCADA system to provide the HMI. The MTU communicates to the remote terminal unit (RTU) that is operated by the LC101 controller through the use of Modbus RTU protocol in master-slave configuration.



(a) P&ID of the SCADA and control loop

(b) Real water tank process

FIGURE 1. Case study on SCADA system integration

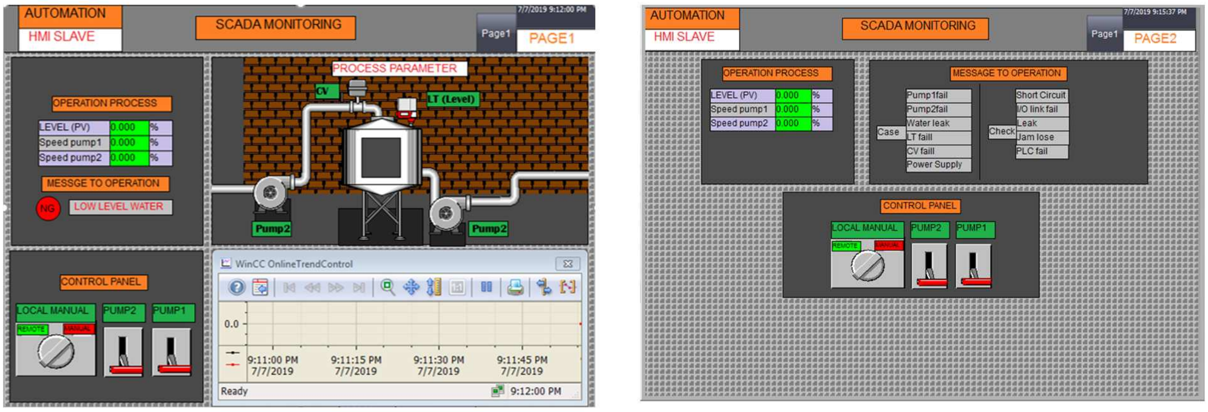
To help the work of an operator, the operational functions of the SCADA usually can access through the HMI graphic screens including main and secondary pages. Table 1 summarizes the major functional design specifications for SCADA system integration in case study, while Table 2 summarizes the potential failure modes and flaw results of the devices from the FMEA approach [6]. Figure 2 shows the HMI screens created by using WinCC software. The parameter values as well as the device statuses received from the RTU can be continuously monitored in real time. The commands can be sent to the RTU to start or stop the water pumps as well as to set the operating mode of the controller. The color scheme of the created HMI is based on the traffic light model for basic operator's actions for effective use to differentiate between classes of information in critical displays. The 'NG' black text on red background and 'OK' black text on green background mean

Table 1. Major functional design specifications for SCADA in case study

Button/Symbol/Value	Description	SCADA Function
PV value in numeric display	To display the process variable (PV) from the LT101 output	Monitoring
PV value in trend graph	To display the evolution of PV from the LT101 output in the trend view	Monitoring
Low alarm flashing	To use flashing to draw attention when low process alarm occurs	Monitoring
Level graphic animation	To display animated tank level	Monitoring
Controller output value in numeric display	To display the output value of the LC101 controller	Monitoring
Inlet pump symbol	To display the P101 pump status	Monitoring
Outlet pump symbol	To display the P102 pump status	Monitoring
Control valve symbol	To display the CV101 valve status	Monitoring
Pump1 on/off button	To start/stop the P101 pump	Control command
Pump2 on/off button	To start/stop the P102 pump	Control command
Auto/Man mode selector	To select the operation mode of the LC101 controller	Control command
'PLC fail' button text	To display the LC101 status	Fault Notification
'LT fail' button text	To display the LT101 status	Fault Notification
'CV fail' button text	To display the CV101 status	Fault Notification
'Pump1fail' button text	To display the P101 status	Fault Notification
'Pump2fail' button text	To display the P102 status	Fault Notification

Table 2. FMEA for water tank process in case study

Device	Function	Failure Mode	Failure Cause	Effect	Critically
LC101	Controller	Short circuit	Power surge	False trip	Safe
		Open circuit	Many causes	False trip	Safe
LT101	Monitoring	Short circuit	Power surge	Overflowing	Safe
		Open circuit	Many causes	False trip	Safe
CV101	Open to fill water tank	Short circuit	Power surge	False trip	Safe
		Open circuit	Many causes	False trip	Safe
P101	Feed water into tank	Jam closed	Dirt, Corrosion	No water	Safe
		Fail open	Power fail	False trip	Safe
P102	Feed water into the next	Jam closed	Dirt, Corrosion	No water	Safe
		Fail open	Power fail	False trip	Safe



(a) Page 1 (b) Page 2

FIGURE 2. WinCC-based HMI screens for the designed SCADA

failure/fault/stop and pass/success/start, respectively. If the process variable (PV) from the LT101 is crossing the alarm limit, then the flashing indication for alarm notification will appear. The alarms should be acknowledged by the SCADA operator. Based on the FMEA technique, potential failures of the controller and field devices are also monitored.

3. **Proposed Process Simulation.** Figure 3 shows a concept of the proposed process simulation for verification before the designed SCADA system integration of Figure 1(a) is implemented in the physical plant. Similarity, both virtual controller and virtual water tank process are simulated in WinCC software. Based on open platform communications (OPC), data exchange between the SCADA MTU and the proposed process simulation can occur in real time. To build the virtual PLC and plant models, all input and output signals as well as the relevant parameters for the controller are identified by internal tags using the Tag Management editor in WinCC Configuration Studio. Each unique tag has a data address and a symbolic name. The tag values are regularly updated in Runtime. Table 3 gives some internal tags created in the case study. Figure 4 shows the created virtual PLC and process models by using the Graphics Designer to mimic specific actions and procedures of the real controller and process. To make the WinCC execution environment to be dynamic, the VBScript is employed to program the required

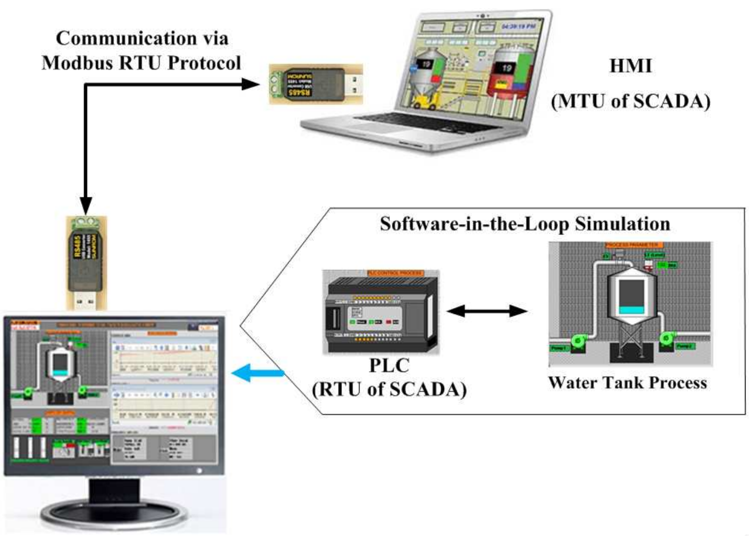
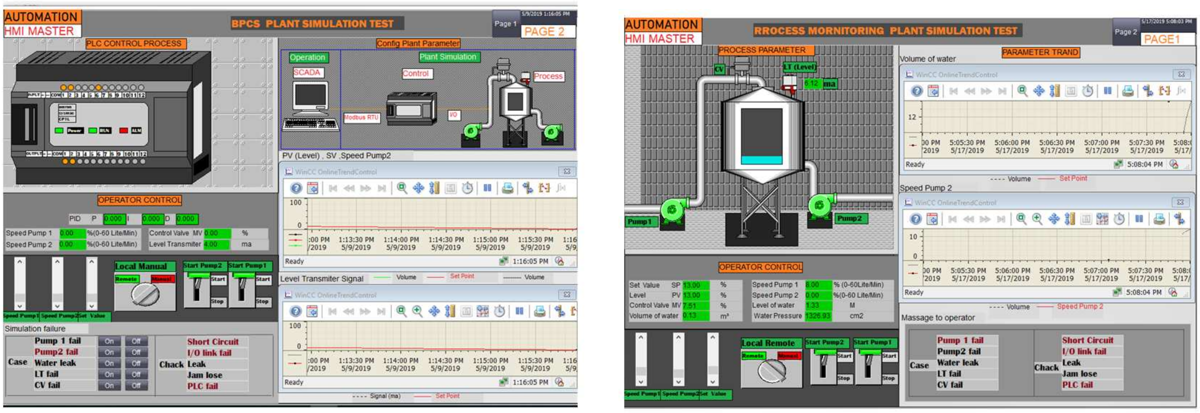


FIGURE 3. Concept of the proposed process simulation for virtual commissioning

Table 3. Some internal tags created for relevant signals and parameters in case study

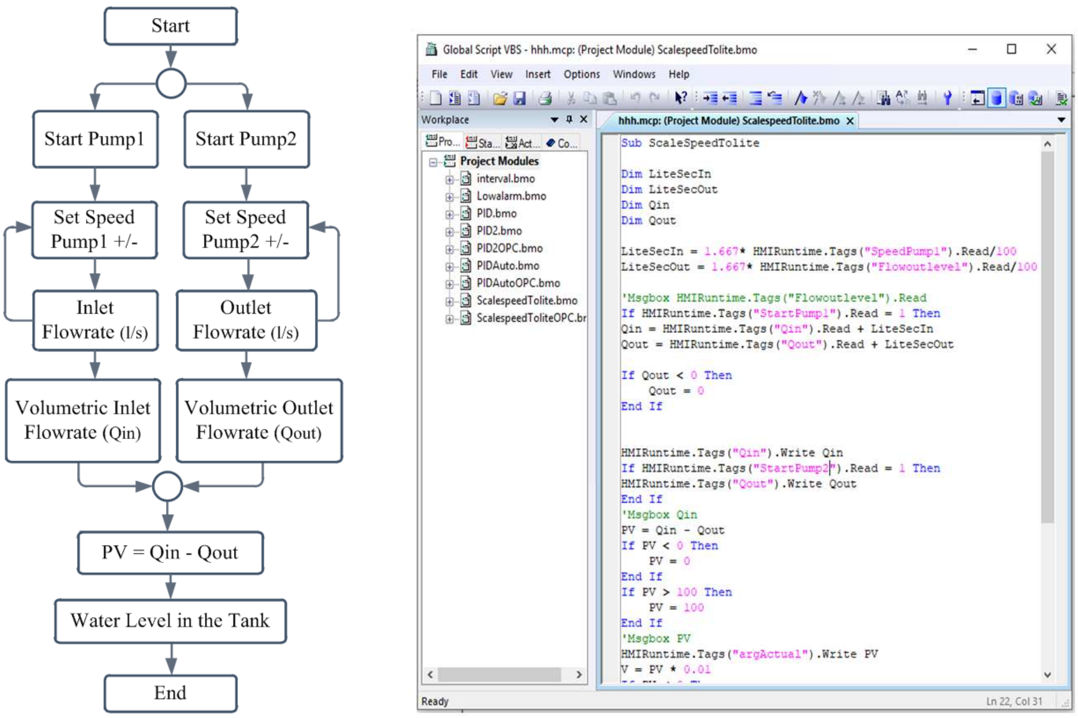
Tag Name	Data Type	Comment
PIDAuto	Binary tag (true or false)	To select the controller mode
StartPump1	Binary tag (true or false)	To start/stop the inlet pump
StartPump2	Binary tag (true or false)	To start/stop the outlet pump
argActual	Unsigned 16-bit value (word)	Actual process variable (PV)
SpeedPump1	Unsigned 16-bit value (word)	Inlet pump speed (rpm)
Flowoutlevel	Unsigned 16-bit value (word)	Outlet pump speed (rpm)
LitesecIn	Floating-point 32-bit IEEE 745	Inlet flowrate (l/s)
LitesecOut	Floating-point 32-bit IEEE 745	Outlet flowrate (l/s)
Qin	Floating-point 32-bit IEEE 745	Water inlet quantity
Qout	Floating-point 32-bit IEEE 745	Water outlet quantity
Volume	Floating-point 32-bit IEEE 745	Water tank volume (m^3)
PIDTEST	Floating-point 32-bit IEEE 745	Setpoint (SP) of control
mPLast	Floating-point 32-bit IEEE 745	Error between SP and PV
mValue	Floating-point 32-bit IEEE 745	Manipulated value (MV)
KP	Floating-point 32-bit IEEE 745	Proportional gain of PID
KI	Floating-point 32-bit IEEE 745	Integral gain of PID
KD	Floating-point 32-bit IEEE 745	Derivative gain of PID
mI	Floating-point 32-bit IEEE 745	Integral term of error
mD	Floating-point 32-bit IEEE 745	Derivative term of error



(a) Virtual PLC model (b) Virtual process model

Figure 4. Created virtual simulation models using the Graphic Designer

actions and procedures by assigning value sequence of internal tags as well as triggering event sequence of graphical objects. Figure 5(a) shows a program flowchart to execute conditional instructions in the Global Script Editor (see Figure 5(b)) to determine the water level in the tank or process variable (PV) in range of 0-100%. It can be described in terms of volumetric inlet and outlet flowrates. Increasing the inlet and outlet pump speeds increase the inlet and outlet flowrates, respectively. Their maximum values are set to 60 l/min (or 1 l/s). The water level in the tank will be stationary when the inlet and outlet flowrates are equal. The operation of the virtual PLC model can be chosen either in manual (Man) mode or in automatic (Auto) mode. In order to regulate the height of water level or the PV in the tank at the target value or setpoint (SP) in Auto mode, the



(a) Program flowchart (b) Global Script VBS window

FIGURE 5. Writing program by using VBScript to determine the water level in the tank

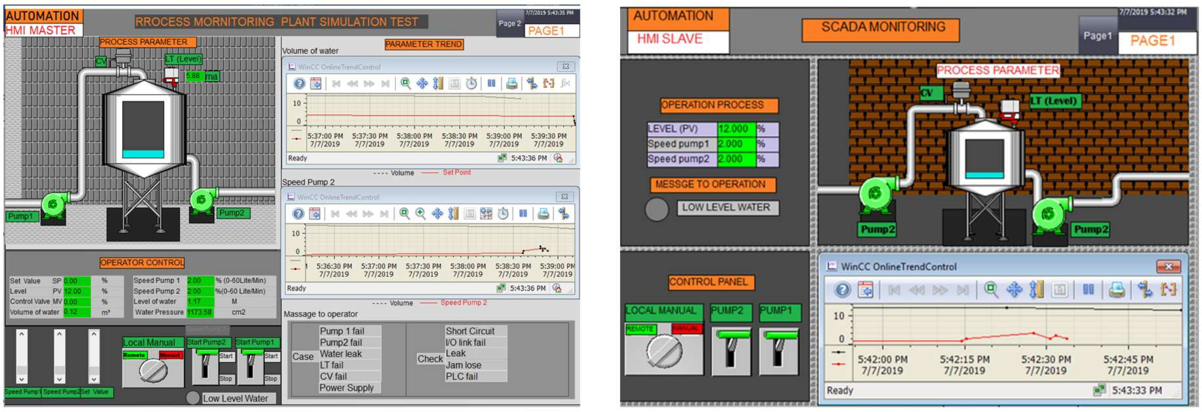
PID algorithm in the PLC is employed to calculate the manipulated value (MV). The error is defined as the difference between the desired SP and the controlled PV.

4. **Experimental Results.** To confirm the proposed system workability, the virtual commissioning was performed by integrating the process simulation into the SCADA MTU as shown in Figure 6. Table 4 gives the results of process simulation operations and SCADA HMI functions. It is seen that the proposed process simulation can be utilized for verifying the correctness of each HMI function for the designed SCADA MTU. Figures 7(a) and 7(b) illustrate the experimental results to compare events on the virtual water tank process and the HMI screen on Page 1, respectively. In case of imitating device failure, the results on the virtual PLC model and HMI screen on Page 2 are shown in Figures 8(a) and 8(b), respectively. From the comparisons, the created HMI screens on the SCADA MTU can be operated in accordance with the design specifications.

FIGURE 6. Experimental setup for virtual commissioning of SCADA functions

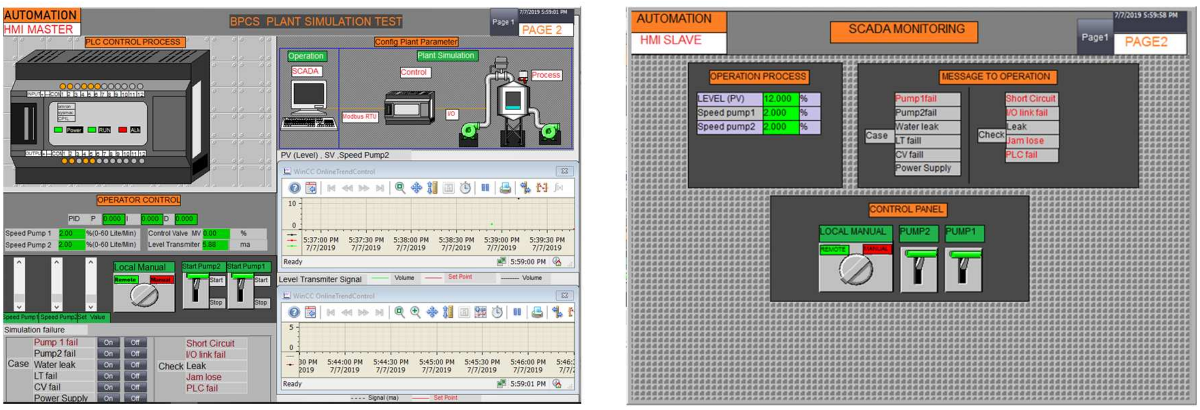
TABLE 4. Virtual commissioning results for the case study

Test Condition	Process Simulation		SCADA HMI Function	
	Pass	Fail	Pass	Fail
To display the PV	×		×	
To display the PV trend	×		×	
To notify low alarm event	×		×	
To display animated tank level	×		×	
To display the PID output	×		×	
To display the P101 pump status	×		×	
To display the P102 pump status	×		×	
To display the CV101 valve status	×		×	
To start/stop the P101 pump	×		×	
To start/stop the P102 pump	×		×	
To select the PID control mode	×		×	
To display the LC101 status	×		×	
To display the LT101 status	×		×	
To display the CV101 status	×		×	
To display the P101 status	×		×	
To display the P102 status	×		×	



(a) Virtual water tank process (b) HMI Page 1 on the SCADA MTU

FIGURE 7. Experimental results to compare events on the virtual process and HMI



(a) Virtual PLC model (b) HMI Page 2 on the SCADA MTU

FIGURE 8. Experimental results to compare failures on the virtual PLC and HMI

5. **Conclusions.** A WinCC-based process simulation with software-in-the-loop for use in virtual commissioning procedures of SCADA system integration has been presented. The integration of new SCADA into existing PID-based control loop in water tank process has been employed as the case study. Experimental results confirm that the proposed process simulation has sufficient performance to perform virtual commissioning. An expansion of using the proposed concept to verify system workability before actual commissioning for integrating SCADA with other systems is the future work.

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