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HMI IMPLEMENTATION USING RADAR CHART FOR DUAL-LOOP SYSTEM

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Abstract. *This article presents a method to implement the Human Machine Interface (HMI) for providing high visibility of dual-loop system to encourage good operations and maintenance practices. The proposed method is based on the employment of radar chart to display key performance metrics of simultaneous and independent control of two identical loops for extensive event monitoring. Two level control loops utilizing two Proportional-Integral-Derivative (PID) function blocks of a single Programmable Logic Controller (PLC) are used as the case study to show the workability of the proposed HMI implementation. Each loop consists of a transmitter for measuring the controlled level, an inverter for inverting the PLC output to adjust a pump speed, and a power meter for measuring the pump power consumption. The transmitter outputs from both control loops are applied to the PLC analog input module, and then separately scaled to be available to each PID block. The PLC analog output module is used to pass the PID block outputs for manipulating inlet flow rates. The performance metrics including the set point, process variable, manipulated variable, and pump power consumption of both control loops are detected and collected by the HMI/Supervisory Control and Data Acquisition (SCADA) station. All detected data of four performance metrics are represented on the axes of radar chart in real time by using the Wonderware InTouch software. The script functions to save and load the specified data to the SQL server database are also created on the HMI/SCADA station. Experimental results confirm that the proposed HMI implementation can function correctly.*
Keywords: HMI, Radar chart, Dual-loop system, PID control, PLC, SCADA

1. **Introduction.** Usually, a Human Machine Interface (HMI) in industrial productions in both discrete and process manufacturers is used to refer to computer hardware and software components that allow an interaction between a plant operator and a control system [1,2]. The HMI can function not only to provide visualization of process parameters, notification of alarms and events, and trending of historical and real-time process data but also to enable manipulation of the machine or process [3]. Therefore, the HMI is a crucial contribution to delivering the effectiveness of the operator in all commonly expected modes of operation [4]. However, the HMI implementation varies on case by case for discrete, batch, continuous, or hybrid process to organize information that is available to the operator. In case of continuous process, the information required for generic tasks including monitoring, controlling, compensating, diagnosing, and optimizing the process should be organized to provide the operator with support to ensure that the process operates consistently within quality parameters [5]. In addition, the HMI based on situation awareness principle should be designed to keep the operator fully informed as the current operational circumstance [6]. Compared to employing proprietary HMI solutions that are optimized to work with particular vendors for Distributed Control System (DCS) and

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Programmable Logic Controller (PLC), a major limitation of using open HMI products developed for general purposes without specific hardware is the lack of documentation of network, system installation, and configuration for focused applications. This implies that system integrators or end users are responsible to provide such documentation. Recently, a technique to design and implement the condition monitoring of wireless field devices by using the open HMI or Supervisory Control and Data Acquisition (SCADA) software called Wonderware InTounch has been introduced [7]. The proposed technique [7] is based on failure modes and effects analysis for creating the HMI system to monitor abnormal conditions of WirelessHART devices. Alternatively, a method utilizing the Wonderware InTounch software to build the graphical HMI for level process control has been also suggested [8]. The alternative method [8] applies a spider chart or radar chart to showing key variables of the interested continuous process for effective operations. In order to extend the usefulness of radar chart for providing ease of comparison of multiple performance parameters, the HMI implementation including system installation, control configuration, tag database generation, and graphical display creation for dual-loop system is proposed in this article. The studied dual-loop system involves the simultaneous and independent control of two identical level loops that use two Proportional-Integral-Derivative (PID) function blocks running in the single PLC to maintain the water tank level at desired height. The Set Point (SP), Process Variable (PV), Manipulated Variable (MV), and pump power consumption (energy) are defined as the key performance metrics to display and compare on the created HMI.

The remainder of the article is organized as follows. The case study of dual-loop system is explained in Section 2, and the proposed HMI implementation is described in Section 3. The experimental results for demonstrating the proposed HMI effectiveness are included in Section 4. The conclusion and future work are lastly given in Section 5.

2. **Case Study on Two Level Control Loops.** Figure 1 shows a Piping and Instrumentation Diagram (P&ID) of the dual-loop case study for simultaneously and independently controlling the water levels in two tanks (Tank1 and Tank2) under the same process conditions. Each feedback control loop is composed of a level indicating transmitter (LIT-101 or LIT-201) for measuring the hydrostatic head pressure to obtain the PV or actual

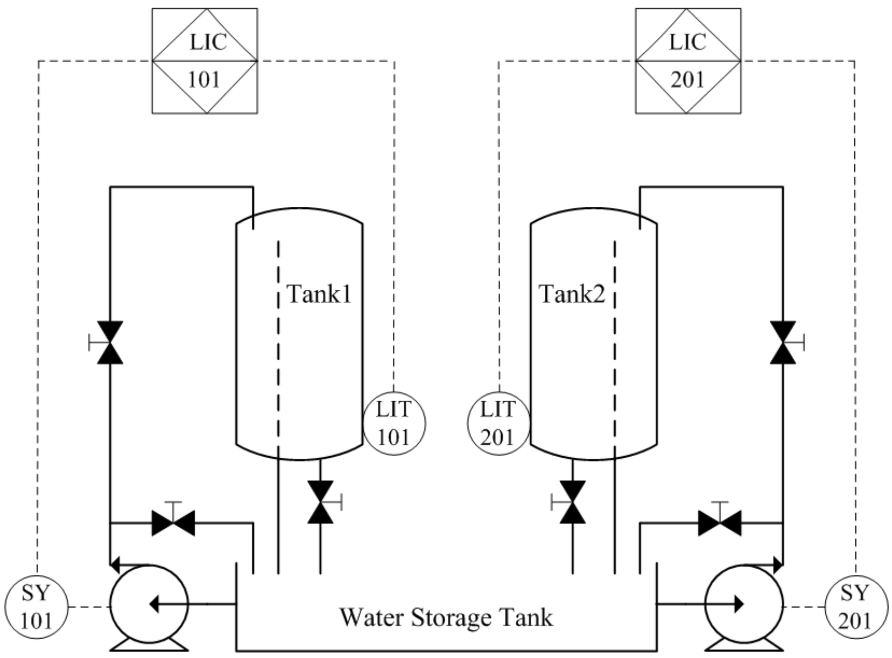

Figure 1. P&ID of dual-loop case study for level control

value of the controlled water level in the tank, a level indicating controller (LIC-101 or LIC-201) by using the internal PID function block of the PLC in reverse action to correct the error between the desired SP and the measured PV, an inverter (SY-101 or SY-201) for inverting the MV or control variable from the PID block output to regulate the inlet flow rate by changing the speed of the water pump. Table 1 summarizes the major details of devices used in the dual-loop case study. In addition, the power meter modeled Primus KM-7 is installed to measure the active power consumed by each water pump.

3. **Proposed HMI Implementation.** Figure 2 shows the network architecture for installation of the studied dual-loop system. The HMI/SCADA station running the Wonderware InTouch software is employed for gathering process data and managing the overall

Table 1. Major details of devices in dual-loop case study

Loop	Device Tag	Function	Model	Vendor
1	LIT-101	Level transmitter to measure the controlled water level in the Tank1	UNE11	Yokogawa
	LIC-101	PLC to provide the control of water level in the Tank1	MicroLogix 1100	Allen-Bradley
	SY-101	Inverter to manipulate the Tank1 inlet flow by changing pump speed	X200	Hitachi
2	LIT-201	Level transmitter to measure the controlled water level in the Tank2	UNE11	Yokogawa
	LIC-201	PLC to provide the control of water level in the Tank2	MicroLogix 1100	Allen-Bradley
	SY-201	Inverter to manipulate the Tank2 inlet flow by changing pump speed	X200	Hitachi

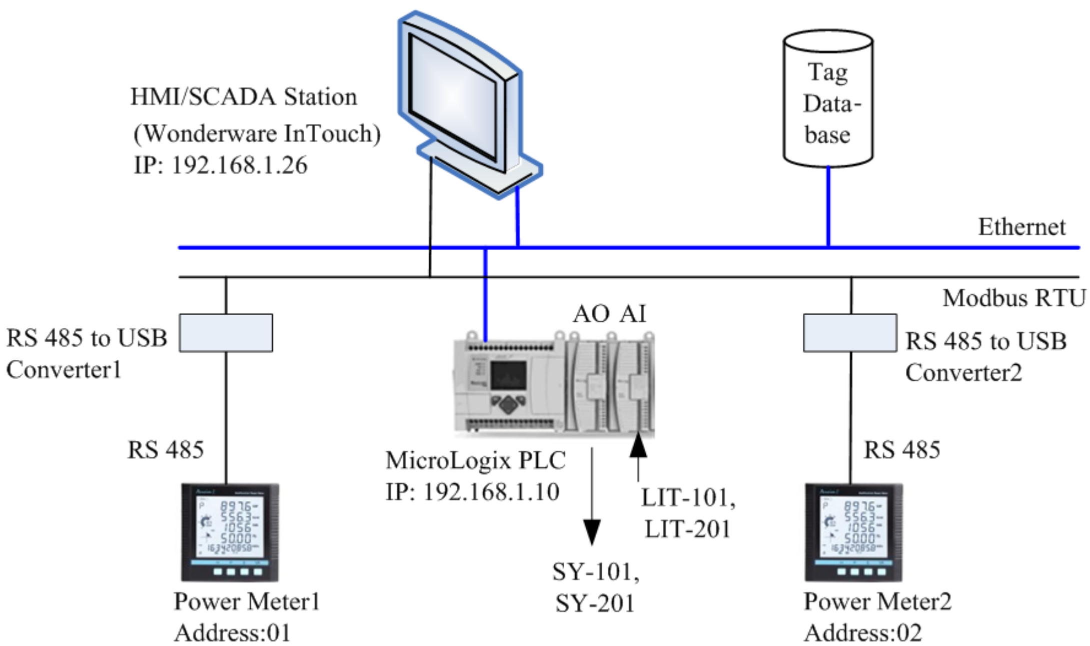

Figure 2. Network architecture for installing the studied dual-loop system

operation. Two power meters send the measured values to the HMI/SCADA station via the RS 485-USB converters by using Modbus RTU protocol with master-slave technique. The HMI/SCADA station and the PLC are connected to a wired Ethernet network. Their network identification assignment is based on the private Internet Protocol (IP) addressing as illustrated in Figure 3. For connecting the 4-20 mA field devices to the PLC Input/Output (I/O) module modeled MicroLogix 1762-IF2OF2, the LIT-101 and LIT-201 transmitters are wired to the Analog Input (AI) CH0 and CH1 channels, respectively, while the SY-101 and SY-201 inverters are wired to the Analog Output (AO) CH0 and CH1 channels, respectively. Figure 4 depicts the data transfer concept from the AI module to the PID function blocks as well as from the PID function blocks to the AO module to program the PLC modeled MicroLogix 1100 by utilizing the RSLogix 500 software [9]. Both AI and AO current terminals supporting the full scale range of 0-21 mA signals are configured to use the raw/proportional format option (0 to 32,760) for input/output digital data files. Based on the Scale (SCL) instruction, the digital data in raw/proportional format are scaled to be available for PID block processing (0 to 16,383). Table 2 summarizes the ranges of input and output data in terms of current signal, the raw/proportional format, and the scaled-for-PID format. Thus, the SCL1 and SCL2 instructions are executed to change the format of the CH0 and CH1 input data files, respectively, from the raw/proportional format into the scaled-for-PID format. On the other hand, the SCL3 and SCL4 instructions are performed to change the format

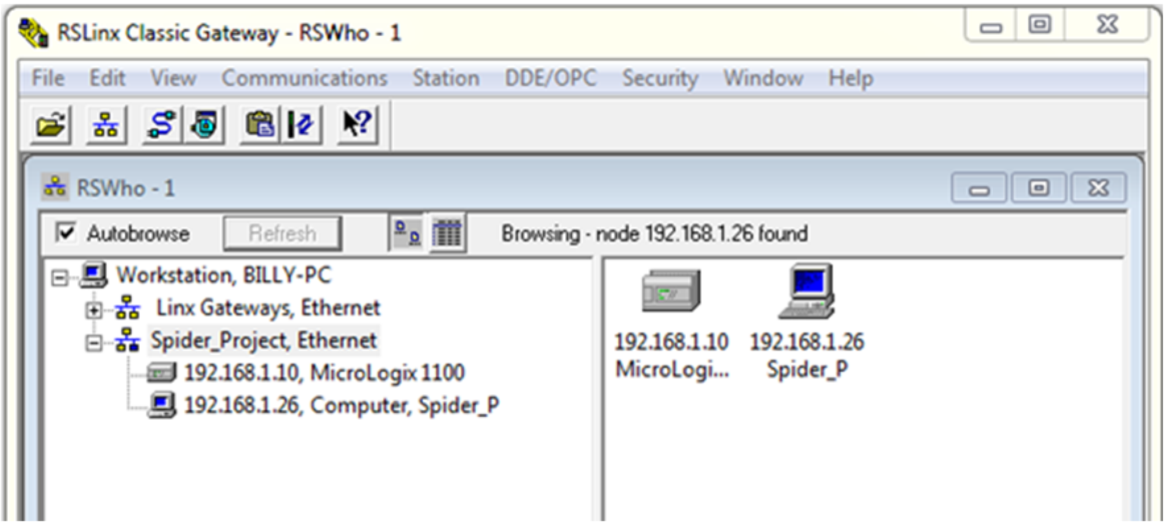

FIGURE 3. IP address assignment for devices connected to the Ethernet network

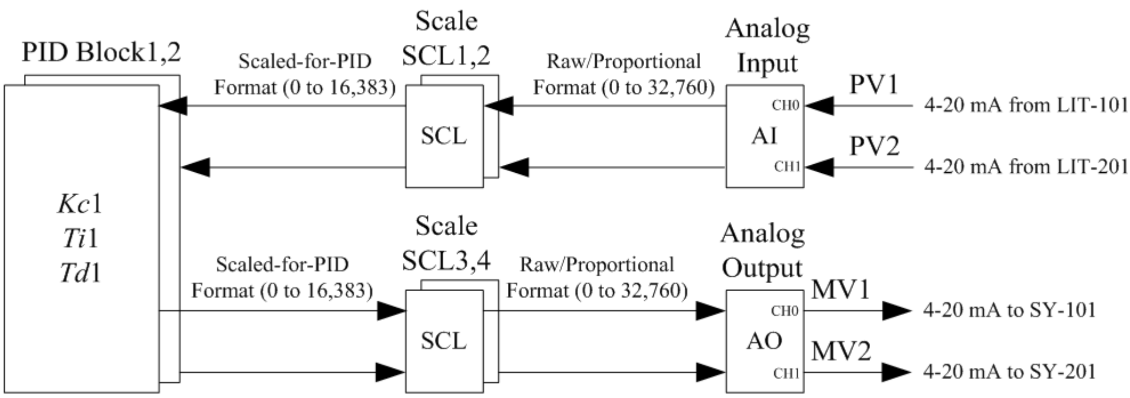

FIGURE 4. Concept of input and output data transfers for PLC programming

Table 2. Ranges of input and output data

Current Signal	Raw/Proportional Format	Scaled-for-PID Format
0 mA	0	−4,095
4 mA	6,240	0
8 mA	12,480	4,095
12 mA	18,720	8,191
16 mA	24,960	12,286
20 mA	31,200	16,383
21 mA	32,760	Over flow

of the PID outputs to be available for the CH0 and CH1 channels of the AO module, respectively, from the scaled-for-PID format into the raw/proportional format. The relation between the input value (IN_{SCL}) and the scaled output value (OUT_{SCL}) of the scale instruction can be given by [9]

$$OUT_{SCL} = \left(\frac{rate \times IN_{SCL}}{10{,}000}\right) + \mathit{offset} \tag{1}$$

where

$$rate = \frac{OUT_{SCL}\max - OUT_{SCL}\min}{IN_{SCL}\max - IN_{SCL}\min} \tag{2}$$

and

$$\mathit{offset} = OUT_{SCL}\min - (IN_{SCL}\min \times rate) \tag{3}$$

where $IN_{SCL}\max$ and $IN_{SCL}\min$ denote the maximum and minimum of the input values required to be scaled, respectively, and $OUT_{SCL}\max$ and $OUT_{SCL}\min$ are the maximum and minimum of the resulting scaled output values, respectively. The PID Block1 is used to control the level in the Tank1 of Loop1, and the PID Block2 is used to control the level in the Tank2 of Loop2. The PID tuning parameters Kc, $1/Ti$, and Td are the controller gain, reset term, and rate term, respectively. The output or control variable of the PID function block for driving the process variable toward the set point can be stated as [9]

$$Output_{PID} = Kc \times \left((E) + \frac{1}{Ti}\int (E)dt + Td \times \frac{d(PV)}{dt}\right) + bias \tag{4}$$

where $E = SP - PV$ is the error in case of setting the controller in reverse action, and $bias$ is the feedforward input for combination with PID feedback control.

The InTouch tags defined to assign the Loop1 and Loop2 process data for the proposed HMI are given in Table 3. The 'InTouch SQL Access Manager' program is utilized to create the database as well as to associate the SQL database to store and read columns and the InTouch tags via a binding process. The 'SQLInsert(ConnectionId, TableName, BindList)' is used for creating the scrip function as shown in Figure 5(a) to store the up-to-date values of InTouch tags in the SQL database by inserting one row into 'TableName'. Moreover, the 'SQLSelect(ConnectionId, TableName, BindList, WhereExpr, OrderByExpr)' is employed for creating the scrip function as shown in Figure 5(b) to retrieve the data from 'TableName' for being browsed by using other SQL functions such as SQLFirst(ConnectionId) and SQLLast(ConnectionId) to bring the values into InTouch tags. The 'SQLSelect' function is also used to create the radar charts for reading the specified InTouch tags that are related to the SP, PV, MV, and energy parameters of both Loop1 and Loop2 from the SQL database.

4. **Experimental Results.** The workability of the implemented HMI was experimentally tested for monitoring and controlling the laboratory-scale plant of the studied dual-loop system. The PID tuning parameters of the PID Block1 and PID Block2 were set to

Table 3. Tags defined to assign the Loop1 and Loop2 process data for the proposed HMI

InTouch Tag		PLC Addressing		Data Type
Loop1	Loop2	Loop1	Loop2	
Loop1_PV	Loop2_PV	PD9:0.SPV	PD19:0.SPV	I/O Real
Loop1_SP	Loop2_SP	PD9:0.SPS	PD19:0.SPS	I/O Real
Loop1_MV	Loop2_MV	PD9:0.CVP	PD19:0.CVP	I/O Real
Loop1_EN	Loop2_EN	30016@long	30016@long	I/O Real
Loop1_Kc	Loop2_Kc	PD9:0.KC	PD19:0.KC	I/O Real
Loop1_Ti	Loop2_Ti	PD9:0.Ti	PD19:0.Ti	I/O Real
Loop1_Td	Loop2_Td	PD9:0.Td	PD19:0.Td	I/O Real
Loop1_sp_max	Loop2_sp_max	PD9:0.MAXS	PD19:0.MAXS	I/O Real
Loop1_sp_min	Loop2_sp_min	PD9:0.MINS	PD19:0.MINS	I/O Real
Loop1_updataloop	Loop2_updataloop	PD9:0.LUT	PD19:0.LUT	I/O Real
Pump_101	Pump_201	O:0/0	O:0/1	I/O Discrete
Loop1_Stop	Loop2_Stop	B3:0/6	B3:0/9	I/O Discrete
Loop1_Run	Loop2_Run	B3:0/1	B3:0/2	I/O Discrete
Loop1_Voltage	Loop2_Voltage	30004	30005	I/O Real
Loop1_Current	Loop2_Current	30010	30011	I/O Real
Loop1_pf	Loop2_pf	30013	30014	I/O Real
Loop1_activepower	Loop2_activepower	30016@long	30016@long	I/O Real
Loop1_apparentpower	Loop2_apparentpower	30016@long	30016@long	I/O Real
Loop1_reactivepower	Loop2_reactivepower	30016@long	30016@long	I/O Real

```
ResultCode=SQLInsert(ConnectionID,"[PROCESS2_DATABASE]", "PROCESS2_SAVE_BL");

ErrorMsg=SQLErrorMsg(ResultCode);
```

(a) Script function to store the data into the SQL database

```
TableName = "[PROCESS1_DATABASE]" ;
BindList = "PROCESS1_LOAD_BL" ;
WhereExpr = "PROCESS1_REPORT_DAY=" + Text(process1_dayselect,"##") +" AND "+ "PROCESS1_REPORT_MONTH=" + Text
(process1_monthselect,"##") +" AND "+ "PROCESS1_REPORT_YEAR=" + Text(process1_yearselect,"####") ;
OrderByExpression = "PROCESS1_REPORT_ID" ;

ResultCode=SQLSelect(ConnectionID,TableName, BindList,WhereExpr,OrderByExpression);
```

(b) Script function to read the stored value in the SQL database

Figure 5. Two created script functions to allow access to the database

$Kc = 1$, $Ti = 0.10$ min/repeat, and $Td = 0$. Figure 6 shows the experimental results by separately displaying the specified performance parameters of each control loop on each spider chart on the same HMI screen, where the interested parameters of the Loop1 and Loop2 are shown on the left chart and right chart, respectively. Figure 7 illustrates the experimental results by mutually displaying the specified performance parameters of both control loops on one spider chart for the single view of the HMI screen. It is seen that the spider chart is appropriate for providing high visibility of dual-loop system to keep the operator informed as the current operational situations for controlling two identical control loops at the same time.

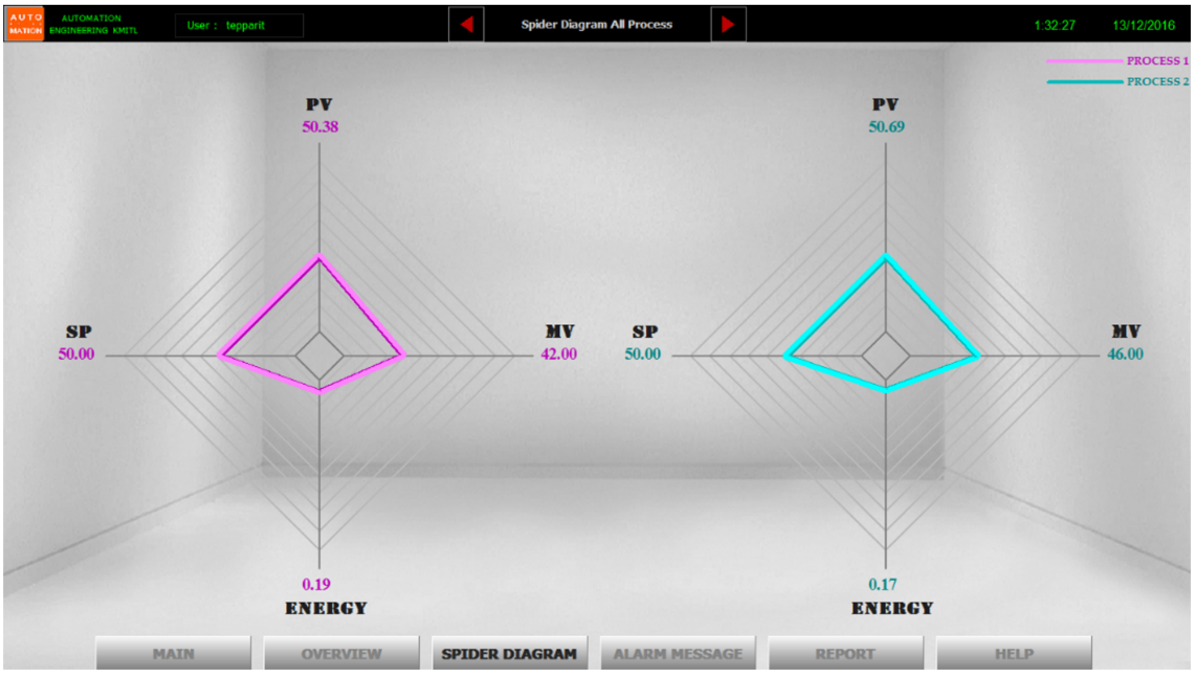

Figure 6. (color online) Results by separately displaying the parameters on two spider charts

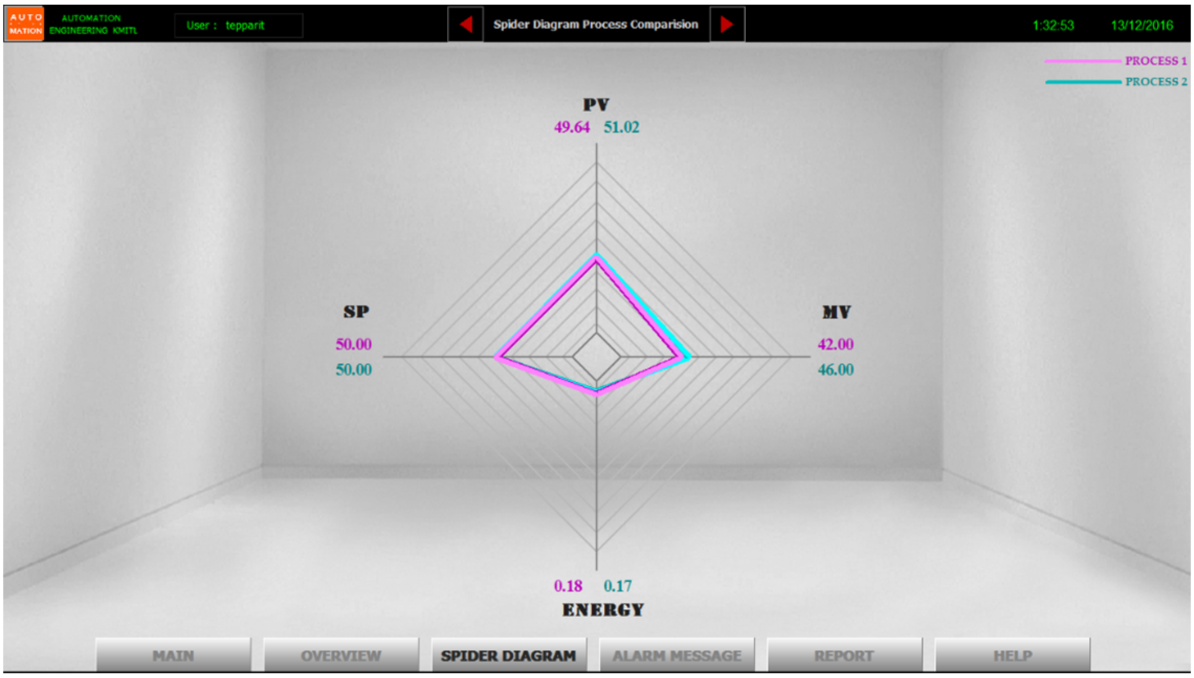

Figure 7. (color online) Results by mutually displaying the parameters on one spider chart

5. **Conclusions.** In this paper, a successful technique by using the radar chart to create the HMI screens for simultaneous and independent control of dual loops has been presented. The HMI implementation for two identical level loops controlled by the internal PID function blocks of the PLC has been described as the case study to show how the proposed technique can be applied. The implemented HMI offers the ability to display the specified performance metrics of two control loops on two separate charts and the same chart, which can be selectable for the operator to provide ease of comparison. A

possible direction for further work is to utilize process data historians to be useful for the HMI users.

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