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CONDITION MONITORING BASED ON FAILURE MODES AND EFFECTS ANALYSIS USING SCADA SOFTWARE FOR WIRELESSHART DEVICES

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Abstract. *This paper presents the design and implementation of condition monitoring for WirelessHART devices by using the supervisory control and data acquisition (SCADA) software called WW InTouch. The design of the proposed system is based on a concept of failure modes and effects analysis (FMEA) for creating the human machine interface (HMI) on the operator workstation. The implementation of the proposed system is based on a technique of WirelessHART-Modbus TCP data transfers by mapping the HART tag names from the field wireless devices to the Modbus registers in the WirelessHART gateway. The script functions running on the HMI for detecting the published diagnostic data of the monitored devices and for identifying the FMEA results of device and power supply failures are created. A WirelessHART temperature transmitter and a wired HART control valve positioner connected with Wireless THUM adapter are employed as the interested field devices for monitoring their abnormal operating conditions to verify the workability of the proposed system. Experimental results from the failure mimic show that the proposed system based on FMEA can function correctly.*
Keywords: Condition monitoring, FMEA, WirelessHART, HART, Modbus TCP, SCADA software, WW InTouch, Script function

1. **Introduction.** Technical diagnostic data of condition monitoring systems such as temperature, vibration, and acoustic noise can be useful in optimizing maintenance activities [1]. The maintenance based on monitoring and evaluating conditions provides the prevention of damages or outages due to unexpected failures in equipment as well as the reduction of costs for fault finding tasks, repairs, or periodic replacements [2]. A good understanding of failure rates, modes, and effects is essential for properly planning maintenance actions [3]. In addition, a systematic approach of failure modes and effects analysis (FMEA) can be applied to improving a remote monitoring design for identifying the major concerns and determining the corrective actions to mitigate the failure effects on the system [4]. Recently, smart wireless instrumentation is becoming increasingly prominent in the operational historian and continuous monitoring for plant modernization because of its technical advantages and cost benefits of wireless technology. A technique to integrate the WirelessHART network at the sensor or instrument level into the host system at the control level by using supervisory control and data acquisition (SCADA) software called 'WW InTouch' for data collection from intelligent wireless field instruments has been introduced [5,6]. In order to improve an effectiveness of the previously proposed system in terms of quality and reliability, this paper aims at presenting an application of the FMEA methodology for designing and implementing the human machine interface (HMI) on the operator workstation of the condition monitoring system for WirelessHART field devices. The proposed method is useful to identify the root causes of faults or problems that require to be solved for enhancing plant operability and maintainability.

This paper is structured as follows. Section 2 describes the system architecture for integrating the WirelessHART network into the host system. Section 3 presents the FMEA-based condition monitoring proposed in this article. Section 4 demonstrates the experimental results obtained from a case study. Section 5 gives the conclusions and future work of this study.

2. **Architecture of Integrated System.** Based on the integrated host system with WirelessHART field devices as shown in the diagram of Figure 1 [5], the process variables measured by the wireless instruments as well as the self-diagnostic data are monitored and collected at the engineering/operator workstation by using WW InTouch software. At the field site, the WirelessHART instruments are installed to measure process variables, which are technical data of the condition monitoring. At the host-level network, the engineering/operator workstation, WirelessHART configurator, and gateway are connected together using an Ethernet switch. A function of the gateway used is to convert the HART protocol of wireless field devices to the Modbus TCP protocol available for the engineering/operator workstation to achieve the interoperability. The WirelessHART configurator is based on the web-based 'Smart Wireless Gateway' application. However, some wireless field devices support limited remote configuration through the 'Smart Wireless Gateway' application, and thus another configurator like the 'Emerson 475 handheld Field Communicator' is required for setting device parameters.

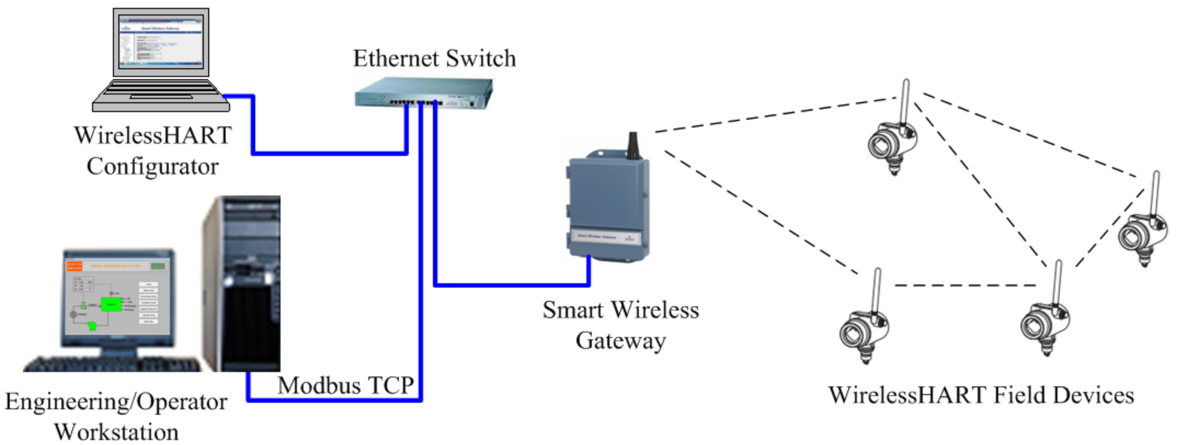


FIGURE 1. Diagram for installing the host system and WirelessHART field devices [5]

3. **Proposed Condition Monitoring Based on FMEA.** To identify the failures or problems of WirelessHART field devices within the proposed condition monitoring by installing the host system and wireless instruments as shown in Figure 1, the design of the HMI running on the operator workstation is based on the systematic FMEA technique, which can be described as follows.

3.1. **FMEA process.** For analyzing all potential failure modes and flaw results of individual WirelessHART field devices, the FMEA process can be performed in four stages [7] as follows.

- List all WirelessHART field devices connected to the condition monitoring.
- For each WirelessHART field device, list all failure modes. The FMEA team can use a brainstorm technique to set up what can go wrong with the system to specify the potential failure modes.
- For each WirelessHART field device/failure mode, list the effect on the next higher level.

- For each WirelessHART field device/failure mode, list the severity of effect.

In order to verify the effectiveness of the proposed system, the FMEA-based condition monitoring for two field instruments is defined as an illustrative case study. These monitored devices are a WirelessHART temperature transmitter modeled Rosemount 648 and a wired HART control valve positioner modeled Azbil AVP302, which is attached with the Emerson Wireless 775 THUM adapter for transmitting the positioner diagnostic data into the WirelessHART network. This means that the proposed system can be used to monitor the abnormal operating conditions of existing installed HART-wired devices for improving maintenance activities without any negative effects to normal device operations. Tables 1 and 2 illustrate the major details of the devices used and their FMEA in our case study, respectively. From the FMEA shown in Table 2, the first and second columns describe the tag and function of the device under review, respectively. The third column gives the failure modes of the device. Usually, one row is employed for each device failure mode. The fourth column shows the primary stress causing the failure mode of the third column, and the fifth column describes how the device failure mode affects the device function of the system. The last column gives how this failure mode affects the higher level by indicating two categories of system level failures: safe failure and dangerous failure.

Table 1. Major details of the devices used in the case study

Device	Tag	Device Model	Communication Protocol
Gateway	YG_1200	Emerson Wireless 1420 Gateway	WirelessHART-Modbus TCP
Adapter	YN_1201	Emerson Wireless 775 THUM Adapter	WirelessHART-Wired HART
Valve Positioner	CV_101	Azbil AVP302	HART (Version 6)
Temperature Transmitter	TIT_101	Rosemount 1420	WirelessHART
Temperature Sensor	TE_101	RTD (Pt100) probe	N/A

Table 2. FMEA for the case study

Tag	Function	Failure Mode	Failure Cause	Effect	Critically
CV_101	Open for coolant	Actuator fail	Dirt	False trip	Safe
		4-20 mA fail	Corrosion Maintenance error	False trip	Safe
		Valve stuck	Power electric surge	False trip	Safe
		Jam closed	Dirt, Corrosion	No cooling	Dangerous
		Fail open	Power fail, Corrosion	False trip	Safe
YN_1201	Convert protocol	Adapter fail	Corrosion of wires	None	Safe
		Adapter out of limit	Power fail	None	Safe
TIT_101	Monitor temp.	High-limit process temp.	Fluid pump stop	No cooling	Dangerous
		Sensor fail	Battery running out	False trip	Safe
Power Supply (Battery)	Supply energy to device	Battery fail	Battery running out	False trip	Safe

3.2. **WirelessHART-Modbus TCP data transfer technique.** To collect the measurement and diagnostic data from the monitored WirelessHART field devices, a technique for data transfer between the wireless field instruments and the operator workstation through the gateway is shown in Figure 2. The published data from each WirelessHART field device such as process variables and diagnostic data are stored as the device point names before mapping into Modbus register numbers. The data transmission between the gateway and the operator workstation is based on the DASMBTCP OPC, which is the software interface for Modbus TCP protocol. In the operator workstation, the Modbus register numbers are mapped into the HMI tags for creating the graphic user interface by utilizing the WW InTouch software. For the case study, Tables 3 and 4 give the parameter part of device point name, data type, Modbus register number, and the HMI tag for the interested parameters of the YN_1201 THUM adapter and the TIT_101 transmitter [6], respectively.

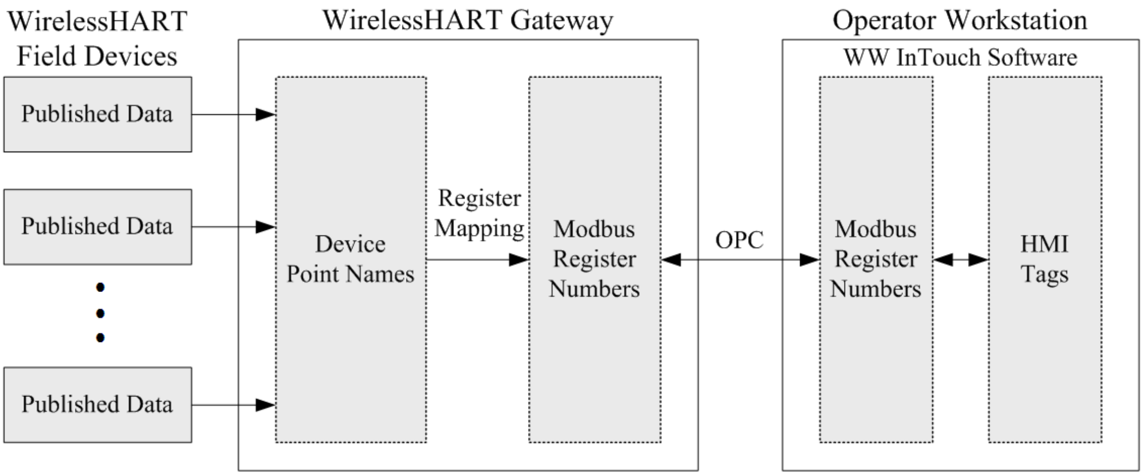


Figure 2. Data transfer technique for collecting published data from wireless field devices

Table 3. Interested parameters of the YN_1201 THUM adapter for creating HMI [6]

Parameter Part of Device Point Name	Data Type	Modbus Register	HMI Tag
COLD_START	Boolean	40140	VALVE_COLD
CURRENT	32-bit float	40100	VALVE_CURRENT
CURRENT_HEALTHY	Boolean	40105	VALVE_CURRENT_STATUS
MONITOR_STATUS	Unsigned 8-bit integer	40145	VALVE_MONITOR
ONLINE	Boolean	40150	VALVE_ONLINE
PRIMARY_VALUE_ OUT_OF_LIMIT	Boolean	40155	VALVE_PV_OUT
PV	32-bit float	40110	VALVE_TRAVEL
PV_HEALTHY	Boolean	40115	VALVE_TRAVEL_STATUS
QV	32-bit float	40130	VALVE_%CURRENT
QV_HEALTHY	Boolean	40135	VALVE_%CURRENT_STATUS
SV	32-bit float	40120	AMBIENT_TEMP
SV_HEALTHY	Boolean	40125	AMBIENT_TEMP_STATUS

Table 4. Interested parameters of the TIT_101 transmitter for creating HMI [6]

Parameter Part of Device Point Name	Data Type	Modbus Register	HMI Tag
AMBIENT_TEMP_FAILURE	Boolean	40160	TT_AMBIENT_FAIL
AMBIENT_TEMP_ OUT_OF_LIMITS	Boolean	40165	TT_AMBIENT_OUT_LIM
COLD_START	Boolean	40170	TT_COLD
CRITICAL_POWER_FAILURE	Boolean	40175	TT_PWR_FAIL
ENVIRONMENT_ CONDITIONS_OUT_ OF_RANGE	Boolean	40180	TT_ENV_OUT
MAINTENANCE_ REQUIRED	Boolean	40185	TT_MAIN_REQ
MONITOR_STATUS	Unsigned 8-bit integer	40190	TT_MONITOR
NETWORK_JOINS	Unsigned 16-bit integer	40195	TT_NET_JOIN
ONLINE	Boolean	40200	TT_ONLINE
PERCENT_RANGE	32-bit float	40205	TT_%
PERCENT_RANGE_ HEALTHY	Boolean	40210	TT_%_STATUS
PRIMARY_VALUE_ OUT_OF_LIMITS	Boolean	40215	TT_PV_OUT
RADIO_FAILURE	Boolean	40220	TT_RADIO_FAIL
RADIO_INTERNAL_ COMMUNICATION_FAILURE	Boolean	40225	TT_COMM_FAIL
RADIO_MALFUNCTION	Boolean	40230	TT_RADIO_MALF
SENSOR	32-bit float	40235	TT_PV_TEMP
PV_HEALTHY	Boolean	40240	TT_PV_STATUS
SENSOR_1_COMMU NICATION_FAILURE	Boolean	40245	TT_SENSOR_COMM_FAIL
SENSOR_1_FAILURE	Boolean	40250	TT_SENSOR_FAIL
SENSOR_1_OUT_OF_LIMITS	Boolean	40255	TT_SENSOR_OUT
SUPPLY_VOLTAGE	32-bit float	40260	TT_SUP_VOLT
SUPPLY_VOLTAGE_HEALTHY	Boolean	40265	TT_SUP_VOLT_STATUS
TV	32-bit float	40270	TT_TV
TV_HEALTHY	Boolean	40275	TT_TV_STATUS

3.3. **Script function creation.** To save the space, a technique for creating the script function running on the HMI for detecting the published device diagnostic data as well as for identifying the FMEA on the TIT_101 transmitter only is explained. From Table 2, all three failure modes for the TIT_101 are high-limit process temperature, sensor failure, and device battery failure. From Table 4, the parameters related with the device diagnostic data for determining the specified failure modes are SENSOR, SENSOR_1_FAILURE, and SUPPLY_VOLTAGE. The mapped HMI tags for these parameters are TT_PV_TEMP, TT_SENSOR_FAIL, and TT_SUP_VOLT, respectively. The scrip function algorithm to detect the device diagnostic data and to identify the FMEA on the TIT_101 transmitter is summarized by the flowchart in Figure 3, where the high limit for process temperature is set to 80°C, and the acceptable device battery ranges between 5-12 V.

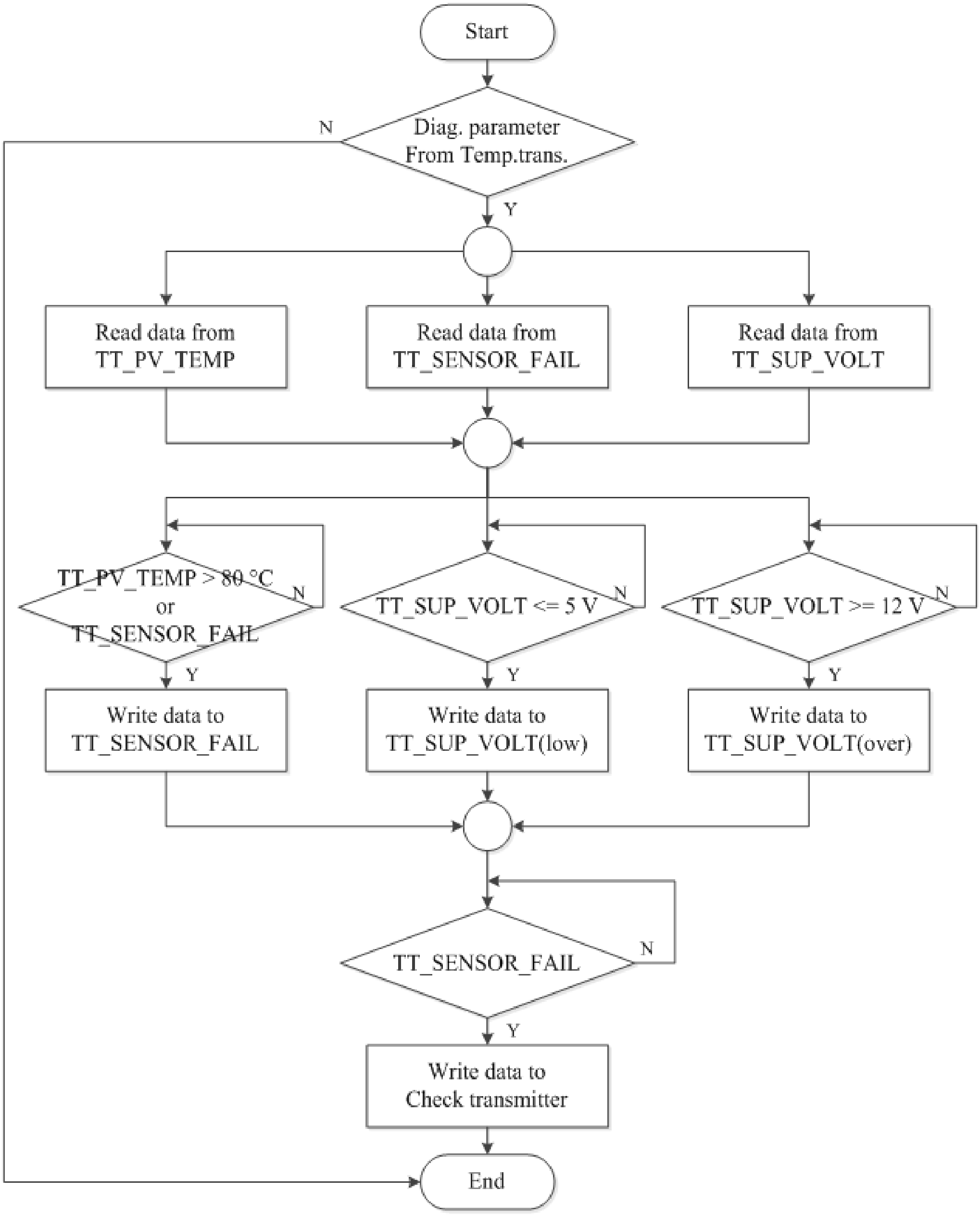


Figure 3. Flowchart of scrip functions for determining the failure modes for TIT_101

4. **Experimental Results.** Figures 4 and 5 show the HMI screens created for monitoring the CV_101 control valve positioner and the TIT_101 temperature transmitter, respectively, when running the proposed system. The measured current input, valve travel, THUM temperature, and the device diagnostic parameters of the valve positioner are displayed in Figure 4. Similarly, the measured process temperature, electronic board temperature, device battery voltage, and the device diagnostic data of the temperature transmitter are shown in Figure 5. The HMI screen for monitoring the potential failures and identifying their root causes is illustrated in Figure 6. The result display uses two colors and different font weights of text messages in the FMEA table: black and normal font weight for normal and red and bold font weight for failure. To mimic the transmitter failure in case of sensor failure, the internal battery of the TIT_101 temperature transmitter was removed from its terminal connector and replaced by an external power supply with 4.5 V; the text messages related with the FMEA on the temperature transmitter are shown in red color and bold font weight.

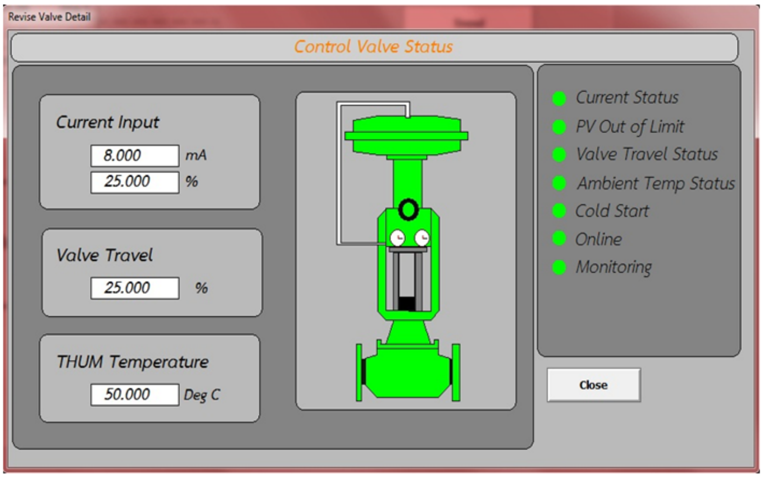


Figure 4. HMI screen for data display of the CV_101

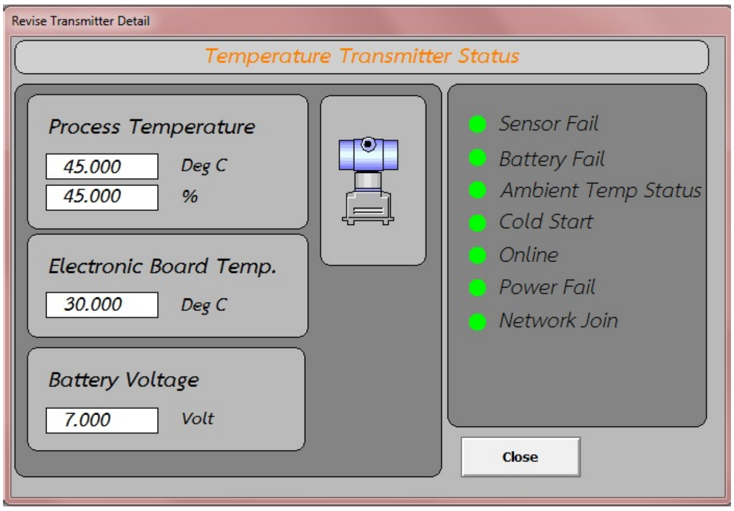
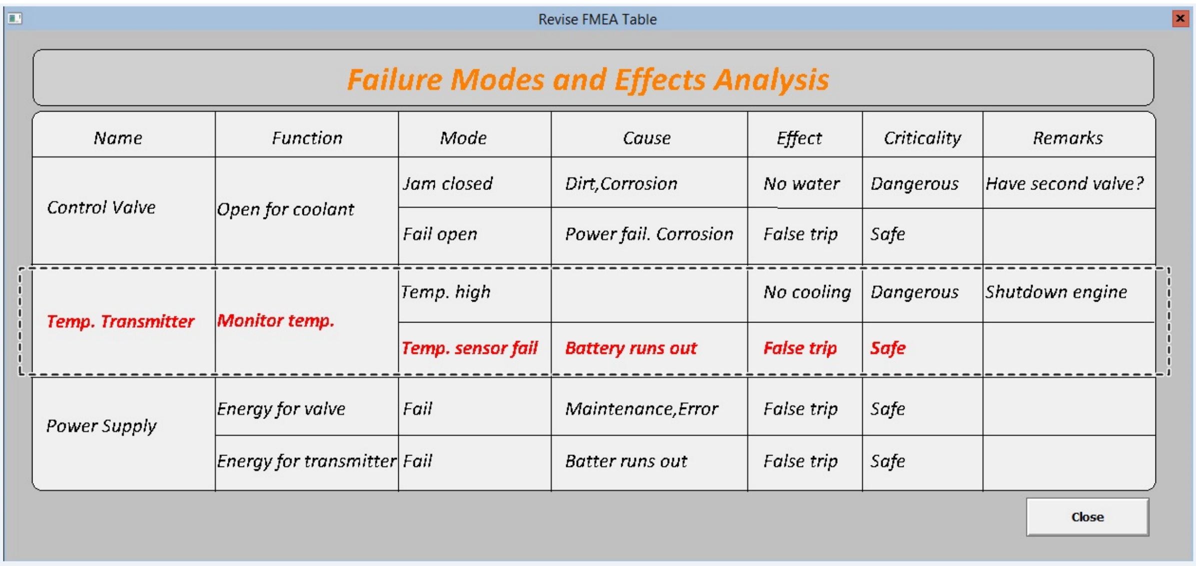


Figure 5. HMI screen for data display of the TIT_101


Revise FMEA Table

Failure Modes and Effects Analysis

Name	Function	Mode	Cause	Effect	Criticality	Remarks
Control Valve	Open for coolant	Jam closed	Dirt,Corrosion	No water	Dangerous	Have second valve?
		Fail open	Power fail. Corrosion	False trip	Safe	
Temp. Transmitter	Monitor temp.	Temp. high		No cooling	Dangerous	Shutdown engine
		Temp. sensor fail	Battery runs out	False trip	Safe	
Power Supply	Energy for valve	Fail	Maintenance,Error	False trip	Safe	
	Energy for transmitter	Fail	Batter runs out	False trip	Safe	

Close

Figure 6. HMI screen for the FMEA on the devices in our case study

5. **Conclusions.** The condition monitoring system using the SCADA software for WirelessHART devices has been presented. The HMI design technique based on FMEA

methodology for providing helpful information in device troubleshooting has been introduced. The performance of the proposed system has been verified by experimental results. In order to be useful in practice, the maintenance planning based on the proposed monitoring system is the future work.

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