SCADA system for oil refinery control

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**Abstract**

A Supervisory Control and Data Acquisition (SCADA)/Programmable Logic Control (PLC) system is always used to control small industries like water treatment stations; electric power stations and irrigation systems. Oil and gas refineries generally rely on a Distributed Control System (DCS) to provide all process and equipment control functionality. In this paper, a SCADA/PLC system is used to control a whole oil refinery instead of the conventional control through DCS. The design and specific implementation method of a SCADA/PLC real system in an oil refinery process is introduced. It consists of four main units: a crude oil storage unit, a crude oil pretreatment unit, a distillation unit and products storage/dispatch unit. The output products from crude oil refinery process are Liquefied Petroleum Gas (LPG), Naphtha, Gasoline, Kerosene and Diesel that have a great usage in our daily life. The reason for using the Multipoint Interface/Decentralized Peripherals (MPI/DP) connection in main control loop instead of Ethernet connection is that MPI/DP speed is 185 kbps and Ethernet connection speed is 10/100 kbps, which increases the speed of transfer data through the system. Displacer level transmitters and automatic servo level gauging transmitters are used for measuring levels in the crude oil refinery process. Also differential pressure flow transmitters are used for measuring flow rate. Temperature transmitters with thermocouple temperature elements are used for temperature control. Constructing a highly stable and reliable SCADA/PLC system instead of DCS must realize automatic management and control of oil refinery process in order to avoid the waste of manpower, physical resources, and also to increase the safety of workers.

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1. Introduction

The oil refinery industries are extremely important because the output products from crude oil refineries as LPG, Naphtha, Gasoline, Kerosene and Diesel have a great usage in our daily life. Many researchers have studied the usage of SCADA/PLC system in the boiler operation, desalination plants and wastewater treatment plants. SCADA screens which are connected to Programmable Logic Controller (PLC) by means of communication cables are used to monitor the boiler operation focusing on the temperature, the level, the pressure and the flow control [1]. Multi-stage flash Brine Recirculation (BR) desalination plant is controlled by SCADA and the corresponding Human–Machine Interface (HMI). The plant consists of eight main cycles with a large number of inputs and outputs signals connected to the S7-300 PLC Siemens controller and also connect with the SCADA system based on (WINCC) software to monitor the system [2]. Industrial wastewater is crucial to sustain community health, clean and safe environment. Applying the SCADA solutions has a positive impact on the operations, maintenance, process development and saving for the wastewater treatment plants (WWTP). A SCADA software application is implemented on the wastewater treatment plant with the interface to the hardware to create a comprehensive real-time applications management environment for a modern wastewater operation [3]. The proportional, integral and derivative
(PID) digital controller based on cascade control system and its experimental validation through three different testing scenarios; namely control action through SCADA, control action using PLC and interfacing of PLC with NI-OPC server is introduced. In this study, Micrologix-1200 PLC and RSVIEW-32 SCADA have been used with RSLinx communication Software. The SCADA/PLC control loop has been implemented with the functionalities such as real time data analysis, set point modifications, automatic report generation and integration of data with MS-Excel and MS-Access. The enhancement in project data analysis is effectively done through the integration of PLC with Lab view. The obtained results proved that the conventional control system can be further enhanced with PLC as well as NI-OPC server significantly.

The organization of this paper is as follows: Section 2 presents the SCADA/PLC system description; Section 3 presents the associated Graphical User Interface (GUI); Section 4 is devoted to the units operation, and finally Section 5 presents the conclusions.

2. The SCADA/PLC system

In order to automate an oil refinery and minimize human intervention, there is a need to develop a SCADA system that monitors the plant and helps to reduce the errors caused by humans. While the SCADA monitors the system, PLC is used for the internal storage of instructions for implementing functions such as logic, sequencing, timing, counting and arithmetic to control various types of machine processes through digital and analog input/output modules. SCADA refers to the combination of telemetry and data acquisition. It includes collecting information via a Remote Terminal Unit (RTU), PLCs and Intelligent Electronic Devices (IED) and transferring it back to the central site to carry out any necessary analysis and control and then displaying that information on a number of operator screens. Three of the most important parts of a SCADA system are Master Station, remote terminals (RTU, PLC, and IED) and the communication between them [5–8]. In this paper, SIMATIC WinCC flexible 2008 is used for the implementation of crude oil refinery units GUI. SIMATIC S7-200 PLC is used to communicate between input and output instruments. The interface between WinCC flexible and the PLC station is MPI/DP. The HMI device baud rate is 9600 and the network profile is Point to Point Interface (PPI) [9]. The reason for using the MPI/DP connection in main control loop instead of Ethernet connection is that MPI/DP speed is 185 kbps and Ethernet connection speed is 10/100 kbps, which increases the transfer data speed between the system components and the SCADA system.

3. SCADA system GUI

As explained before, an oil refinery process consists of four main units: crude oil storage unit, crude oil pretreatment unit, distillation unit and products storage/dispatch unit. In this paper, three SCADA GUIs are designed to monitor and control oil refinery gas processes.

3.1. Crude oil storage unit/crude oil pretreatment unit GUI

SCADA GUI consists of:

- A feed pump (P-01) with a variable speed slider.
- Differential pressure flow rate transmitters (FT-01 and 02) with the output signal 4–20 mA. Its restriction flow element is an orifice plate with a differential pressure range of 0–2500 mmH2O. (FT-01 and 02) have a flow rate range from 0 to 400 m³/h, where 0 m³/h is the flow rate when the pump is off and 400 m³/h is the flow rate when the pump is running at maximum speed. It has an output field to show its reading in the percentage flow.
- A motor operated valve (MOV-01) at the inlet of tank (TK-01).
- A crude oil storage tank (TK-01) with a floating roof tank selected to hold evaporation losses to a minimum and to minimize the fire and explosion risk from the stored stock. Its capacity is 39,750 m³.
- An automatic servo level gauging transmitter (LT-01) used to measure the liquid level in the tanks due to its high accuracy. The area of the storage tank is very large and the very small error in liquid level measurement will lead to a great error in the liquid volume measurement.
- A motor operated valve (MOV-02) at the outlet of tank (TK-01).
- A pump (P-02) that discharges the crude oil from tank (TK-01) and feeds it to the vessel (V-01) with a variable speed slider.
- An oil/water separator vessel (V-01).
- A displacer level transmitter (LT-02) that measures the crude oil level in the vessel (V-01).
- A displacer level transmitter (LDT-03) that measures the crude oil level in the vessels (V-01, 02, and 03) and their red indication show that they are in the run mode, while the push buttons of (P-02) with the output signal 4–20 mA. Its restriction flow element is an orifice plate with a differential pressure range of 0–2500 mmH2O. (FT-01 and 02) have a flow rate range from 0 to 400 m³/h, where 0 m³/h is the flow rate when the pump is off and 400 m³/h is the flow rate when the pump is running at maximum speed. It has an output field to show its reading in the percentage flow.
- Pump (P-03) discharges sour water from the water settling pot of (V-01) and feeds it to the waste water treatment unit.

Fig. 1 shows the crude oil storage unit/the crude oil pretreatment unit GUI when (P-01) is in the run mode. The push button of (P-01) and the green indication show that it is in the run mode, while the push buttons of (P-02 and 03) and their red indication show that they are in the stop mode. The variable speed sliders of (P-01 and 02) are only activated when the pumps are in the run mode. The blue indication of (TK-01) shows that there is a crude oil level in it. The green indication of the line shows that there is a liquid flow, while the red indication shows that there is no flow. The green indication of (MOV-01) shows that it is fully open, while the red indication of (MOV-02) shows that it is fully close. The “Distillation” and “Home page” push buttons are for navigation between screens.

(Fig. 1) reading shows that the crude oil flow rate to (TK-01) is 58%, while (FT-02) is 0%.

Fig. 2 shows the crude oil storage unit/the crude oil pretreatment unit GUI when (P-01, 02, and 03) are in the run mode and there is a pop-up alarm screen which shows that the crude oil level in (V-01) is high, and the blue indication of (V-01) confirms the alarm.
3.2. Distillation unit GUI

SCADA GUI consists of:

- A pump (P-04) that discharges the crude oil from (V-01) at the crude oil pretreatment unit, and feeds it to (E-01), (H-01) and (T-01) at the distillation unit with a variable speed slider.

- A heat exchanger (E-01).

- Differential pressure flow rate transmitters (FT-03A/B) that measure crude oil flow rate to and from (H-01). They have an output field to show their readings in the percentage flow.

- A flow control valve (FV-03) that controls crude oil flow rate in the distillation unit. It has an output field to show its percentage opening.
- A distillation tower (T-01).
- Temperature transmitters with the thermocouple temperature elements (TT-01, 02, 03, 04, 05, 06, and 07). Thermocouple temperature element is used instead of Resistance Temperature Detector (RTD) because it is capable of measuring wider ranges of temperatures [10].

Fig. 3 shows the distillation unit GUI when (P-04) is in the stop mode. The push button of (P-04) and the red indication show that it is in the stop mode. The red indication of the line and the 0% readings of (FT-03A/B) show that there is no flow in the unit. The seven temperature transmitters (TT-01, 02, 03, 04, 05, 06, and 07) readings are 27°C because there is no crude oil flow.

Fig. 4 shows the distillation unit GUI when (P-04) is in the run mode. (P-04) is in the run mode and its variable speed slider is active. The vaporized state of the crude oil is obvious inside (T-01). (FV-03) indication shows that it is open by 75%. (TT-01) measures the temperature of output crude oil from (E-01) which is 300°C. (TT-02) measures the temperature of output crude oil from (H-01) which is 700°C. (TT-03) measures the temperature of the output gas from (T-01) which is 30°C. (TT-04) measures the temperature of the Naphtha output from (E-01) which is 70°C. (TT-05) measures the temperature of output Kerosene from (T-01) which is 120°C. (TT-06) measures the temperature of output Diesel from (T-01) which is 200°C.

3.3. Product storage/dispatch unit GUI

SCADA GUI consists of:
- Pumps (P-05, 06, 07, 08, and 09) to discharge LPG, Naphtha, Gasoline, Kerosene and Diesel respectively from the distillation tower (T-01) at the distillation unit and feed them to their storage tanks in the product storage/dispatch unit.
- LPG storage tank (TK-02) which is a spherical tank. Its capacity is 2400 m³
- Naphtha, Gasoline, Kerosene and Diesel storage tanks (TK-03, 04, 05, and 06) which are fixed roof tanks. The capacity of each is 28800 m³
- LPG metering station with the input field.
- Naphtha, Gasoline, Kerosene and Diesel loading arms (LA-01, 02, 03, and 04) with the input field for each.

Fig. 5 shows the product storage/the dispatch unit GUI when it is in the stop mode. The push buttons of (P-05, 06, 07, 08, and 09) and the red indication of them show that they are in the stop mode. The push button of LPG metering station and the zero value of the input field show that it is in the stop mode. The push buttons of (LA-01, 02, 03, and 04) and the zero value of their input fields show that they are in the stop mode.

Fig. 6 shows the product storage/the dispatch unit GUI when it is in the run mode. The push buttons of (P-05, 06, 07, 08, and 09) and the green indication of them show that they are in the run mode. The push button of LPG metering station and the appearance of the picture show that it is in the run mode. The push buttons of (LA-01, 02, 03, and 04) and the appearance of their pictures show that they are in the run mode. The associated pictures of LPG metering station and loading arms show where these products are used.

Three additional GUI’s are designed. These are, the home page GUI; the alarms GUI and the trends GUI.

Fig. 3. The distillation unit GUI when (P-04) is in the stop mode.
Fig. 7 shows the home page GUI with the operation sequence diagram. The “select page” symbolic input/output field is used to select a page from a drop down list. This symbolic input/output field action is activated after pressing on the “Go” push button.

The operation sequence diagram is presented in the home page. The “crude oil storage unit/the crude oil pretreatment unit”, “The distillation unit” and “The product storage/the dispatch unit” push buttons are used for fast navigation.

Fig. 8 shows the alarms view GUI which presents the alarms that appear during the operation while Fig. 9 shows the designed GUI for (FT-01) and (FT-02) trends in the percentage flow rate during operation. Fig. 10 shows the
designed GUI for (LT-01) and (LT-02) trends in the percentage level during the operation.

4. Units operation

4.1. Crude oil storage unit

The motor operated valve (MOV-01) opens and pump (P-01) suctions the crude oil and feeds it to (TK-01). The differential pressure flow rate transmitter (FT-01) measures the crude oil flow rate to (TK-01). The automatic servo level gauging transmitter (LT-01) measures the level of the crude oil in (TK-01). Logic high level alarm from (LT-01) reading (LAH-01) is used to alert the panel operator that the level in (TK-01) is high to take the necessary action to avoid over filling of (TK-01). This action can decrease the speed of the feed pump (P-01) or increase the speed of the discharge pump (P-02). Logic high–high level alarm from (LT-01) reading (LAHH-01) stops (P-01) and closes (MOV-
01) automatically without the intervention of the panel operator. It is an emergency shutdown action. (LAH-01) and (LAHH-01) are two logic alarms from the reading of (LT-01) but (LAH-01) is at a percentage level less than (LAHH-01) and they occur at different times. (LAH-01) is only an alert alarm for the panel operator while (LAHH-01) is for emergency shutdown action.

4.2. Crude oil pretreatment unit

Crude oil is seldom produced alone because it is generally mixed with water. Water creates several problems and usually increases the unit cost of oil production. The water must be separated from the oil, treated, and disposed of properly. Water from petroleum formations generally contains many ions. Sodium and chloride ions are usually present in high concentrations, while other ions are present in wide ranging quantities. At the interface, these ions may react chemically with the hydrophilic groups to form insoluble salts that cause corrosion to the equipments. Oil/water separation is usually based on a gravitational separation. Because water has a higher density (1000 kg/m$^3$) than the crude oil density (886 kg/m$^3$), water droplets have a tendency to settle down [11]. Vessel (V-01) is used for this process and its water pot is used for collecting settled water. The motor operated valve (MOV-02) opens and pump (P-02) suctions crude oil from (TK-01) and feeds it to the oil/water separator vessel (V-01). The logic low level alarm from (LT-01) reading (LAL-01) is used to alert the panel operator that the level in (TK-01) is low. The logic low–low level alarm from (LT-01) reading (LALL-01) stops (P-02) and closes (MOV-02) the same idea as (LAH-01) and (LAHH-01). Differential pressure flow rate transmitter (FT-02) measures the crude oil flow rate to (V-01). The displacer level transmitter (LT-02) measures the level of crude oil in (V-01). The logic high level alarm from (LT-02) reading (LAH-02) is used to alert the panel operator that the level in (V-01) is high. The logic high–high level alarm from (LT-02) reading (LAHH-02) stops (P-02) and closes (MOV-02). The displacer level transmitter (LDT-03) measures water/crude oil interface level in water settling pot of (V-01). The logic level alarms (LAHH-03 and LALL-03) from (LDT-03) reading automatic start/stop (P-03) which suctions water from (V-01) water settling pot and feeds it to the waste water treatment unit. Fig. 11 describes the automatic start/stop cycle of (P-03). The amount of water in the crude oil is very low so the filling of the settling pot with water takes a long time which makes the automatic start/stop cycle of (P-03) stable [12].

4.3. Distillation unit

The crude oil is a final product. It would have just been a low-grade fuel struggling to establish itself against coal. Many compounds in the crude oil can be separated into groups which have characteristics that make them considerably more valuable than the whole crude oil. Distillation is a separation process which requires differences to be recognized and utilized. Many products can be separated by detecting a difference in a physical property. Crude oil
distillation is a process in which heat is used to separate a mixture of hydrocarbons into two or more relatively pure products (or fractions) by the difference in their respective boiling points or boiling ranges. When a mixture of hydrocarbons is heated, the light components are the first to boil and go into a vaporized state. These vapors are cooled and condensed to form a fraction. Therefore, the purpose of crude oil distillation is primarily to split the crude into several distillate fractions of a certain boiling range [12–14]. Pump (P-04) suctions the desalted crude oil from (V-01) and feeds it to (E-01) to increase its temperature to about 300 °C before charging to (H-01). This heater increases the crude oil temperature to about 700 °C that is required for the distillation unit operation. (FV-03) control feeds flow to the distillation column. Most of the lighter fractions immediately vaporize, or flash and start rising up the tower. These vapors are cooled and condensed to form fractions. LPG condenses at about 30 °C, Naphtha condenses at about 40 °C, Gasoline condenses at about 70 °C, and Kerosene condenses at about 120 °C. The logic low level alarm from (LT-02) reading (LALL-02) is used to alert the panel operator that the level in (V-01) is low. The logic low–low level alarm from (LT-02) reading (LALL-02) stops (P-04).

4.4. Product storage/dispatch unit

Pump (P-05, 06, 07, 08, and 09) discharge LPG, Naphtha, Gasoline, Kerosene and Diesel respectively from the distillation tower (T-01) at the distillation unit and feed them to their storage tanks in the product storage/dispatch unit. The LPG metering station is used to measure the volume of gas transferred from producing regions to consumption regions. Naphtha, Gasoline, Kerosene and Diesel loading arms (LA-01, 02, 03, and 04) are used to transfer products from the piping systems to the consumption regions. LPG is used as a cooking fuel. Naphtha is used primarily for producing high octane gasoline, and it is also used as a solvent for cleaning applications. Gasoline is primarily used as a fuel in the internal combustion car engines. Kerosene is widely used to power jet-engine airplanes, aircraft. Diesel is primarily used as a fuel for diesel engines as mechanical automobiles engines and power generator engines.

5. Conclusions

The SCADA real system for oil refinery process control is designed to monitor and control all the system process instead of the conventional control through DCS is presented in this paper. An oil refinery process consists of four main units: a crude oil storage unit, a crude oil pretreatment unit, a distillation unit and products storage/dispatch unit. SIMATIC WinCC flexible 2008 is used to design six GUIs of the four main units which are used as an interface between the human (operator) and the machine (oil refinery field). These GUIs are the crude oil storage unit/the crude oil pretreatment unit GUI, the distillation unit GUI, the product storage/the dispatch unit GUI, the home page GUI, the alarms GUI and the trends GUI. The alarms view GUI presents the alarms that appear during operation. The trends GUI shows the differential pressure flow transmitters (FT-01) readings which is responsible for measuring the crude oil flow rate to tank (TK-01), and (FT-02) readings which measures the crude oil flow rate to vessel (V-01) in the percentage flow. It also shows the reading of the automatic servo level gauging transmitter (LT-01) which measures the crude oil level in the tank (TK-01) and the displacer level transmitter (LT-02) that measures the crude oil level in the vessel (V-01) in the percentage level. The most important benefits of using a SCADA system are monitoring and controlling the oil refinery process all over the time, decreasing the operation time and increasing the safety of workers. Before using a SCADA/PLC system to control the oil and gas refineries, DCS has been used in controlling it till now. The advantage of using SCADA/PLC system is that the scan time which means monitoring the system, detecting the problems, and executing the actions is much faster than DCS. The DCS tends to be more
expensive and tends to use proprietary hardware and software. The SCADA system can record and store a very large amount of data. The SCADA screens are more realistic than the DCS screens for the user and the operator can monitor the process of the plant from any place all over the world.

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