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PLC - HMI Based Pipeline Leakage Detection System In Petroleum Transfer Lines

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Abstract

A novel design for pipeline leakage detection system in petroleum transfer lines using Bernecker and Rainer (B&R) Programmable Logic Control (PLC) – Human Machine Interface (HMI) is proposed which uses real-time information from the field to estimate the hydraulic behavior of the product being transported. This project comprises of pressure relays and provides a method for detecting and localizing leak of petroleum in pipeline network. PLC analyzes the data received from pressure relays to identify the presence of leak in the pipe network. Data from two or more pressure relays are compared by the PLC and if there is a non-tolerable variation then there is a chance of leak between the sensors compared. The more frequent the sensors are kept, the leakage can be localized and detected more efficiently. As the pipe networks are wide spread, the data from the sensors are transmitted using Wireless Sensor Network (WSN) and it is received in the main base station where the PLC is kept. HMI makes easy to monitor each and every sensors connected to the device. A protocol has been developed that can be used to evaluate the performance of leak detection systems. This paper presents the results of a pilot study and verification of concept of a novel methodology using PLC-HMI for pipeline leakage detection and assessment of petroleum distribution system.

Keywords: PLC – HMI, Pipeline leakage detection system.

Introduction

"A Small Leak Will Sink A Great Ship". Wastage of precious crude oil or refined petroleum will affect the amount of petroleum and gas availability for usage.

Oil Leakage can immediately turn into a Fire hazard. This will release many harmful gases which can be carcinogen in nature and will lead to many respiratory diseases. When oil leakage occurs, it contaminates the soil and its orientation making the soil infertile and inhabitable which drastically changes the biodiversity and damage the plants in that region. Also it causes environmental pollution as shown in Figure.1. and Figure.2.

Figure 1: Environmental Pollution due to Oil Leakage

Figure 2: Environmental Pollution due to Oil Leakage

Hongying Yang [2] solved the problem of discriminating leaks and valve adjusting operations in leak detection of oil pipeline based on dynamic pressure transducer (DPT). Li Yi-Bo [3] proposed Negative pressure wave technique an effective method for paroxysmal oil leakage detection and location. The monitoring system acquires operational parameters of the pipeline from the existing SCADA system. Likun Wang [4] described that for different pipelines the system of pipeline detection based on SCADA and designed the system of communication structure using WLAN.

Li Wei [5] introduced a system with the advanced algorithm and precise GPRS remote transmission technology, automatic completion of leak detection and alarm and troubleshooting. Peng, Shanbi [8] implemented real time emulation from pipeline's head to tail and from tail to head. Salam [9] analyzed the pattern of the pressure changes computationally to detect the location and the size of the leakage. Sornmuang [12] used water leakage signals from a field-test yard. The results show that the leaking pipeline can be efficiently detected. Yibo Li, [13] designed a pipeline detection & location system with 2% resolution of the total flow. Zhang Yu [14] applied the leakage detection system based on negative pressure wave method to crude oil pipelines.

Lufan Zou et al [6] discussed that due to the severity of the economic and environmental impact associated with leakages from pipelines, oil and gas industries are constantly seeking more efficient and reliable pipeline monitoring technologies. Many monitoring solutions have been considered over the past few decades, with underlying technologies. With the target of improvement with more efficient and reliable pipeline monitoring technologies, PLC - HMI based pipeline leakage detection system in petroleum transfer lines is proposed. The paper is ordered as follows: Section 2 deals with the PLC utilized in this prototype model. Section 3 discusses the correlation between pipeline pressure and acceleration. Section 4 describes the proposed leakage detecton system. Section 5 demonstrates the Lab Scale Experimental Set – up. Section 6 illustrates the B&R Automation studio and Visualization PP45 (HMI). Section 7 furnishes the prototype results and its analysis. Section 8 deals with the conclusion of this work.

Programmable Logic Controller (PLC)

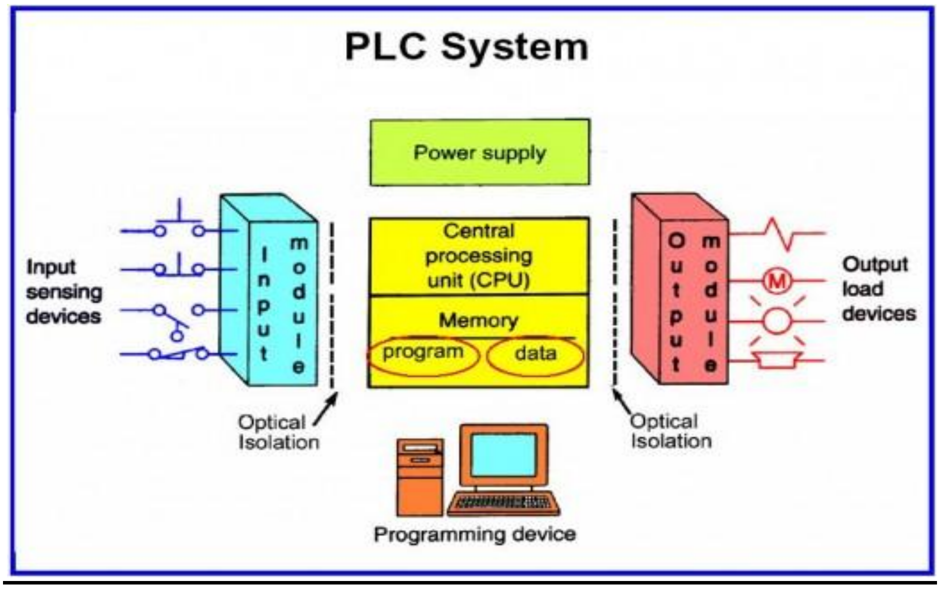


Figure 3: PLC System

B&R X20 Standard CPU

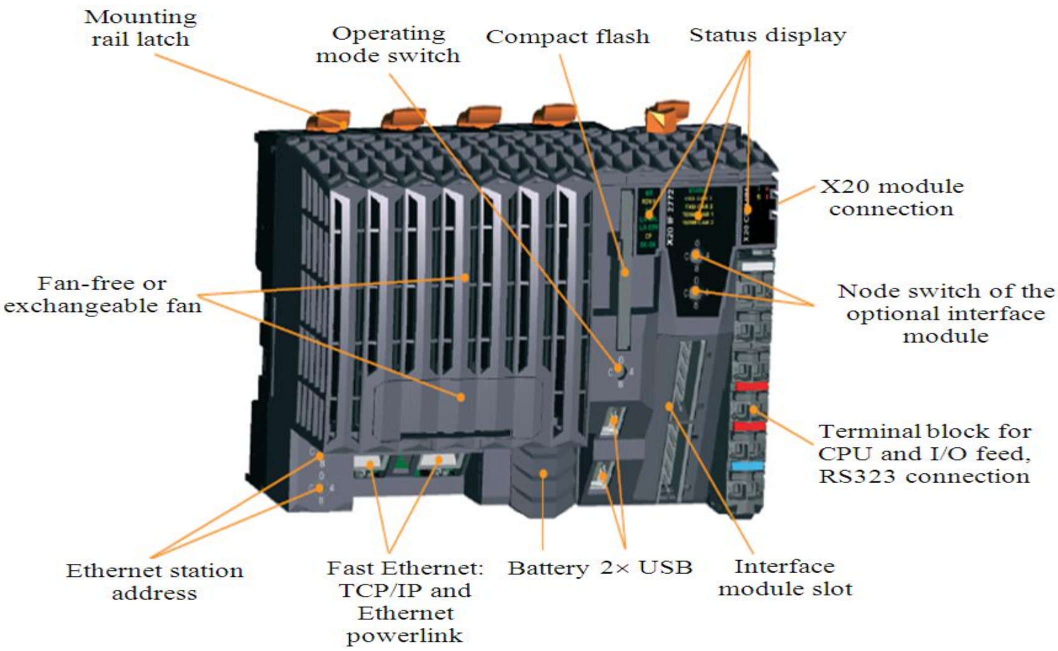


Figure 4: B&R PLC-X 20 standard CPU

Figure 5: B&R X20 standard CPU Module

Figure.3. represents the PLC system which consists of Input/output modules, power supply, CPU, memory and programming devices. A power supply integrated in the CPU with I/O supply terminals provides power for the backplane, I/O sensors and actuators, eliminating the need for additional system components.

In B&R - PLC, RS232, Ethernet, Flash memory card and USB are standard equipment. Flash memory card is utilized in this work. In addition, CPU has a POWERLINK connection for real-time communication.

The optimally scaled X20 system CPU line used in this work is shown in Figure.4. and Figure.5. will satisfy a wide range of requirements with the highest performance. It will master cycle times of 100 µs

Correlation Between Pipe Line Pressure and Acceleration

Two strongly correlated quantities [7] are Flow-induced pipe vibrations and Pressure variations. Internal pressure p of a pipe, p = ***po+dp***

where ***po*** is the nominal pressure and ***dp*** is the pressure variations.

As, the nominal pressure ***po*** does not contribute to the flow-induced pipe vibrations only the pressure fluctuations ***dp*** will be considered. The pressure fluctuations ***dp*** is balanced by the elastic stresses, ***pel***, and the inertia stresses, ***pin***, in the pipe wall, i.e., ***dp = pel+ pin.***

Assuming ***Fel*** is the unidirectional force developed against the pipe wall, then

$$\frac{Fel}{A} = \frac{PelDl}{2tl} = \frac{PelD}{2t} \quad (1)$$

Where A is the cross sectional area, ***D*** is the pipe diameter, ***l*** is arbitrary length of the pipe, and ***t*** is the pipe wall thickness. Hook's law declares:

$$\frac{Fel}{A} = E\varepsilon = \frac{E\pi\delta D}{\pi D} = \frac{E\delta D}{D} \quad (2)$$

Where, ***E*** is pipe's elastic modulus, ε is strain and δD is pipe's diameter deformation.

From Equations 1 and 2,

$$Pel = \frac{2tE\delta D}{D^2} = \frac{4tE\delta}{D^2} \quad (3)$$

Where δ is the displacement of the pipe wall.

The inertia force,

$$Fin = ma = (\pi tlD\rho)a \quad (4)$$

Where m is the mass, ***a*** is the acceleration, and ρ is the mass density of the pipe.

From Equations 3 and 4 the pressure fluctuations ***dp*** can be expressed as

$$dp = Pel + Pin = \frac{4tE\delta}{D^2} + t\rho \quad (5)$$

Thus the correlation between pressure variations and pipe wall acceleration obtained.

Further assuming

$$\delta = \delta o(\sin\omega t) \qquad (6)$$

Equation 5 can be rewritten as:

$$dp = \left(\rho - \frac{4E}{D^2\,\omega^2}\right) ta \qquad (7)$$

The correlation derived is more evident. Evans et al. (2004) took simple approach to simulate the piping system as one dimensional beam model represented in Equation 8.

$$dp = -\frac{A\gamma}{g}a \qquad (8)$$

Where g gravitational acceleration, A cross sectional area of the beam and γ specific weight of the beam. Equation 8 specifies that the acceleration of the pipe is proportional to the pressure fluctuations in the fluid.

Based on this mathematical model, the utilization of pressure variation measured on the pipe surface as a measure of pipeline health is highlighted.

Proposed Leakage Detection System

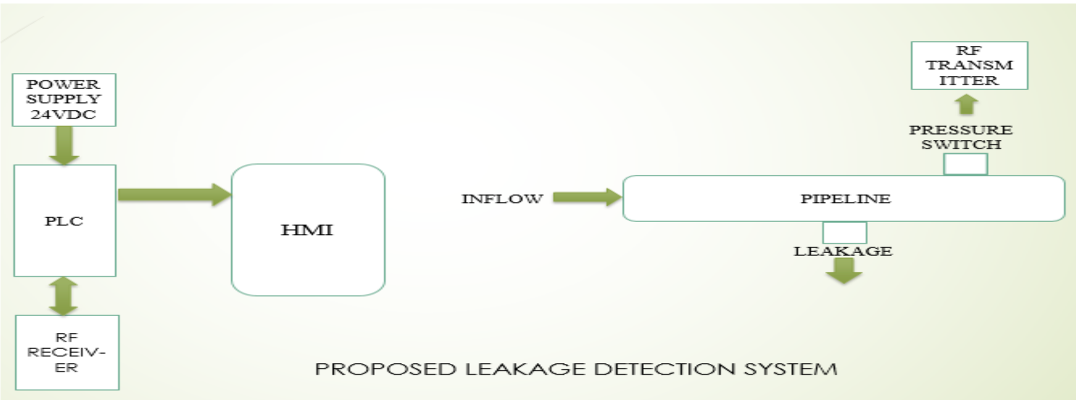


Figure 6: Proposed Leakage Detection System

The proposed leakage detection system is shown in Figure.6. for leak detection of a fluid in a pipeline network, comprising of pressure relay deployed at two or more locations in the pipeline network. A processor configured to receive and process the signals generated by the pressure relay. One RF module is configured to transmit from the pipe line and to receive the signals at the PLC - HMI. The processor of the pressure relay is used to detect malfunction of the pressure signal generated by the pressure relay.

PLC configured to analyze the signals generated by one or more of the pressure relays to identify the presence of one or more leaks in the pipe network. PLC will determine whether there are any significant pressure drops based on the pressure signals in the pipeline network in a location. Finally PLC – HMI will issue an alert after a leak has been located in the pipeline.

Figure 7: Pressure Switch

Figure.7. represents a pressure switch, used in the lab scale experimental set up that closes an electrical contact when a certain set pressure has been reached on its input. The switch is designed to make contact either on pressure rise or on pressure fall. Pressure Range: (0-3) bar or (0 – 43) psig. Difference Pressure Range: (0.25 – 1.5) bar or (10-25) psig.

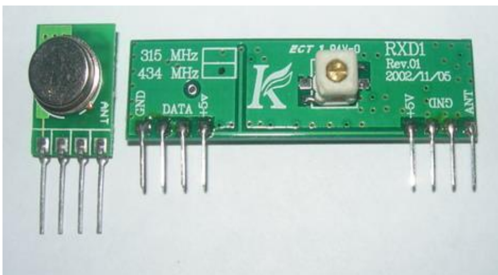


Figure 8: RF Module

Figure.8. represents a RF module (Radio Frequency module), small electronic device used in this prototype to transmit and receive radio signals from prototype to PLC Hardware.

Lab Scale Experimental Set Up:

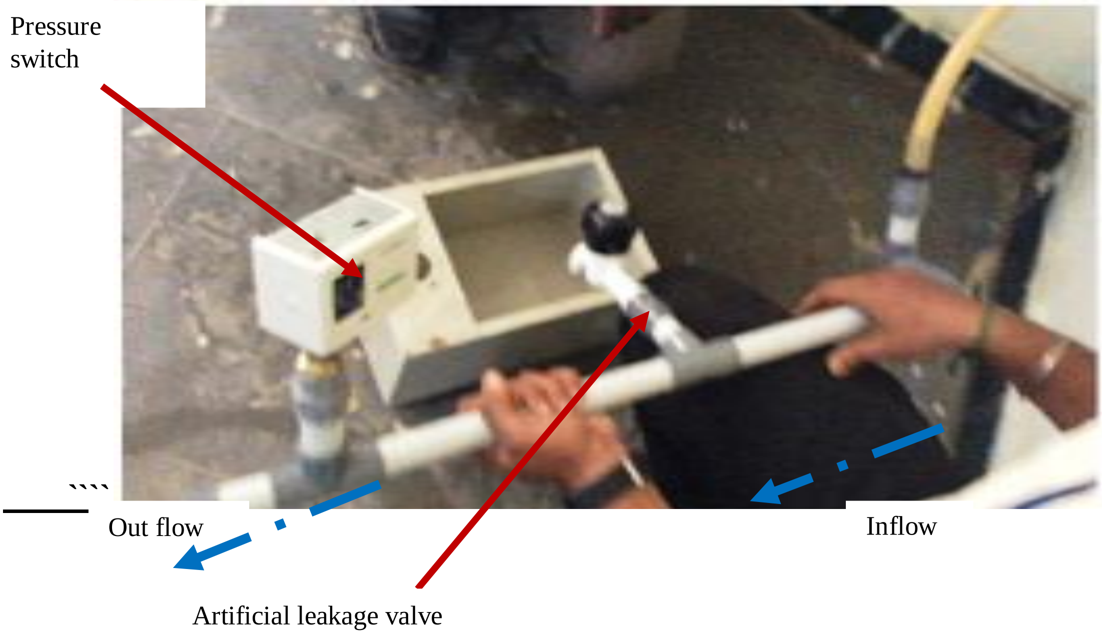


Figure 9: Lab Scale Experimental Set Up.

In Lab scale Experimental set up shown in Figure.9, inflow and outflow of the pipeline is represented, Pressure switch is connected in the pipeline and by using Artificial leakage valve, leakage in the pipeline is allowable for testing.

In this system, we have a network of pipeline(s) which transports fluids from a source to its destination. A pressure is maintained in the network for the optimum transportation of the fluids. We have employed a series of pressure switches over the pipelining network. Every switch is connected to a RF module. This module act as a transmitter and it transmits the Data from the sensors to the controller i.e. PLC (Programmable Logic Controller). A RF module is connected in the PLC end which acts as a receiver and the Data is fed to the PLC. This communication happens over the RF communication. In the PLC, the acceptable range for pressure of the fluid is set. As this system runs on real time, the PLC would be acquiring Data from the switches on a continuous basis. Whenever there is a leakage in the pipeline network, there will be a change in the pressure flow rate and temperature of the fluid. The pressure relay will transmit the Data to the PLC. The PLC will detect the difference in the pressure of the fluid as it has crossed the acceptable range. This will generate an Alarm in PLC - HMI. The PLC with HMI is shown in Fig.10. In the PLC we can set the priority for alarm level. If the leakage is considerably small then it can be set as low priority and whereas when there is considerable amount of change in the flow rate and the temperature, then such a situation would be set at high priority.

Figure 10: PLC with HMI

Model number: 4PP045.0571-062
Specification: 5.7" inch QVGA color LCD display
10 touch-keys
64 MB DRAM

B&R Automation Studio and Visualization PP45 (HMI)

B&R Automation Studio is the integrated software development environment that contains tools for all phases of a project. The controller, communication and visualization are all configured in one environment. That reduces both integration time and maintenance costs. Figure.11. represents the ladder diagram used in this prototype.

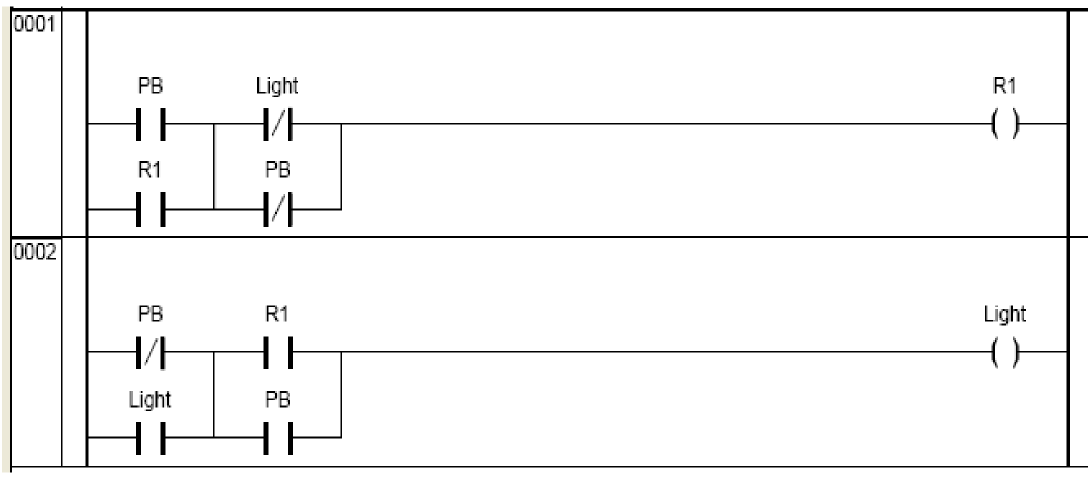
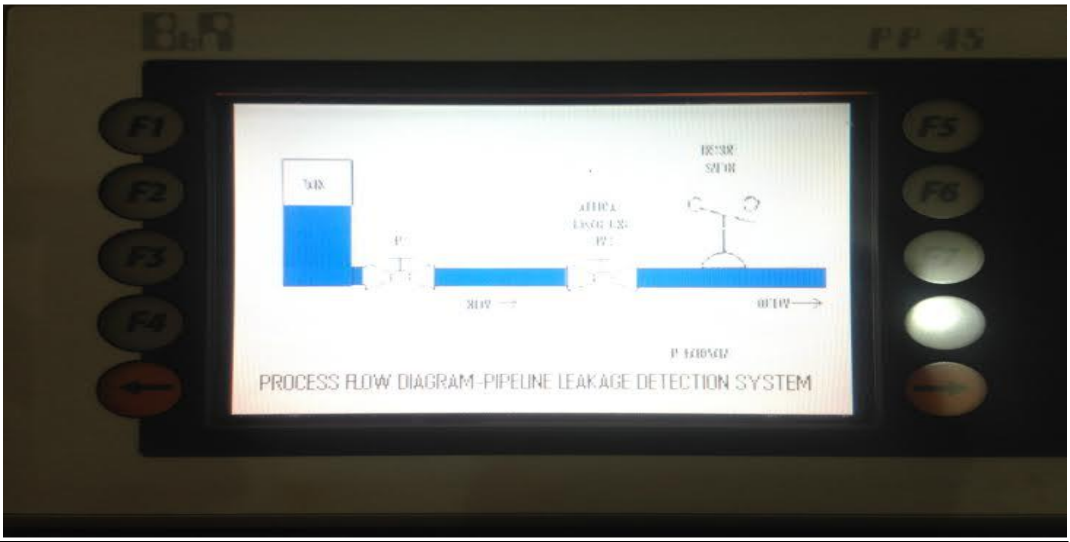


Figure 11: Ladder Diagram

PB - START/STOP SWITCH
LIGHT - WARNING INDICATOR
R1 - WARNING MEMORY

The visualization system an effective tool integrated in Automation Studio is used in this project to create line displays with keys and touch screens.

B&R PLC - HMI Display At No Leakage



B&R PLC-HMI Display While Leakage

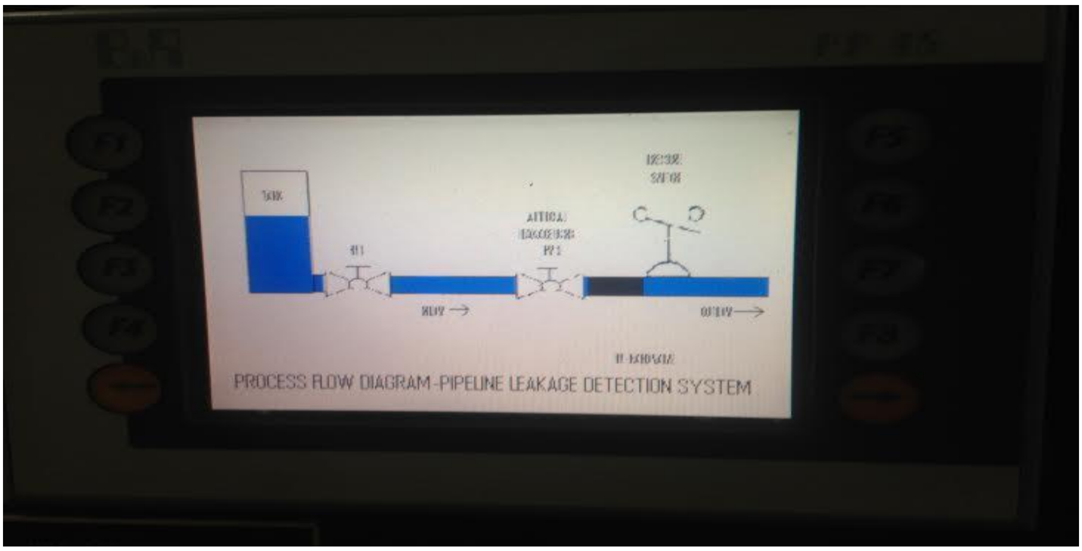


Figure 12 & 13: B&R HMI Displays At No Leakage And While Leakage

Prototype Results and Analysis

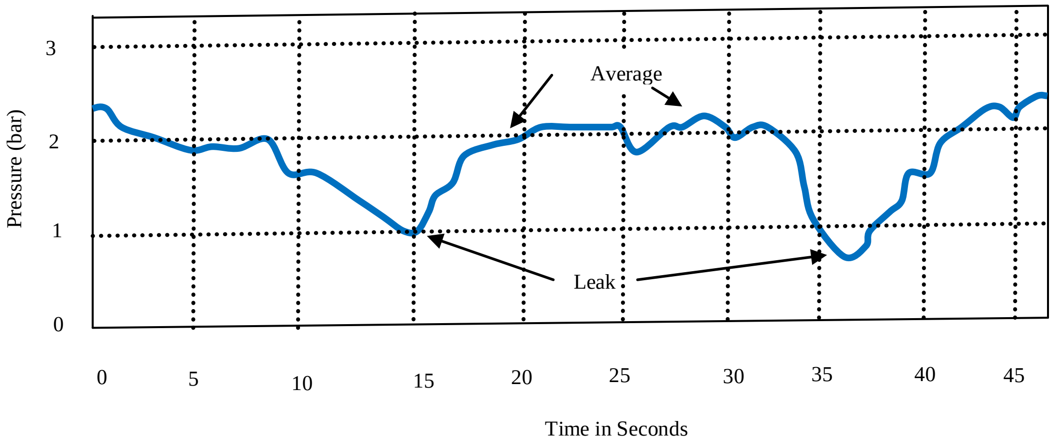


Figure 14: Pressure during leakage and average operating conditions

Figure. 12. & Figure. 13. represents B&R - HMI Displays at No Leakage and While Leakage conditions respectively. Figure. 14. represents the pressure of the prototype model during leakage and average operating conditions.

Conclusion

The designed system for leakage detection in Petroleum transfer lines detected and localized the leaks if anywhere in a pipeline network. More number of sensors will provide high resolution and it will improve the detection probability. PLC analyzed the data received from pressure relays and identified the presence of leak in the pipe network. Using PLC the accuracy of the leak detection is high even with more number of sensors distributed over the pipeline network. This system could be used effectively in identification and localization of leakage.

The system designed is a solution to wide range of problems faced by pipeline leakage in petroleum transfer lines. Thereby this system is used in reducing the impacts of cost by oil leakage.

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