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PLC based System for Measuring Concentration of Oxygen in Mines for Miners Safety with O2 Sensor

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***Abstract*— *The health of the human being is always a primary concern of every industry. The mining industry is a risky business. The objective of this paper is to save miners life by considering one measure safety point, measuring the concentration level of oxygen before entering in mines for work. I have used Programmable Logic Control System for converting raw value (electrical signal) generated by O2 sensor to engineering value, which I will display using Human Machine Interface (HMI) readable by humans. As we are aware that in mines there are lots of gases flow in airstream and sometime chemical reactions occurs which affects composition of mine air, results oxidation reduces the percentage of oxygen. So before we enter in mines everyday for work we will measure the concentration of oxygen level in mine.*

As we already know that dry air contain 20.9470% of oxygen (21% O2) with 78% nitrogen and 1% other gases. We will program our logic by considering the 20% oxygen is present in our mine's atmosphere. If oxygen level varies below 20% than a alarm will trigger, that alarm will display on HMI and Operator will alert miners before any casualty occur.

Keywords* — human machine interface, miners safety, oxygen, O2 sensor, programmable logic control.

I. INTRODUCTION

Oxygen is the most prime constituent for living beings because it preserves life on the earth. It is said that 90% of biochemical and metabolic actions or motion need oxygen.

Our system is at the bottom of a coal mine and it is measuring the concentration of O2 in the mine's air or atmosphere. The main applications of our system are:

1. Measurement of oxygen in atmosphere.
2. Critically usable for measuring mines oxygen levels.

This is a 'programmable logic controller' based system tuned with 'electrochemical oxygen sensor' primarily used to measure oxygen levels in the ambient air. This project's main tools are as following:

1. Programmable logic controller
2. Oxygen sensor
3. Human machine interface
4. Power supply (24V dc)

The electrochemical oxygen sensor produce a 4-20mA analog signal and Plc will process this signal and it will de-code that signal based on our logic and Human machine interface will show us the concentration level of oxygen in mines. DC power supply will power up all components like Sensor, PLC and HMI.

Our task is to prevent hazardous accidents which can happen in mines due to low or sudden change in mines oxygen level. So in this work, we make a Plc based system using oxygen sensor which will monitor the oxygen level in mine's atmosphere and will alert if O2 level decreases. Measuring oxygen is a critical task. As air is flowing in the mine's atmosphere the O2 sensor will sense the air and measure the oxygen level and generate an output signal in accordance with the oxygen concentration in air and that output will become an input signal to programmable logic controller than plc will process this signal and percentage of oxygen will display on human machine interface which is connected with plc via profibus communication.

Our machine has two cycles: sampling and alarming.

When it's sampling, it will measure the oxygen concentration of the air passing by the sensor.

When oxygen level decrease the standard set point, it will generate an alarm on the human machine interface screen and the operator will sound the buzzer which will alert the miners and their life can be save from unwanted accident.

II. LITERATURE REVIEW

India is one of the biggest shippers of iron ore, chromites, bauxite, mica and manganese, and India is ranked fifth between the mineral producing countries in terms of volume of production. The mining sector contributes nearly 2.4% to India's GDP. India manufactures approximately 88 minerals, which include fuel, atomic, metallic and non-metallic minerals. India's mining prosperity is depends on Odisha, Andhra Pradesh, Rajasthan, Chhattisgarh, Jharkhand, Madhya Pradesh, and Karnataka. So the mining industry is administering both at the federal and state level. Under the constitution of India, the state has power to control mines and mineral development. This mines and mineral department regulate EHS (Environment, Health, and Safety) unit in every mine. EHS unit regulate and provide miners a safe and healthy environment to work. The atmospheric air in mines can be polluted by the presence of other gases such as carbon monoxide, hydrogen sulfide, methane, and excess of carbon dioxide.

Human Beings breathe easiest with 21% oxygen present in air. When other gases mixed with air, oxygen levels drop and that is when the trouble starts. To stop converting this trouble in dangerous accident, we will measure the oxygen concentration in mine's air. For measuring O2 in mine we will use 'Zirconium oxygen sensor'. When air passes through the mine environment, its gases balance or content level changes due to other (different) kinds of pollutant along its path. These pollutant are CO2, carbon monoxide, sulphur dioxide, methane etc.

The literature review presents the block diagram representation, network model, gaseous composition of air and oxygen sensor which explains the concept of measuring oxygen in mine's using programmable logic controller.

2.1 Block Diagram

The block diagram shows the oxygen measuring system of mine's. All the components are connected in proper order and show how this system measures the O2.

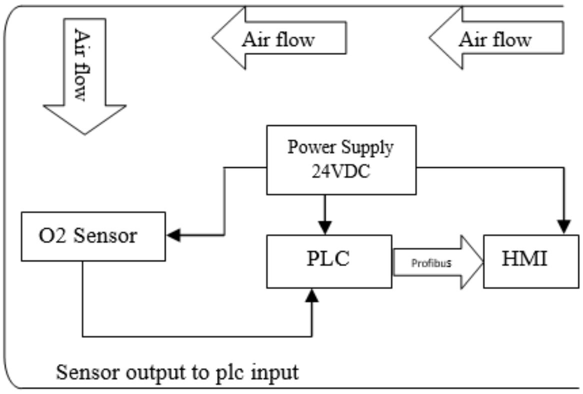

Fig 1.1 Typical block diagram of Mine's oxygen measuring system

2.1.1 Network Model

In this work, our task is to measure the oxygen level in mine using O2 sensor. Sensor will transmit data to the control unit and that control unit will process data value send by sensor and evaluate it than generate result. We can understand the network model via following flow chart. Which represents the idea of whole process that how we will measure the oxygen concentration in mines. This flow chart also shows the alarming system if oxygen concentration decreases below the set point, which we have been taken from standard oxygen concentration required for human being to live.

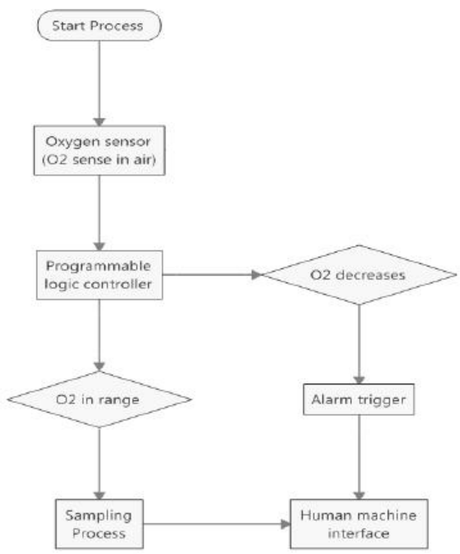

Fig 1.2 Typical Network Model diagram

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2.1.2 Gaseous Composition of dry Air

Air is the deceptive combination of gases that surrounds the earth. Air holds major stuff, such as oxygen and nitrogen that most species need to survive. Humans are off course one of them. Standard dry air is the mixture of gases that mixed up at sea level. It is made up of nitrogen, oxygen, argon, carbon dioxide, neon, helium, krypton, hydrogen, and xenon. Masses of air are constantly moving due to that standard dry air is not accurate everywhere at once. The dry air composition in atmosphere is as follows:

Table 1.1: Standard Composition of Dry Air

GAS NAME	CHEMICAL SYMBOL	%BY VOLUME
Nitrogen	N2	78.084
Oxygen	O2	20.947
Argon	Ar	0.934
Carbon dioxide	CO2	0.033
Neon	Ne	0.001818
Helium	He	0.000524
Methane	CH4	0.000179
Krypton	Kr	0.0001
Hydrogen	H2	0.00005
Xenon	Xe	0.000009

Based on above concentration of oxygen level in air, we will measure the concentration level of mine's oxygen using oxygen sensor.

2.1.3 Oxygen Sensor (OXY-FLEX ANALYZER)

The Sensor assembly consists of sensing cell, pumping plate, sensing plate, heater coil. At the core of the O2 sensor is the sensing cell, consists of two 'Zirconium dioxide (ZrO2)' squares coated with a thin porous layer of platinum which acts as electrodes. These electrodes generate necessary catalytic effect for O2 to dissociate, allowing the oxygen ions to be transported in and out of the ZrO2. The cell assembly is surrounded by a heater coil which produces 700 degree centigrade for operation. The ZrO2 square works as an electrochemical oxygen pump, which maintain the pressure inside the chamber is always less than the ambient oxygen pressure outside the chamber. This difference in oxygen pressure generates an output signal which could be a voltage (0-10V) or current (4-20mA) signal.

2.1.4 Electrical Connection and Pin diagram

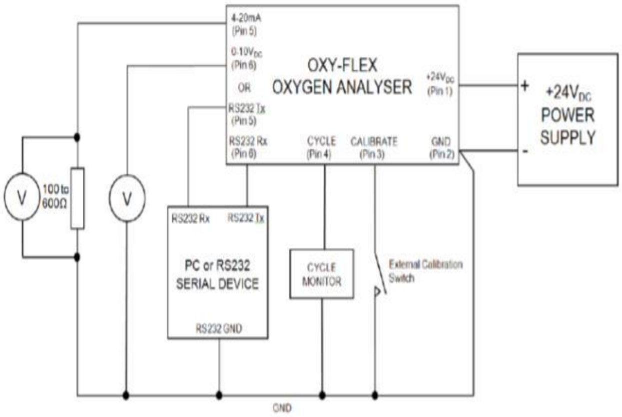

Fig 1.3 Electrical Connections

Pin out description is as follows:
Pin 1: 24Vdc
Pin 2: 0Vdc
Pin 3: Calibrate
Pin 4: cycle
Pin 5: 4-20mA/RS232 TX
Pin 6: 0-10Vdc/RS232 RX

2.1.5 O2 Sensor Technical Datasheet

- Supply Voltage: 24Vdc
- Current Consumption: 500mA at 24Vdc.
- Digital output: RS232
- Analog Output: 0 – 10Vdc and 4 – 20 mA

III. LOGIC MODEL

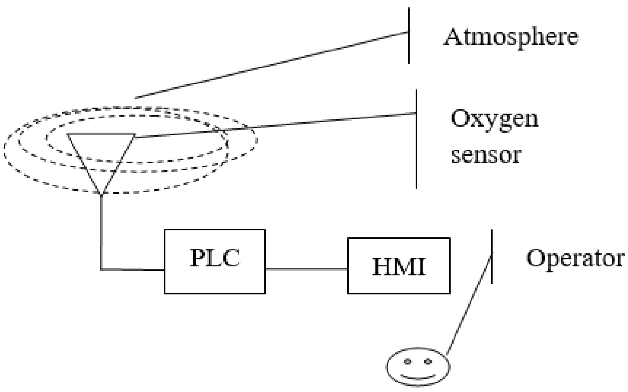

Fig 1.4 A typical Logic Model

The logic model shows that the logic of measuring the oxygen concentration in air is totally based on standard oxygen present in atmosphere.

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It is important to note that the sensor will generate a 4-20mA analog signal. We will break this analog signal according to standard available oxygen in atmosphere using scaling formula.

3.1 Mathematical Scaling Formula

$$\left(IN4 \times \frac{(IN3\text{-}IN2)}{(NI1\text{-}IN0)} \right) + \left(IN2 - \left\{ IN0 \times \frac{(IN3\text{-}IN2)}{(IN1\text{-}IN0)} \right\} \right)$$

Here,

IN0---- Integer value low limit (0)

IN1---- Integer value high limit (27648)

IN2---- Low limit of Oxygen value (0)

IN3---- High limit of Oxygen value (21)

IN4---- Integer count of analog value (mA) or sensor output

We have signal coming in current: 4 – 20 mA from sensor output. Now, how do we use this amp in our logic? Well, we can't, so we have to turn this signal into number. We use chips to do that. It's electronics. So let's say we have a 4-20mA signal that we want to use to measure oxygen from 0 – 21 percent. How do we do it?

Well, first we need to break that 4 – 20 mA down into much more than just whole amp. 4, 5, 6, 7…. That's never going to be useful to us. We need more values. So how many can we get? Well, that depends on our chips (built into our analog IO modules).

Here in Siemens PLC, I am using AI8×12bit analog module, means this module has 8 – analog input channels. Here I am using only one channel for one sensor output. This channel address start from PIW256 and in module's hardware configuration we already defined its input scale range from 4 to 20 mA. Siemens standard integer value range is from 0 to 27648. So here 4 mA represent 0 and 20mA represent 27648.

This is all done by chips used in analog module. We only have to define desired address and its scaling range.

IV. TESTS AND SIMULATION ANALYSIS

4.1 Tests

Now we will break this 4 to 20mA in 0 to 27648 integer value and perform scaling using standard oxygen available in environment which is 21%(0 to 21%). Here we will also cross verify our scaling by assuming that 0 to 21% is 0 to 100%

Means 0 = 0% of oxygen

And 21 = 100% of oxygen

Because in our environment 21% oxygen is available, this is 100% in terms of availability.

Mathematically,

Test_1

When sensor output = 4 mA, than

IN0 = 0 (Integer value low limit)

IN1 = 27648 (Integer value high limit)

IN2 = 0 (Low limit of Oxygen value)

IN3 = 21 (High limit of Oxygen value)

IN4 = 0 (milliamps coming from sensor or integer value at 4 mA)

Put all values in above scaling formula-

[0*(21-0)/ (27648-0)] + [0-{0*(21-0)/ (27648-0)}]

We will get the resultant value = **0%** of oxygen concentration.

Test_2

When sensor output = 10mA

IN0 = 0 (Integer value low limit)

IN1 = 27648 (Integer value high limit)

IN2 = 0 (Low limit of Oxygen value)

IN3 = 21 (High limit of Oxygen value)

IN4 = 13824 (milliamps coming from sensor or integer value at 10 mA)

Put all values in above scaling formula-

[13824*(21-0)/ (27648-0)] + [0-{0*(21-0)/ (27648-0)}]

We will get the resultant value = **10.473%** of oxygen concentration.

Test_3

When sensor output = 20mA

IN0 = 0 (Integer value low limit)

IN1 = 27648 (Integer value high limit)

IN2 = 0 (Low limit of Oxygen value)

IN3 = 21 (High limit of Oxygen value)

IN4 = 27648 (milliamps coming from sensor or integer value at 10 mA)

Put all values in above scaling formula-

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[27648*(21-0)/ (27648-0)] + [0-{0*(21-0)/ (27648-0)}]

We will get the resultant value = **20.947%** of oxygen concentration.

4.2 Simulation Analysis

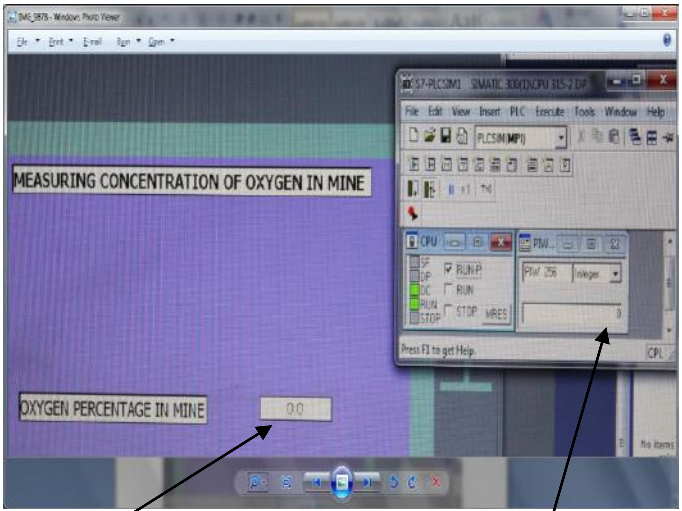
4.2.1 Test_1 Analysis

Sensor output = 4mA

Raw count value = 0

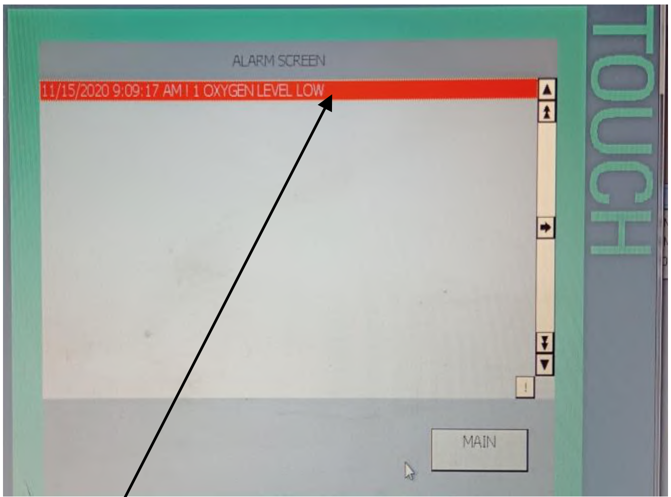
Oxygen concentration = 0%

Level of oxygen = Low, so alarm will trigger to alert operator to take appropriate action. Now we will see all this in simulation environment using following pictures:



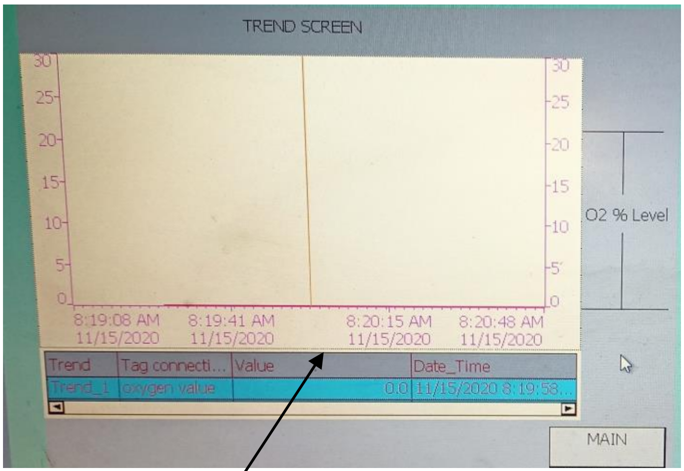
0% oxygen concentration raw count value 0

Fig 1.5 Simulation Result_1



Showing low level alarm

Fig 1.6 Alarm Screen_1



Showing trend for 0 % O2 concentration

Fig 1.7 Trend Screen_1

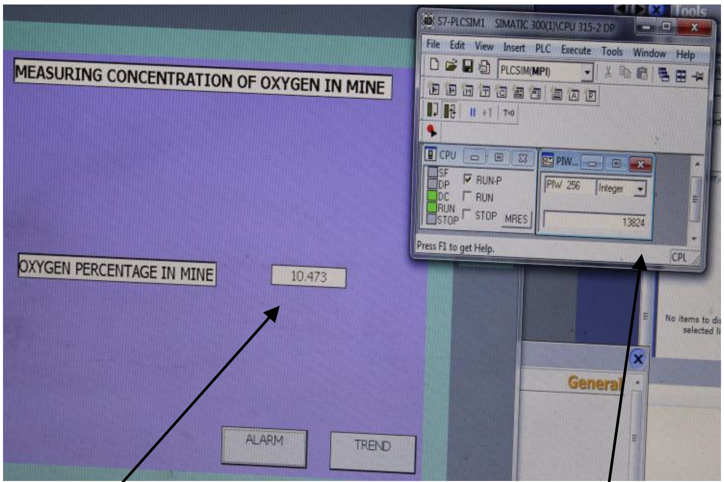
4.2.2 Test_2 Analysis

Sensor output = 10mA

Raw count value = 13824

Oxygen concentration = 10.473%

Level of oxygen = Low, so alarm will trigger to alert operator to take appropriate action. Now we will see all this in simulation environment using following pictures:



10.473% oxygen concentration raw count value 13824

Fig 1.8 Simulation Result_2

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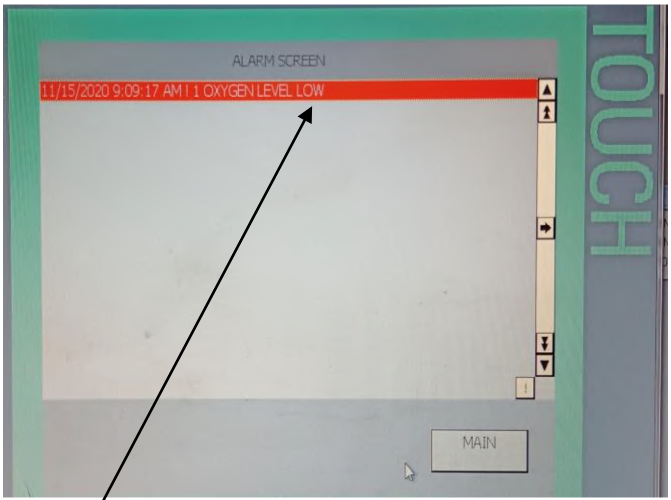
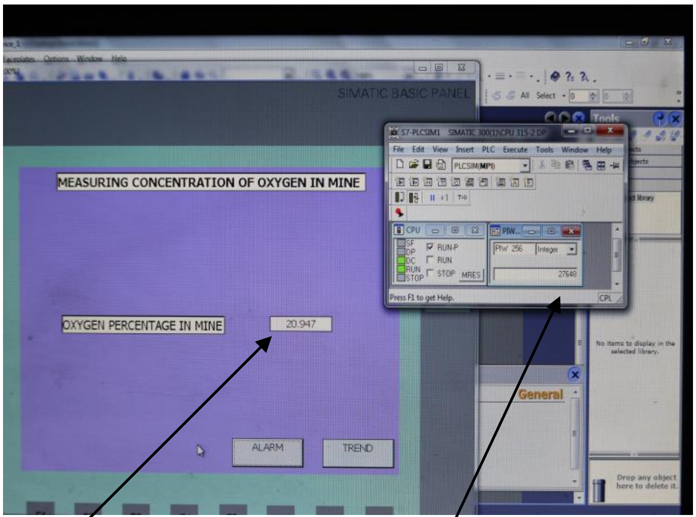


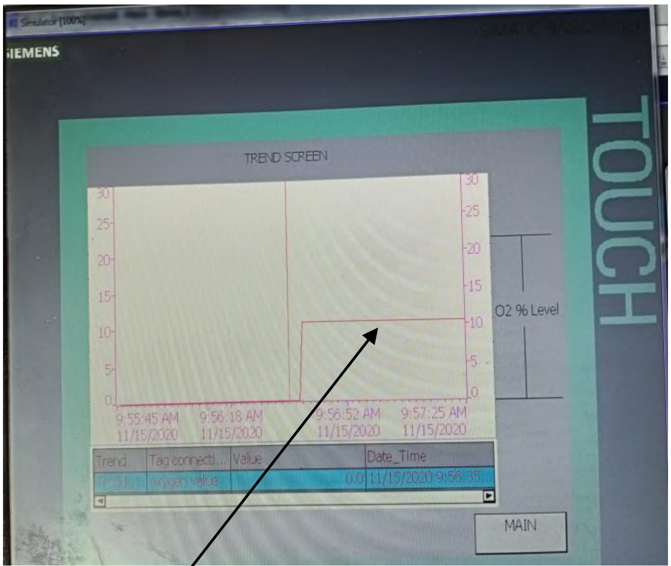
Showing low level alarm

Fig 1.9 Alarm Screen_2



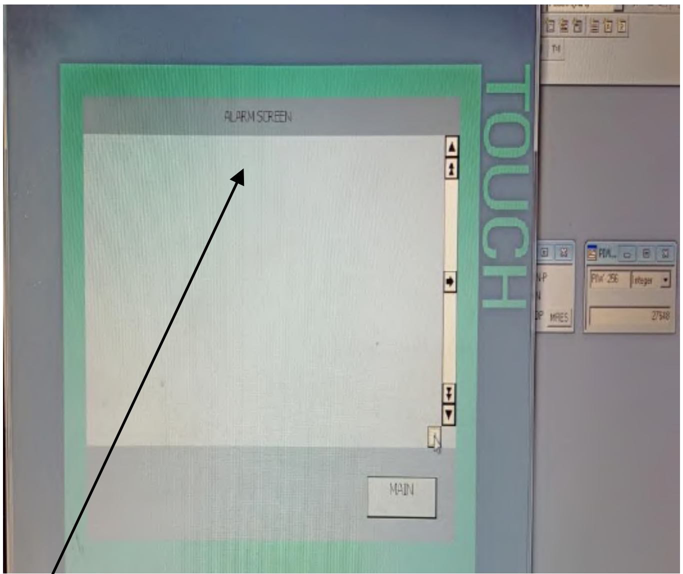
20.947% O2 concentration raw count value 27648

Fig 2.1 Simulation Result_3



Showing trend for 10 % O2 concentration

Fig 2.0 Trend Screen_1



No alarm

Fig 2.2 Alarm Screen_3

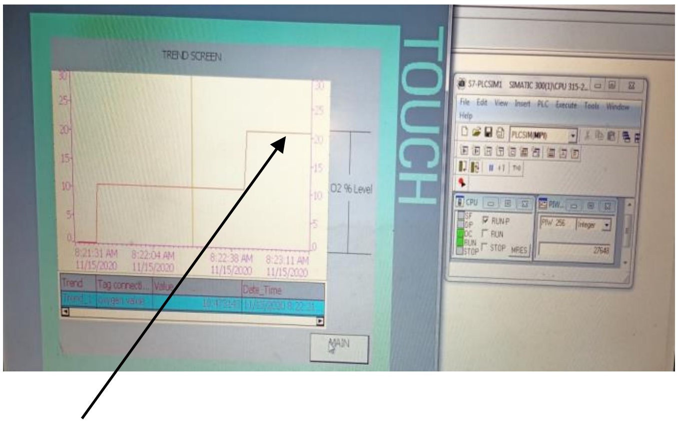
4.1.3 Test_3 Analysis

Sensor output = 20mA

Raw count value = 27648

Oxygen concentration = 20.947%

Level of oxygen is in good condition. Now we will see all this in simulation environment using following pictures:



Showing trend for 20.947% O2 concentration

Fig 2.3 Trend Screen_3

V. CONCLUSION

This study will help in the field of mining industry to setup new age of safety equipment or in other words how we can use this technology to save human life. This study reduces the unwanted accidents in mining field.

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