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Electronic Design of Liquefied Petroleum Gas Leakage Monitoring, Alarm, and Protection System Based on Discrete Components

Hussain A. Attia*, Halah Y. Ali**

**Department of Electrical, Electronics and Communications Engineering / School of Engineering*

***Department of Biotechnology / School of Art and Science*

American University of Ras Al Khaimah, Ras Al Khaimah, UAE.

Abstract

Liquefied petroleum gas (LPG) is an important source of energy commonly used for domestic purposes like cooking and heating in developing countries and also for many commercial, industrial, and agriculture purposes. LPG gas represents as an asphyxiant gas and because it is flammable, it is very important for health and safety requirements monitor continuously the gas leakage and doing the necessary actions at the cases of gas leakage. Many studies present a high performance gas leakage monitoring and protection systems through either microcontroller units or computerized systems with wireless data communication technology. The high cost and the complexity of these systems that are the main demerits. This paper presents an alternative engineering solution of a simple system through a full electronic analog design based on discrete components. The proposed electronic system works on continuous detecting LPG gas leakage level though suitable gas detector, then based on the electronic design, a suitable actions of gas valve control signal and sound alarm signal will be produced at happing state of the gas leakage. Both Electronic design and simulation results of discrete components based are done by using National Instruments NI Multsim software for electronic circuits design. The simulation results reflect the effectiveness of the presented design and give indication of promising prototype of monitoring and protection system of LPG gas leakage for home and/or industrial applications.

Keywords: Liquefied Petroleum Gas, gas leakage, LPG detector, Operational amplifier, drive circuit, Buzzer, Valve.

INTRODUCTION

Liquefied petroleum gas (LPG) is a commonly gas use in the world wide in different applications of home and industrial locations that because it characterized by cheapness and availability. LPG is a simple asphyxiant gas and flammable, LPG is heavier than air and stay in low levels and spread in the same level in case it leak in ground floor. For safety requirements, continuous monitoring to the gas leakage is an important measures and solutions in home or industrial locations. Many studies are focused on this side of health and safety requirements in the proposed systems as shown in [1]-[10] based on microcontroller units as well as wireless communication messaging ability. Accuracy, complexity, and highly cost are the main characteristics of these systems. On the other hand, the different aims work of [11]-[25] are designed and introduced based on discrete components for sensing, monitoring, and controlling actions.

Work in [1] proposes an integrated system for continuous monitoring, siren buzzer alarming, gas valve shutting down, and GSM modem for wireless communication alerting to the security. The system is starting by stage of deployed gas sensors for gas leakage sensing and informing a certain microcontroller unit which designed in addition to wireless signal transition by Zigbee technology. Study in [2] develops wirelessly alarm system via continuous data monitoring of gas detectors. The two types of sensors MQ3 and MQ9 are used for alcohol and Liquefied Petroleum Gas (LPG) detection respectively. The proposed monitoring system includes Arduino Uno microcontroller unit, LEDs, buzzer, and exhaust fan. The system includes also Zigbee uits for data monitoring on LABVIEW display. PIC (Peripheral Interface Controller) microcontroller is used in [3] to do automatically control for the methane tank that to control the energy source of the output methane gas through control gas concentration. The designed algorithm of the microcontroller unit works on analysis the input data of temperature and concentration sensors then decide the suitable actions for the valves duty cycle that to control the material and water in methane tank. The research in [4] introduced a low cost indoor air quality (IAQ) monitoring system through a certain developments in side of data collection. The data represents concentration of a various parameters which present in indoor air. The presented work in [4] includes IAQ monitoring system implementation of both parts of hardware and software implementation. The system is able to communicate data wirelessly through a ZigBee network that for more reliable IAQ system.

Various parameters are measured and monitored in the system of [5] through a LCD display which appears readings of temperature, smoke and alcohol levels. The mentioned parameters are firstly sensed by suitable sensors then through an Analog Digital Converter ADC, the sensed values are converted to digital forms to have capability of digitally reading. Through the control system, the mentioned parameters are monitored and compared to set points and whenever these points are exceeded by smoke and/or alcohol sensors, a system buzzer system will be automatically switch ON. The proposed system had ability of wirelessly data communication by using GSM module. Study in [6] focused on indoor air pollution which represents a major determinant in developing countries. Work in [7] proposes an automatically detecting device, this device works on stopping the gas leakages in vulnerable areas. The system started by LPG (Liquefied Petroleum Gas) gas sensor which enters sensing values to the microcontroller unit, the measured values are compared with set values and based on the result of comparison, the LED and buzzer alarm will be activated. In addition to the above mentioned, the system in [7] able to do

SMS messaging via GSM for alerting the customer of specified mobile-phone.

The paper of [8] shows system which works on gas level detection, monitoring and then controlling the system based on the instantaneous LPG leakage state. The system includes a suitable DC motor which derived by a DC relay that used to do automatically controlling to the stove knob. The system of

[8] had merit of automatic rebooking of cylinder through comparing gas level with normal weight of cylinder. The work in [9] focused on home security from a three sides, namely; Intruders, Gas Leak and Fire, the presented system works on sending a state report by SMS message to a certain emergency number in case happing of any of the three mentioned parameters, the system includes 8051 microcontroller as well as mobile communication technology. A microcontroller based system is presented in [10] works on firstly detect gas leakage state, and produce a temporary alarm till leakage gas state ends. Beside alarm producing, the system is also control shutting off the gas supply valve at state of high leakage gas level.

Many studies and electronic designs based on discrete components for different purposes are presented in [11]-[25]. In the same point of discrete components design view; the work in this paper proposes a complete electronic design with simulation results of discrete components based for an accurate analog system, this system works on monitoring, alarm and deciding suitable protection actions against the state of LPG gas leaking for home and/or industrial applications.

LPG AND HUMAN HEALTH EFFECTS

LPG is the acronym for liquid petroleum gas. It is a mixture of aliphatic hydrocarbon gases such as Propane and Butan with smaller amount of ethane, propylene, butanes, and pentane. Mercaptan is a foul-smelling odorant added to LPG for odor detection as the LPG is an odorless gas. The physical and chemical properties of its components made it very dangerous especially with any failure and/ or negligence of safety requirements, it can create potential health hazard in case of leakage since it is heavier than air, so it move away from its source with the air movement but settles and accumulate along ground.

Inhalational exposure to LPG can result in serious organ system dysfunction, irritation in the eyes and the respiratory tract tissues, drowsiness, hallucination and feeling of euphoria, inhalation high concentration of LPG inhibit central nervous system as it has narcotic effect ,unconsciousness , somnolence, lightheadedness, cyanosis, cardiopulmonary arrest, and sudden death is the most feared complications Nevertheless LPG has no toxicologically important effect but, by consuming the atmospheric oxygen, carbon monoxide will produce which is toxic. It is highly flammable gas possibly can ignite this gas even when switch lights if any undetectable leakage from cylinder occur which result in dangerous burning ends with death [26], [27].

It is simple asphyxiant gas as it displacing the ambient oxygen that means the oxygen concentration become less than 21% which is the oxygen level that should be in enclosed spaces, thereby reducing the oxygen supply to the vital organs (lung, heart, and brain) causing symptoms such as weakness, headache ,hypoxemia, rapid breathing and increasing heart rate, reduced coordination, confusion, ,error of judgment, nausea , and fatigue which prevent self-rescue then coma and death resulting from tissue hypoxia. The common reason of death is hypoxia after inhalation of carbon monoxide, sulphur dioxide, nitrous oxide resulting from inadequate ventilation and combustion of LPG , then leads to consuming the atmospheric oxygen and producing these asphyxiant gases especially carbon monoxide that decrease the capacity of hemoglobin for carrying oxygen and adhere to red blood cells producing carboxyhemoglobin (COHb), this compound prevent carrying oxygen to the tissues leading to suffocation, as they found in study presence of high concentration of COHb in blood of non-smoking women they were using LPG for cooking [27], [28].

From the above; It is conclude that LPG properties made it not recognized until it is too late to take any action particularly for infants and children because of their higher rate of oxygen consumption per unit body weight compared with adults and the growing rate and metabolism also higher that causing unintentional co-related death [29]. So, for health and safety requirements, its highly important that the early gas leakage detection, alarm and protection actions.

PROPOSED ELECTRONIC MONITORING, ALARM, AND PROTECTION SYSTEM

The proposed system includes four stages which are namely; LPG sensor circuit, adaptation circuit, op-amp comparator with hysteresis, and drive circuit as shown in Figure 1. First stage designed to sense the state of LPG gas leakage and works on producing analog voltage with a certain DC range proportional with concentration of the gas leakage. Second stage works on modifying the DC voltage range to the longer range and started from 0 V at lower gas concentration 200 ppm to 10 V at higher gas leakage with concentration 10000 ppm. Third stage represented by op-amp comparator with desired hysteresis band. Forth stage includes drives sub-circuits for 12 V electrically controlled gas value, 12 V sound and red light alarm.

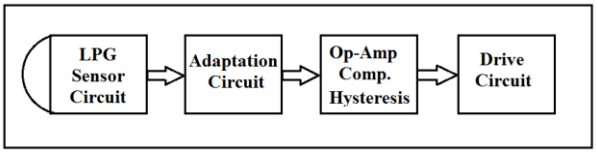
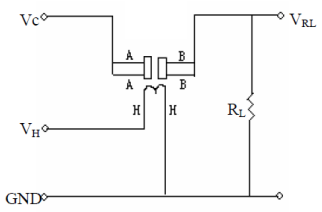


Figure 1. Block diagram of the proposed system

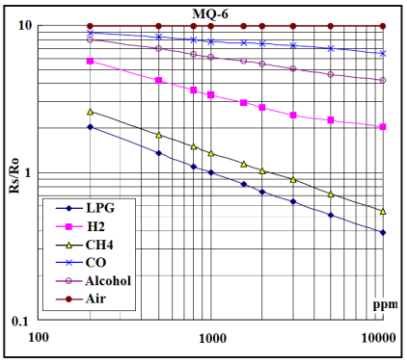
A. LPG Sensor Circuit

The selected gas leakage sensor type is MQ-6 [30], [31], the LPG sensor is characterized by high sensitivity to LPG, iso-butane, propane, while small sensitivity to alcohol, smoke, as well as fast response, stable and long life with simple drive circuit. Sensor resistance value is changing based on difference in gas kinds and concentration. So, its recommend

to calibrate the detector for 1000ppm of LPG concentration in air load resistance (RL) about 20KΩ. Figure 2 shows sensor wire connection, sensor sensitivity characteristics of MQ-6, and sensor electrical equivalent circuit.



(a)



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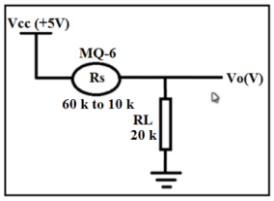


(c)

Figure 2. Sensitivity characteristics of the MQ-6 at Temp: 20℃, Humidity: 65%, O2 concentration 21%, RL=20kΩ, Ro: sensor resistance at 1000ppm of LPG in the clean air, Rs: sensor resistance at various concentrations of gases; (a) sensor wiring, (b) sensor sensitivity characteristics, (c) sensor electrical equivalent circuit.

Based on the sensor electrical equivalent circuit, the sensor output voltage can be calculated by (1);

$$V_{RL} = (Vcc * R_L)/(R_L + R_S) \quad (1)$$

The value of the sensor output voltage will be varied depending on R_L value (20 kΩ), the instantaneous value of sensor resistance R_S (60 kΩ to 10 kΩ) based on LPG gas concentration and based on (1). Table1: Demonstrates the output voltages at different gas constrictions of same conditions of Figure 1.

Table 1: Output voltage of MQ-6 at different LPG gas concentrations

LPG Gas Concentration (ppm)	200	500	800	1000	2000	3000	5000	8000	10000
R_S/R_O	≈ 2.0	≈ 1.45	≈ 1.15	1.0	≈ 0.72	≈ 0.63	≈ 0.51	≈ 0.42	≈ 0.38
R_S (kΩ)	60.0	43.5	34.5	30.0	21.6	18.9	15.3	12.6	11.4
V_{RL} (V)	1.25	1.57	1.83	2.0	2.40	2.57	2.83	3.07	3.18

B. Adaptation Circuit

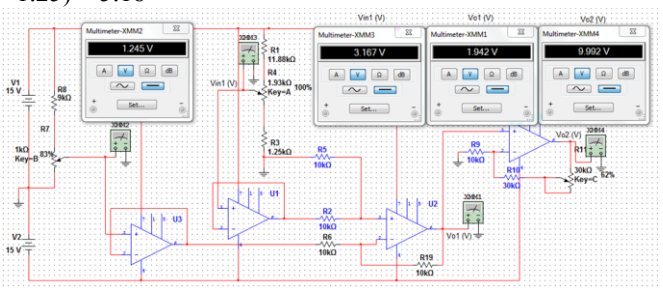
This circuit designed to receive the DC voltage from LPG gas sensor circuit with range 1.25 V to 3.18 V and works on modifying this range that to have longer range with modifying the starting point to make it starts from 0 V at 200 ppm gas concentration and increase the DC output voltage range that to end at 10 V at gas concentration 10000 ppm. Figure 3 represents the designed electronic circuit with simulation results that to demonstrate the function of the circuit. the circuit includes to op-amp sub-circuits; first on is a subtraction part that to subtract 1.25 V from the input DC voltage as shown in (2) below, while the second part is an amplifier with controlled voltage gain which set that to have 10 V when the input voltage 3.18 V, the equation of this part is explained in (3), and (4);

$$Vo1 = Vin1 - 1.25 \quad (2)$$

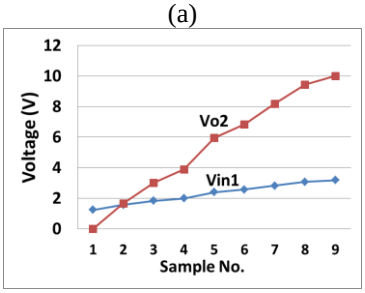
$$Vo2 = G * Vo1 \quad (3)$$

$$G = Vo2 / Vo1 \quad (4)$$

The desired value of the second part gain G equals 10 / (3.18 – 1.25) ≈ 5.18



(a)



(b)

Figure 3. Adaptation circuit; (a) electronic design, (b) simulation results

C. Op-Amp Comparator with Hysteresis (Positive Feedback. Schmitt Trigger)

It is important to do the analog comparison by op-amp with not only one level but with two levels as a certain band that will immune from noise effect. in other word it is needed to avoid the switching around one comparison level. The suitable op-amp circuit for this request is positive feedback op-amp which is work as Schmitt trigger [32], as shown in Figure 4.

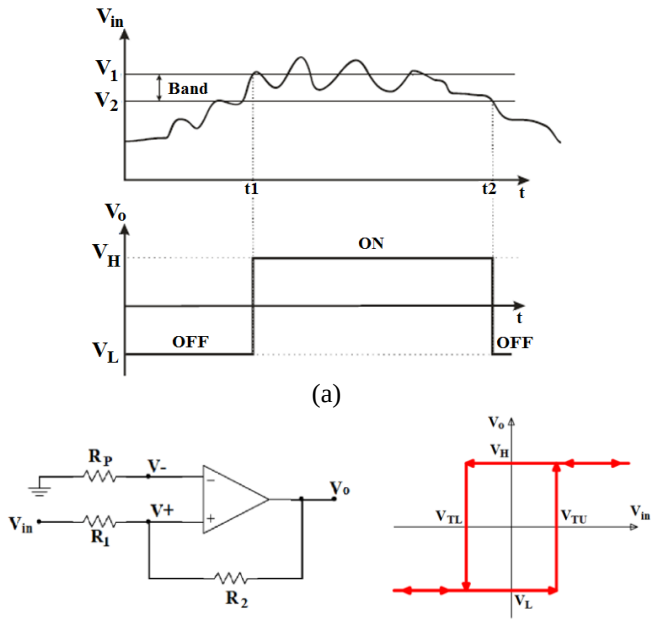


Figure 4. Positive feedback. Non-Inverting Schmitt Trigger; (a) hysteresis effect explanation, (b) op-amp circuit with hysteresis behavior

The desired upper and lower limits can be designed through;

$V_{TL} = -(R_1/R_2) \cdot V_H$ (5)

$V_{TH} = (R_1/R_2) \cdot V_L$ (6)

where V_H represents the positive saturated output voltage, and V_L represents the negative saturated output voltage, the hysteresis band can be shifted to any reference point as shown in Figure 5;

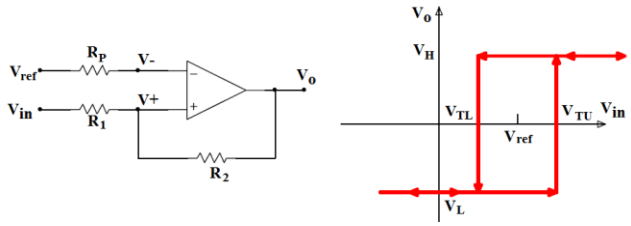


Figure 5. Positive feedback. Non-Inverting Schmitt Trigger with reference voltage and hysteresis behavior

The designed values for R_1 , and R_2 are 1 kΩ, 14 kΩ respectively, and the reference voltage is 1.9 V, the values of V_L , and V_H are -13.94 V, and + 13.95 V shown in Figure 6. The hysteresis function is proved through the simulation records of Figure 6, the desired voltages upper V_{TU} and lower V_{TL} limits of the voltage hysteresis band that are designed at Upper limit 3 V to sense LPG gas leakage 30% that to activate the alarm and protection parts, while the lower limit 1 V to remove the alarm in case there is no dangerous level of gas leakage and the case is only effect of other noise effects.

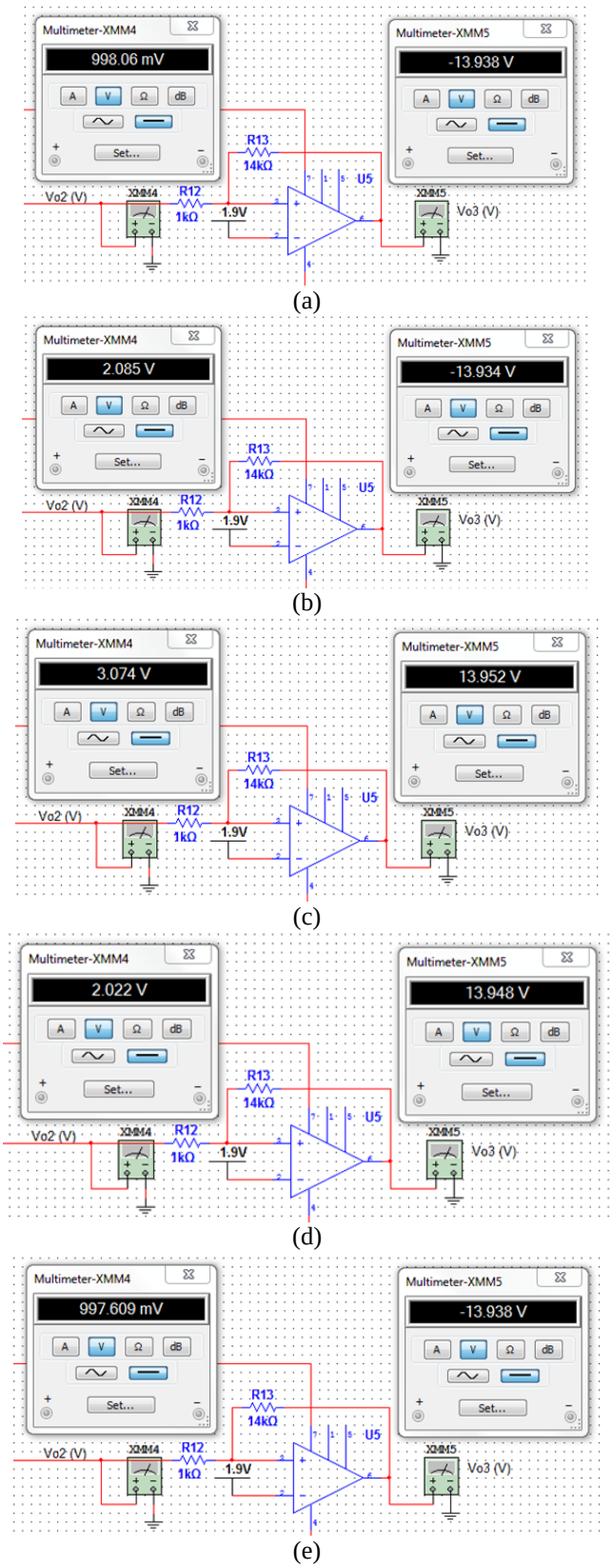
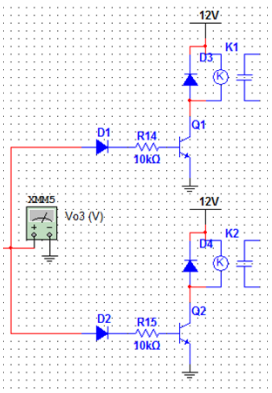


Figure 6. Electronic designed Non-Inverting Schmitt Trigger with reference voltage 1.9 V with hysteresis band, and simulation result

D. Drive Circuit

This circuit includes drives for the gas vale which is activated by DC 12 V, the drive circuit also activate 12 V red light lamp and buzzer sound alarm, the ventilation action is also important, the protection system include also part of ventilation which activated by drive circuit. Figure 7 shows the drive circuit which include two separated relays, first relay for alarm activity of light and sound while the second relay for protection activity of valve and ventilation activity.



Figue 7. Drive circuit

CONCLUSION

The introduced work in this paper presents an analog design with simulation results for a complete system alarm and protection system based on electronic discrete components as an alternative solution instead on micro controller based solutions that to avoid the complexity and high cost. the proposed system senses accurately the leakage state of LPG gas in home or industrial locations through continuous sensing to gas leakage level, and accurate protection function by big range of the designed adaptation circuit and the hysteresis function of the designed Schmitt trigger op-amp. Gas valve and ventilation parts can be controlled through the presented system that to avoid any dangerous case that may happen from the leakage of gas. The collected simulation results reflect the effectiveness of the proposed system and promise for an active prototype.

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