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Wireless Multi Probe Ash Hopper Level Monitoring System

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Abstract: This project is a novel idea of monitoring ash level in the ash hoppers in thermal power plant. Poor maintenance of ash handling system of furnace bottom ash hopper and ESP hopper will result in the accumulation of ash in the hoppers and the design capacity of load bearing structures may be exceeded. Excessive ash buildup in the furnace bottom hopper can disturb proper combustion of fuel leading to unsafe conditions. Failure of structures are known to have happened when ash reaches abnormal level. Ash level measurement with capacitance type sensor atdifferent levels of the hopper enables automatic shutdown during unsafe conditions. The signals received from the field sensors will be taken to a local electronic circuitry. Further the signals are processed and sent to a display in a remote location. An RS465 port is also provided to send the signal from local electronics to the plant control room for display in the distributed control system.

Keywords: capacitance measurement; ash hopper; multiprobe ; thermal power plant; clinkers

I. Introduction

This solid level measurements in bunkers and hoppers are required in many industries. In a coal fired thermal powerplant ,pulverized coal is burnt in the boiler furnace. Heat released in the furnace is conveyed to the water and steam circuit. A portion of ash produced after the completion of combustion falls to the bottom ash hopper. The fly ash in the flue gas are collected in the economizer and air heater hoppers. The major portion of ash is collected downstream in large electrostatic precipitators. The ash handling systems conveys the ash to a distant location in the power plant area where it is transported out of the plant. A large coal fired plant burns about 300-400 tonnes per hour of coal. With ash content of 30-40 percent in coal, we can imagine the ash produced each hour in the boiler. It is possible that blockage occurs at the outlet of hoppers or ash evacuation system fails leading rise of ash level in hoppers. It is therefore necessary to monitor ash level in the hoppers and raise an alarm when abnormal level is reached.

In this project, we use capacitor type of sensors to detect presence or absence of coal ash at point location. There are different designs of this type of measurement in the markets. They are marketed by reputed manufacturer ad RF admittance type point level sensors. The design of this system envisages change in the capacitance due to change in the medium, ash is known to have a dielectric constant between 1.8 to 2.8. The change in capacitance for dielectric medium with fluegas and ash will be almost two. We detect the change in capacitance directly with an electronic circuit. A capacitance sensor is inserted in the hopper. The electronic circuitry sends a pulse stream to the sensor through a resistor of suitable value. We know the shape of response of an RC circuit subjected to a dc pulse. It is the exponential in rise and decay. The change in capacitance for flue gas and ash causes change in time constant. This change is detected in a microcontroller and an alarm can be generated.

Multiprobe arrangement can give information of presence of ash at different hopper levels. Fig 1 shows a bunker with probes local electronics.

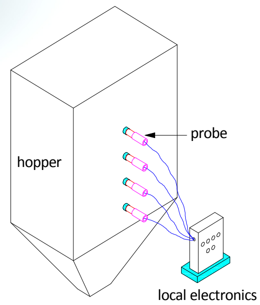


Fig. 1. Conceptual diagram

II. WORKING OF CAPACITOR

An The value for the capacitance is calculated from the formula given below:

where, $\in$ is permittivity of the medium
A is area
D is distance between plates

$$\in = \in_o \in_r \quad (2)$$

Where,
$\in_o$ is permittivity of free space
$\in_r$ is relative permittivity

The value of relative permittivity depends on the dielectric material between the plates .A parallel plate capacitor is shown in Fig 2 below. The plates are made of conductive material while the medium between the plates is of a dielectric material. The higher the value of dielectric constant, the more will be the value of the capacitance and the more will be the quantity of charge stored in the plates. In the capacitance type of level measurement, the value of the capacitance changes when ash in the hopper reaches the level of the sensor. The dielectric medium in this case will be ash.

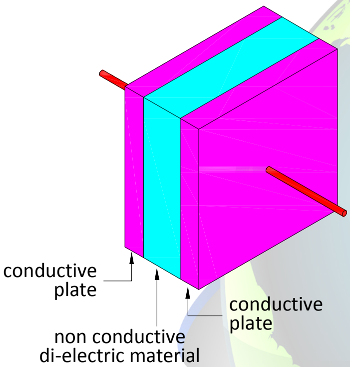


Fig.2. Parallel plate capacitor

III. SENSOR DESIGN

The design of the sensor is shown in Fig 3. The sensor consists of a metallic portion and an insulator portion. While the metallic portion forms one plate of the capacitor , the hopper itself forms the other plate of the capacitor. The design of this sensing element depends on the size of the hopper. The material of the sensor is decided based on the conditions of measurement. The metal rod in the probe itself can be made of stainless steel which can withstand high temperatures. The insulator portion of the probe is selected according to medium temperature. Teflon can be used up to 250^{0}C. For higher temperatures Ceramic material is used. The sensor probe is inserted into the hopper.

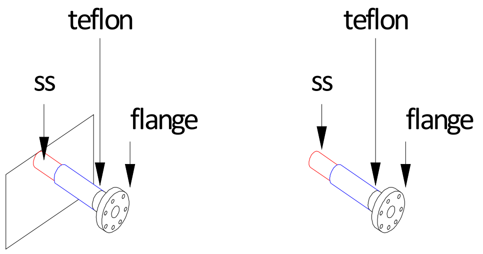


Fig. 3. Sensor design

IV. RESPONSE OF RESISTANCE AND CAPACITOR CIRCUIT TO A PULSE TRAIN

Fig 5 illustrates the response of a simple series RC circuit to a pulse train. When the capacitor is fully discharged, i.e Vc is zero, let the switch be thrown to position1. The capacitor gets charged through. The transient response of the voltage across the capacitor during the charging cycle can be got from solving the equation

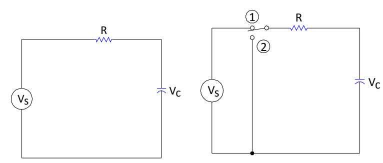
$$Vs = Ri + 1/c\int idt; \quad (3)$$

The solution of this equation is

$$Vc = Vs\ (1 - e^{t/RC}) \quad (4)$$

When the switch is thrown to the position 2, the capacitor discharges through the resistance. The transient response of the voltage across the capacitor during the discharge cycle can be got from solving the equation.
The solution of this equation is,
In these equation RC is known as the time constant tau "τ". It is the time required to charge the capacitor, through the resistor, from an initial charge voltage of zero to ≈63.2 percent of the value of an applied DC voltage, or to discharge the capacitor through the same resistor to ≈36.8 percent of its initial charge voltage.

Fig.4. RC circuit



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As is obvious the time constant depends on the value R and C. If R is constant and capacitor C changes from a value C1 to a higher value C2 the time constant is proportionally increased to that extent.

Now let a pulse train be applied to the RC circuit. The pulse width is adjusted approximately four times the time constant. This is equivalent to applying a DC voltage for the charging cycle and then shorting the RC circuit for the discharge cycle.

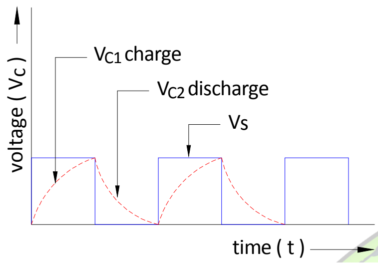

Fig.5. Voltage response of RC circuit to a pulse train

V. Principle of Capacitance Type Measurement for Ash Level Measurement

Having described the transient response of a series RC circuit, it is now explained how the principle can be used for ash level detection.
During the discharge cycle of the capacitor, let at time t1 the voltage across the capacitor be V1 and at time t2 let the value of the voltage across the capacitor be V2.

$$V1 = Vs\ e^{t1/RC}$$

$$V2 = Vs\ e^{t2/RC}$$

$$V2/V1 = Vs\ e^{t2/RC} / Vs\ e^{t1/RC} \qquad (7)$$

From the above two equations,

$$C = (t2-t1)/\ln(V1/V2)\ R$$

If time t1, t2 are measured for a voltage setting of V1 and V2 which are known and resistance also is known, capacitance C can be computed.

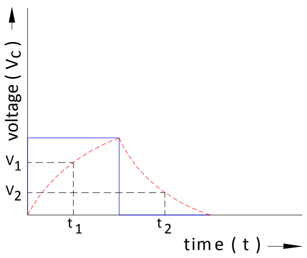

Fig.6.

In the system designed, a pulse train is applied to the capacitance sensor through a resistor and the responses are fed to a microcontroller. We detect the change in capacitance value by measuring the change in the time difference t2 – t1 with and without ash bridging the sensor and then give an alarm when ash reaches the capacitance sensor located at
the abnormal level point.
Assuming an active area of the sensor to be a rectangle of 5cmx10cm, and a spacing of 5cm the theoretical capacitance for air is computed as:

$$C_{air} = \epsilon\ A/D \qquad (9)$$

$$= 8.854\times10^{-12} \times 0.05 \times 0.10 / 0.05$$

$$= 0.8pF$$

Assuming relative permittivity of ash to be 2,

$$C_{ash} = 2 * C_{air} = 1.6pF \qquad (10)$$

The difference is 0.8pF, which is a very small value. A suitable circuit to detect a minimum difference of 0.5pF is required.
In the actual working since the capacitance value is small, a

Figure-9 Frequency response without capacitance multiplier

capacitor multiplier circuit is used to enable the differentiation between the mediums easier. A capacitor multiplier circuit is shown in the Fig-7.
A "capacitance multiplier" circuit increases the effective value of a small capacitor C1 to a much larger value. The capacitance seen at output is:

$$C_{out} = C1 * R1/R3 \qquad (11)$$

This circuit works for ground- referenced capacitances. The output capacitance can be measured by placing an AC source in series with a resistor tied to Vout and running an AC frequency response analysis. As seen in the result below, the 100pF capacitor has been multiplied by 1,000.

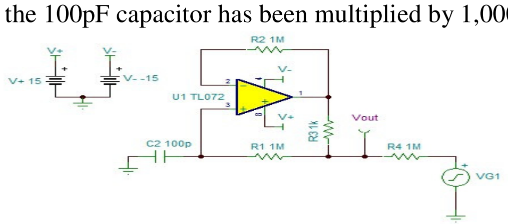

Fig.7. Capacitance multiplier circuit

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Without capacitance multiplier:

Fc = 1/2πRC = 1/2 πx10^{6}x100x10^{-12} = 1.59KHz

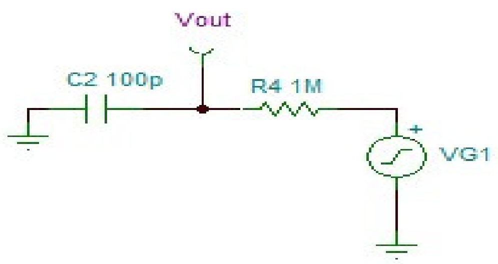

Fig.8.

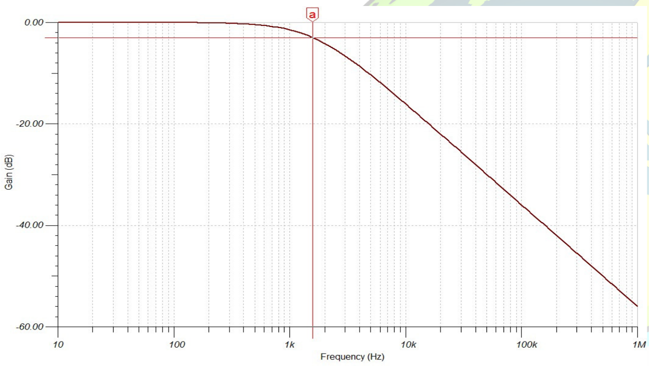

Fig.9. Frequency response without capacitance multiplier

With capacitance multiplier:

Fc= 1/2 πx10^{6}x1000x100x10^{-12} = 1.59 Hz

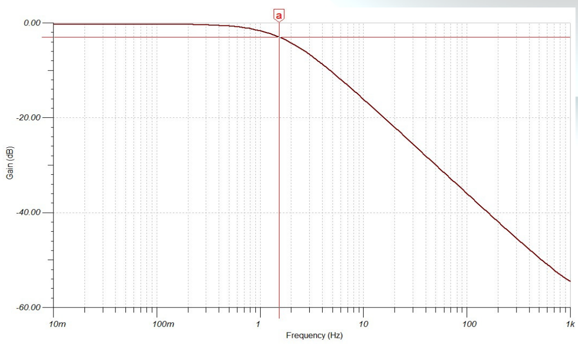

Fig.10. Frequency response with capacitance multiplier

Simulation results of capacitor multiplier circuit is shown in Fig-11.

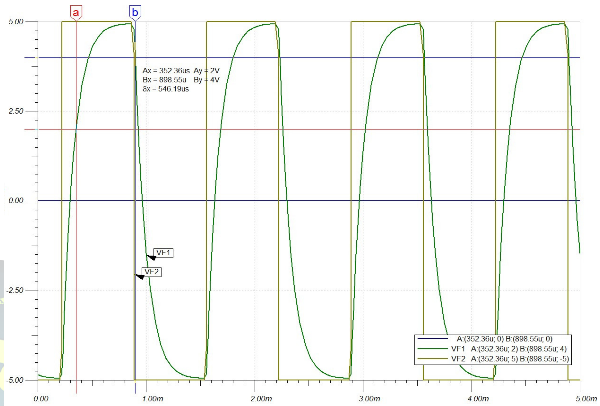

Fig.11.

VI. Block Diagram of the Capacitance Level Monitoring System

The block diagram of the system is shown in Fig-12. The system uses aPIC18Fmicrocontroller for implementing the strategy. The square wave excitation is generated by using the internal PWM module. A unipolar to bipolar circuit converts the unipolar output to an AC bi polar square wave excitation. This signal is applied through a resistor to the ash level sensor. A capacitance multiplier multiplies the capacitance. An analog multiplexer is also used for simulating an onboard capacitance for diagnostic purposes. The bipolar signal response is converted to a unipolar signal. The charging and discharging waveform of capacitor which can be used to sense the change in capacitance value. The A/D converter in the controller digitizes the analog signal. The interrupt routine checks if the voltage read V is above V_l and below V_u and sets/resets a CCP output pin based on if $V_l<v<V_u$. If the CCPx pin is configured as an output, a write to the port can cause a capture condition.

Therefore, both the times are captured as t1 and t2.

With V_l and V_u being the same, the t1 and t2 times for the sensor when the capacitance changes between air and ash will be different. The difference, t2-t1, can be used to detect the change in capacitance and therefore the presence of ash.

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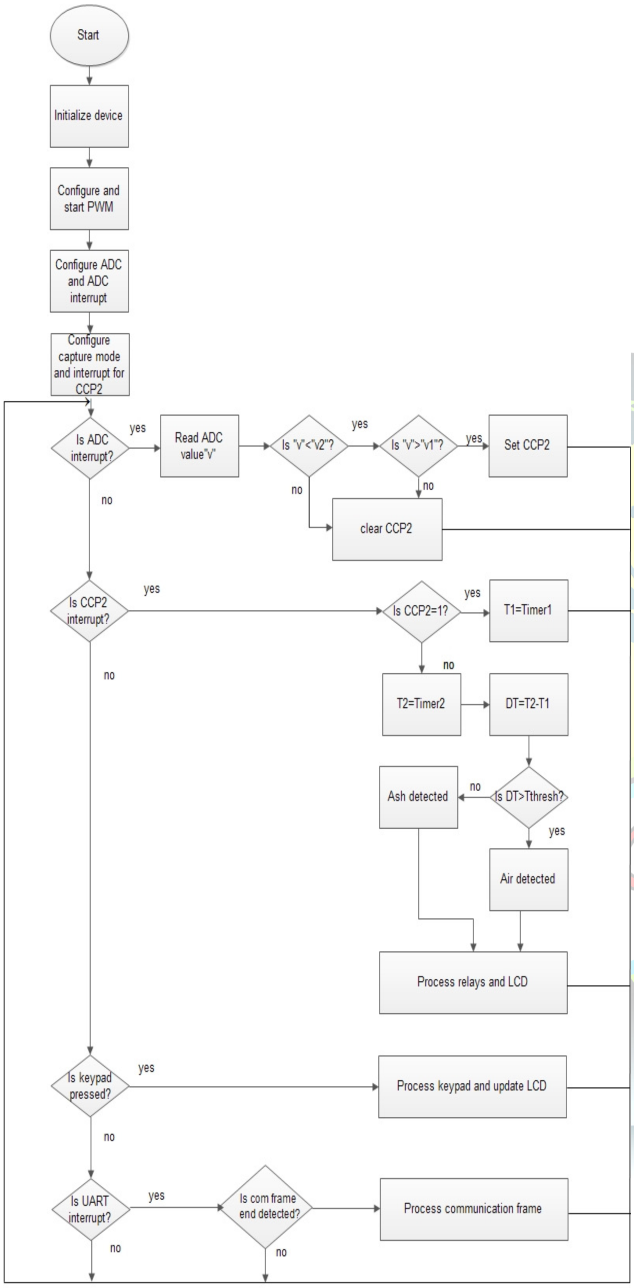

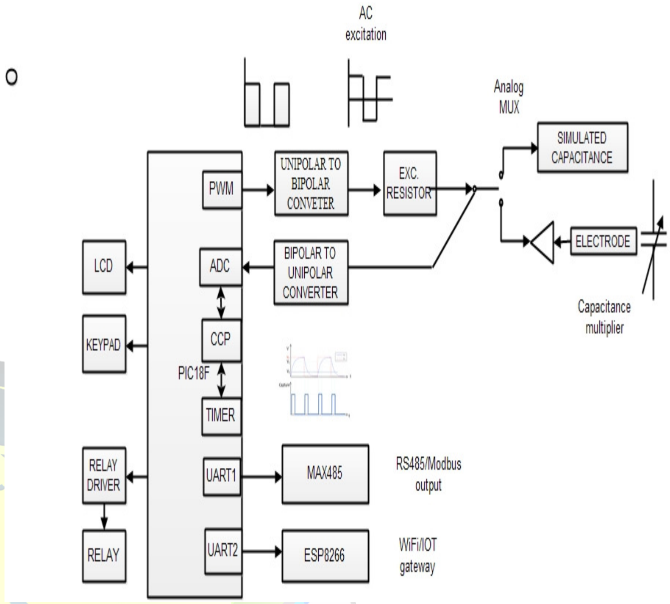

Fig.13. Block diagram of the system

Alarm can be generated when a minimum number of probes arranged at discrete levels along the hopper detect ash. Further logics are built to detect a faulty probe and a faulty cable based on the time difference calculated being too low or too high. Outputs available for integration with plant control system include potential free contact for each probe, a common potential free contact for alarm, Modbus RS485 interface for monitoring the status of the sensors as well as setting thresholds, etc while providing a single interface to plant distributed control system for customers who need the display in the Human Machine Interface system(HMI).

A wifi module is also added to provide an IOT interface with a gateway device so that the status is available over the internet as well.

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VII. Simulation and Results

For ash:

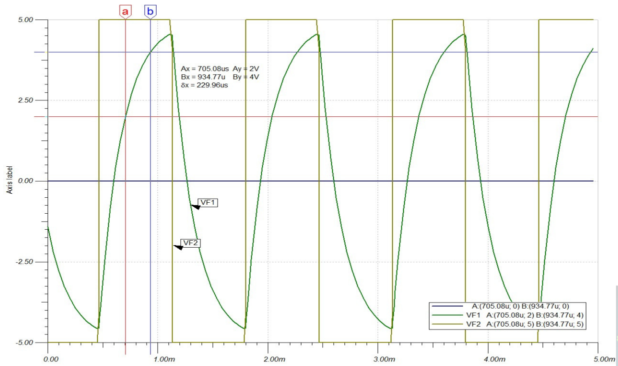


Figure-13 Simulation result for ash

T1=705.08us; T2= 934.77us; ΔT= 229.96us

For air:

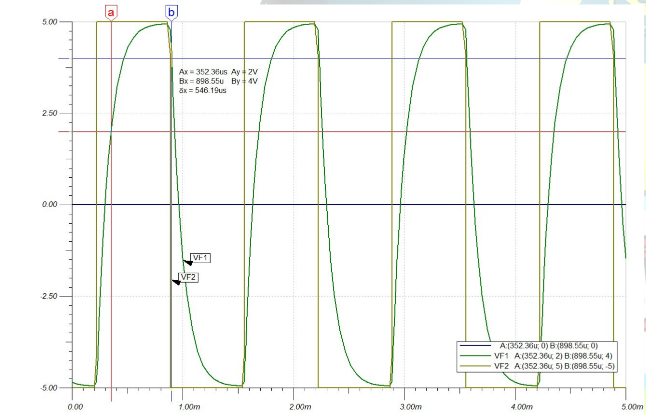


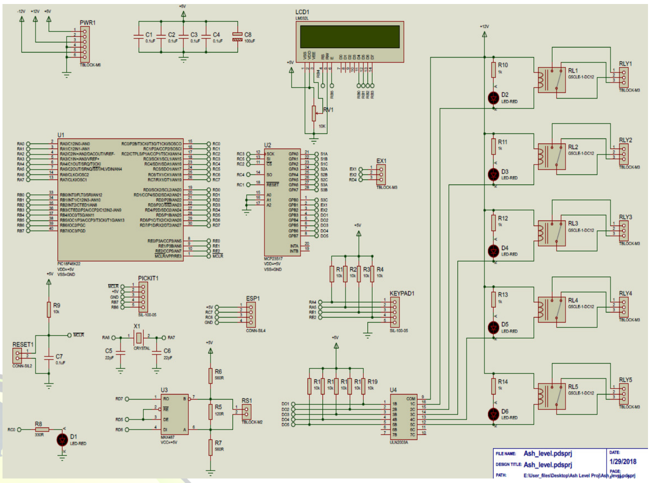
Fig.14. Simulation result for air

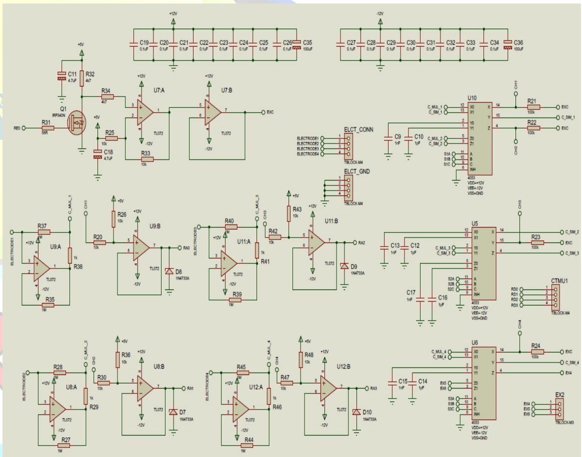
T1=352.36us; T2= 838.55us; ΔT= 546.19us

When the difference in time T2-T1 is greater than a set threshold, say 400us, the decision may be ash detected.
The system has been designed, fabricated and tested and found working satisfactorily.

VIII. PCB Design and Layout

The schematics and PCB layout of the designed system was developed in Proteus software with firmware written in Microchip XC8. The flowchart for the software program is included below:





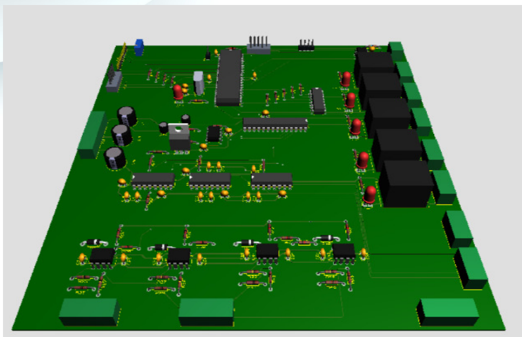


Fig.15. PCB design and layou

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IX. CONCLUSION

The ash level measurement is very much crucial in the thermal power plant. The excessive ash deposit in the hopper due to the block of clinkers will overpower the weight bearing capacity of the hopper and might end up in even explosion of the entire system. So, for a safe operating limit this design will provide a monitoring with alarms and indication lights. The usage of capacitance level measurement enables a more specific and accurate status. The further extension of the same can be designed for the automatic ash clearance with tripping.

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