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A Novel System of Alerting Electric Leaks in Transmission Poles Using Smart Digital Systems

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Abstract **Electrocution has been a common issue round the world. The varied causes of an electric leak in utility poles or transmission towers have kept the issue unaddressed for a long time. With all the present-day solutions like ELCBs, RCCBs, the problem of electric leakage detection has been reduced to a certain extent. There are several factors for an electric leak to occur. Any form of contaminants or cracks in insulators can create a path between the high voltage lines and the utility pole. Improper earthing of the poles forces the electricity to discharge to ground through the human body when touched in case of a leak. Failure of protection devices has also proved to be one of the causes in few instances. A common feature that every mentioned system lack is an 'alert' feature. Though this feature cannot aid in the prevention of such electric leaks, it can alert the people around it so that they can maintain a safe distance from the pole thus preventing life loss. So, the proposed work is to detect electric leak and to alert both the people and the respective department about the leak in order to prevent the loss of life while also getting the issue resolved at the earliest. The circuit for this was initially designed using microcontroller which is now converted into digital logic circuit in order to improve its functional efficiency. The digital circuit was designed using proteus simulation tool and its functioning was verified for different working conditions.**

Keywords – Digital circuit, ELCB, Electrocution, Insulation failure, Leakage, RCCB, Transmission lines.

I. INTRODUCTION

Power grid transmission systems that carry high voltage are located away from human dwelling places. These high voltages are stepped down by transformers and are carried to each home and streetlights using utility poles. Though the voltages are lesser than transmitted, they are much above the dangerous level a human can withstand. Failures in the protection devices or insulations [1] in these poles can be disastrous. The protection features these voltage lines are equipped with are mostly mechanical systems which would switch the power OFF once a fault is detected.

With RCCBs, dropout fuses in place, most of the faults and short circuits could be prevented. This is possible by the protection devices since most of the faults occur in a closed path. Though voltage ELCBs were used to detect voltage with reference to ground, they aren't used now as their design wasn't reliable and needed a significant leak voltage to energize the trip coil inside it. Other existing models (like RCCBs) work based on sensing current and they tend to fail when the sensed leak current is less than their minimum threshold value for activation [2]. These devices monitor the difference between the current flowing through the line and the neutral wires. For fuses like drop out fuses, 'fuse carrier contact erosion' is one of the major causes of failure [3]. In case of a leak, the protection features will function only when the leaked current gets earthed.

The introduction of Fiber-reinforced poles (FRP) [4] reduced the chances of electricity conduction on the poles since they had poor conduction properties. They had all the properties a transmission pole must have. The high cost of implementation made them less popular than other material poles.

Wooden and concrete poles conduct electricity [5] due to insulation failures due to dampness or moisture present on them which in most of the cases does not get earthed because of the uneven dampness on them. This could create a situation where the leak would persist without actuating any protection feature[7]. When a pole under such conditions is touched, the electricity would discharge through our body to the ground. This would trigger the activation of the protection device before which one would have undergone severe pain or major injuries depending upon the voltage level. This could also be fatal when the device fails to activate. The chances of the leak getting earthed is less in such poles [8].

There are several reasons for an electric leak to occur and alerting people about the leak can help prevent life loss even if the supply is not interrupted by the protection devices. This can be a solution for leaks not alone in utility poles but also in street light posts [9] and other high voltage carrying poles along the streets.

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II. SET UP

The circuit as a whole is divided into sensor and control sections. The sensor circuitry will be placed on the pole directly whereas the control circuitry will be kept along with the Hub circuit.

The sensor is designed in a compact way to fit it directly onto the pole. The sensor's leak sense terminals will be connected to the body of the pole and ground. The terminal will be connected to the pole by a metal band in order to improve conductivity, to avoid loose connections and mainly to detect leaks anywhere on the curved surface area of the pole.

The alert lights/ sound alert is also place on the body of each pole. This will not only help in isolating a defective pole but also help the public to maintain a safe distance from the defective pole.

The control unit is placed separately away from the pole. It is positioned in a way it would be near the middle pole if n poles in a stretch are being monitored. The control unit consists of an MCU or its digital equivalent along with the Wi-Fi circuit to transfer the data to the app. The wire connection from each pole can be made using low current rated wire since the sensor does not need a source to be powered and only signals will be transferred from the sensor to the control circuit.

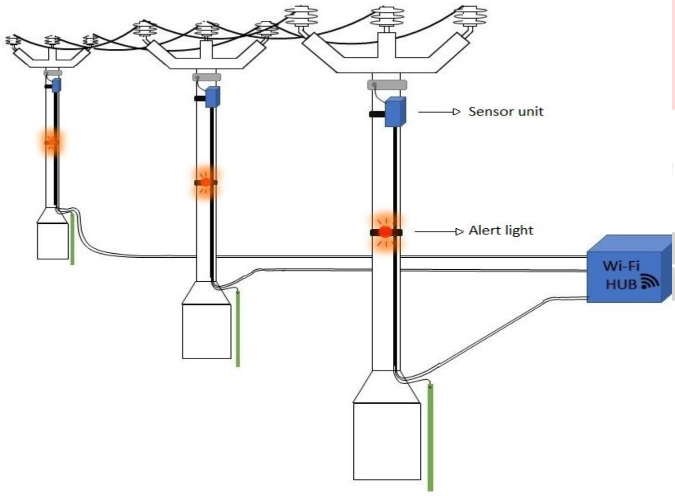

Fig1: *Device setup*

III. DIGITAL DESIGN

In order to develop the alert-based detection device for electric leaks, the system has been divided into different functional blocks as shown in Fig 1. The control unit for the system is designed using digital logic elements instead of a microcontroller in order to reduce the cost of the overall design. The system is equipped with necessary features to prevent its malfunction during operation.

IV. BLOCK DIAGRAM

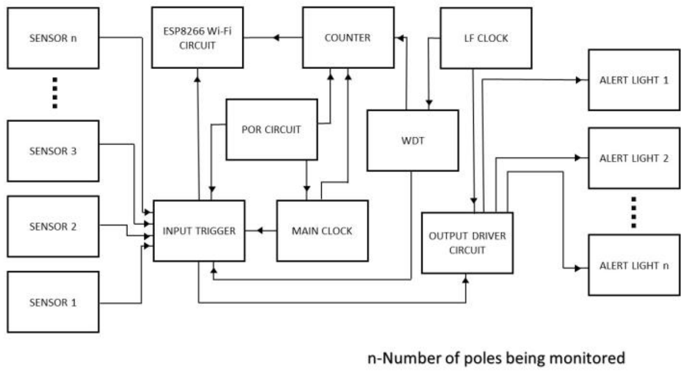

Fig 2: *Block diagram*

V. CIRCUIT - CONSTRUCTION

The circuit is developed using digital elements. The circuit is divided into 7 parts.

1. Sensor
2. Input trigger
   i Asynchronous Input trigger circuit
   ii Decoder Input trigger circuit
3. Counter
4. Output driver
5. Clock
6. Output
7. Power on Reset (POR)
8. ESP8266 circuit
9. Watch dog Timer (WDT)

VI. SENSOR

The sensors are the part of the system that will sense the high voltage leaks and convert them to suitable output for further processing. Since the sensors need to be placed directly onto the utility poles, they are designed in a compact way without compromising its functionality. The extended life of the sensor and reduced device faults are ensured by using discrete component instead of using microcontrollers or other switching devices.

The circuit (Fig 3) is constructed by employing capacitors to divide the electric leak potential in order to step it down to a lower voltage. X-rated high voltage capacitors are used for this application since their peak voltage ratings are much higher than normal capacitors. A bleeder resistor is used in parallel either with both the capacitors or with one of the capacitors that drop most of the voltage across it to ensure safety while handling.

The two X-rated capacitors are connected in series with one end connecting to the pole and the other end to the ground. The values are selected to provide very less current flow from the pole to the Earth(ground) even when the electric leak potential goes up to the line voltage. The drop across the capacitor with higher capacitance among the pair is

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connected to a bridge rectifier. This converts the AC_{leak} voltage to a pulsating DC voltage. This is then smoothened out using a filter capacitor and is fed to a simple voltage regulator circuit using Zener diode. The regulated output is then fed to an opto-coupler to provide an isolated output.

The calculations are made considering a 220V utility pole. Values of the capacitors alone needs to be changed for different voltage levels.

C_1=0.22 µF X_{C_1}=14468Ω
C_2=2.2 µF X_{C_2}=1446.8 Ω
$V_{C_2} = 0.0909 * AC_{leak}$

Maximum leak voltage condition:

The voltage is based on the voltage carried by the utility pole as well as on the maximum voltage rating of the capacitor.

AC_{leak} (max) = 240V
$V_{C_2} = 0.0909 * 240$
$V_{C_2} = 21.8VAC$

DC_{leak} (max) = V_{C_2} – Voltage drop across the full bridge rectifier

= 21.8 – 1.4
= 20.4V

Minimum leak voltage condition:

The minimum voltage is set based on the functioning of sensor for lower voltages after testing. The sensor functions without any variation in output state at voltages above 25VAC . So, the minimum voltage is selected to be 30VAC. The value was also selected based on the lower threshold voltage that a human can withstand which as per studies must be greater than 40VAC [6] .

AC_{leak} (min) = 30V
$V_{C_2} = 0.0909 * 30$
$V_{C_2} = 2.727VAC$

DC_{leak} (max) = V_{C_2} – Voltage drop across the full bridge rectifier

= 2.727 – 1.4
= 1.327V

The optocoupler used here is 'PC817'.

The optocoupler used at the output helps in isolating the high voltage leak from the other sensitive control circuits. The output of the optocoupler is an active-low output. This is connected to the 'input trigger' circuit.

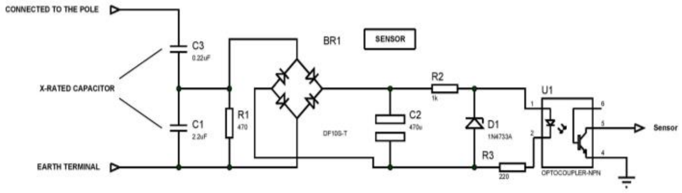

Fig 3: *Sensor circuit*

VII. INPUT TRIGGER

The function of this circuit is to enable a sensor at a time to transfer its output state the ESP8266 circuit. A pull-up resistor is used at the inputs of the circuit since the output of the sensor is of open-collector type and is active low. This circuit combines the functionality of a multiplexer and a ring counter.

Input trigger circuit is designed in two methods:

1. Synchronous input trigger circuit.
2. Decoder based input trigger circuit.

Master Reset	Input trigger	Sensor input	Output
1	x	x	0
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1

Table 1: *Truth table for input circuit*

i. Synchronous Input trigger circuit

The circuit (Fig 4) uses D-flip flops to enable each sensor at a time and logic gates to produce the output. This version of the circuit is designed to perform the intended function even if the counter is replaced with any other alternate design or removed. If 'n' stages are needed then 'n-1' stages are used to produce the output and a last stage is added to reset the circuit. The design is shown in figure 3.

Pros:

- Since the circuit uses repeated functional blocks, it can be cascaded easily.
- Can work without any external input other than clock.

Cons:

Since it is a synchronous circuit and is independent of control from other circuits, it will require an external 'Output mismatch reset' circuit in case this is used with a counter circuit to ensure triggering of nth sensor corresponding to the counter's output. Can be used when lesser output stages are needed.

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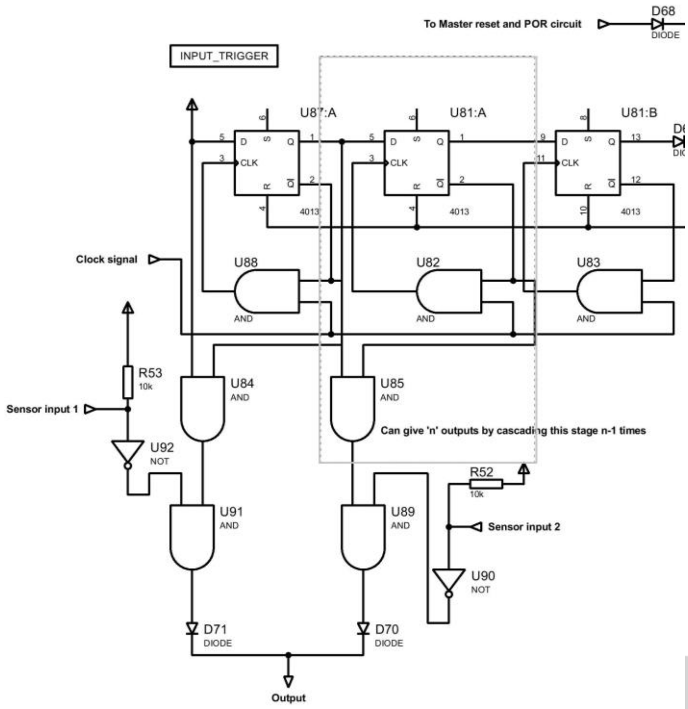

Fig 4: *Synchronous input trigger circuit*

ii. Decoder Input trigger circuit

The decoder-based design (Fig 5) is used to produce the same functionality as the Synchronous input tigger circuit. The circuit cannot work without an external counter since its outputs are dependent on the input binary pattern.

Pros:

- Since the circuit is controlled by the counter, no mismatch at output occurs.
- With no output mismatch, this circuit can be used when many poles are to be monitored.

Cons:

- The design cannot be easily cascaded, hence cannot be expanded without modifications.
- Complexity of the circuit increases with increasing stages.

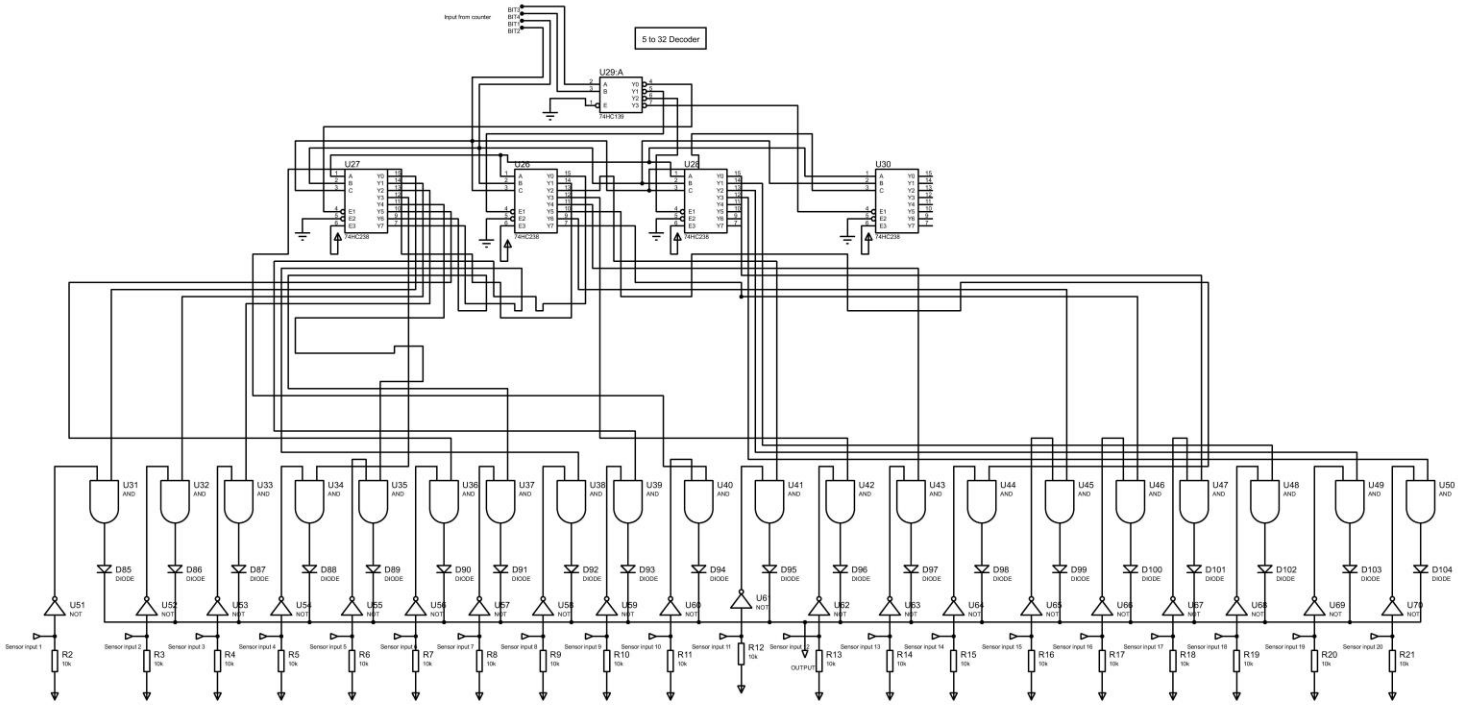

Fig 5: *Decoder input trigger circuit*

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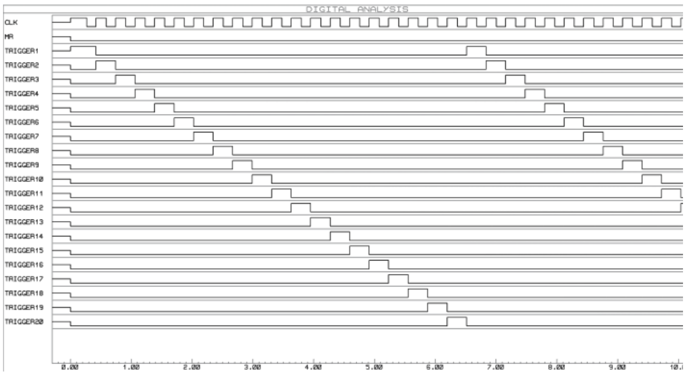

Fig 6: *Output graph of input trigger circuit*

VIII. COUNTER

Counter circuit (Fig 7) generates the count from 0 to n which would represent the pole number. This output is fed to Input trigger circuit to enable it to read the appropriate sensor and it is also fed to the ESP8266 circuit to transfer the pole number data to the app.

The circuit uses ripple counter constructed using ‘n’ T-flip flop stages. For counting ‘n’ stages, number of flip flops required is given by, $\lceil \log_2 n \rceil$. The n^{th} output can be given to a simple combinational circuit to reset the counter to zero. The figure shows the construction of a 5-bit counter which can handle up to 32 poles, but the circuit shown restricts the maximum output to 19 by applying a reset condition on the next count.

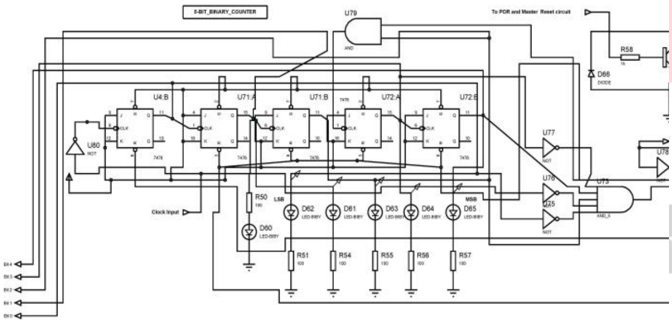

Fig 7: *Counter circuit*

Present state	Next state
00000	00001
00001	00010
00010	00011
00011	00100
00100	00101
00101	00110
00110	00111
00111	01000
01000	01001
01001	01010
01010	01011
01011	01100
01100	01101
01101	01110
01110	01111
01111	10000
10000	10001
10001	10010
10010	10011
10011	00000

Table 2

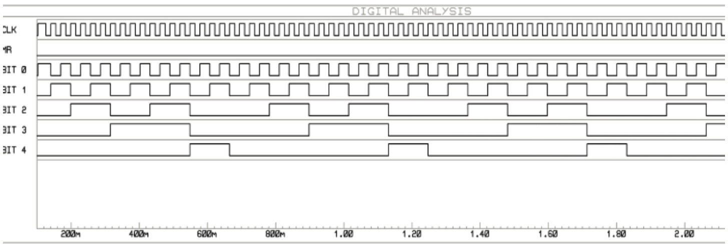

Fig 8: *Output graph of counter circuit*

IX. OUTPUT DRIVER CIRCUIT

This circuit (Fig 9) drives the alert lights/ sound alert output. A separate low frequency clock source using astable 555 timer circuit is used to generate the output pulse for the driver. The clock pulse directly drives Power MOSFETs which then powers individual BJT NPN transistors dedicated for each pole. The control signal for the NPN transistor is fed from the ‘Input trigger’ circuit.

Having BJTs connected at the drain of the Power MOSFET makes them individually addressable by external control while the Power MOSFET switches according to the input square pulse while also taking care of the current demands of each branch of the output.

Frequency of the LF clock source:

$$f = 1.44 /((R_1+2R_2)*C)$$

$$f = 1.44/ ((10^3+(20*10^3))*(33*10^{-6}))$$

$$f = 2.08 \text{ Hz}$$

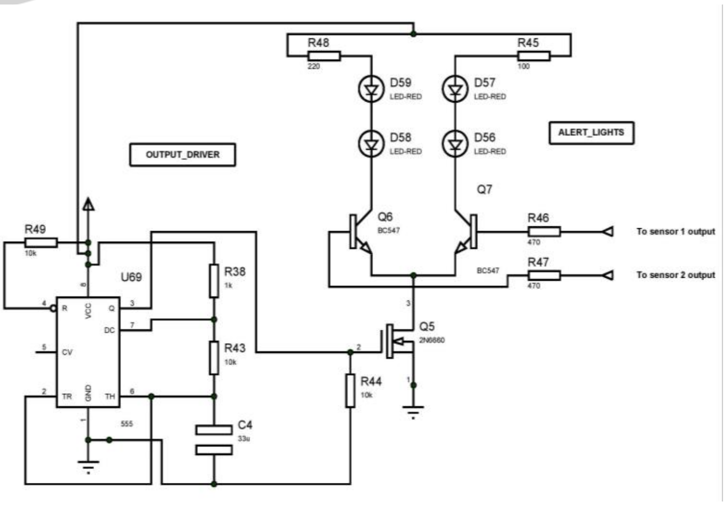

Fig 9: *Output driver circuit*

X. CLOCK SOURCE

Clock source generates (Fig 10) the clock pulse for the entire circuit except for the WDT and output driver circuit.

An astable 555 timer circuit is used here to generate the clock pulse. Frequency in the range of 2 to 5 KHz is used to ensure stability of the circuit.

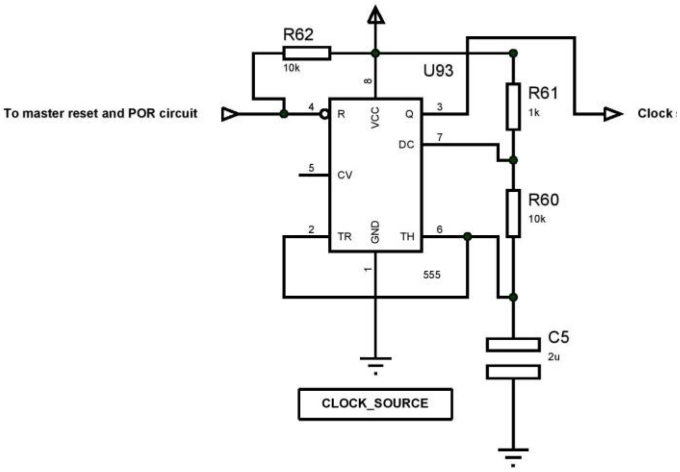

Fig 10: *Clock source circuit*

XI. POWER ON RESET CIRCUIT

Power on reset circuit (Fig 11) has been designed using a simple RC network. The output is connected to the reset pin of all the other modules present in the circuit. This will prevent the appearance of random values/ counts on the output of the flip flops during start up.

The resistor- capacitor network determines the power on reset latency. The reset of the clock source is also connected to the POR circuit in order to activate the system only after the other sub systems get out of their reset state. This prevents any type of output mismatch during power up in the circuit.

The circuit is designed with an 80µF capacitor in series with a 1KΩ resistor which produces a delay of about 80ms.

This circuit also has the Master Reset switch connected in parallel in order to reset the circuit manually.

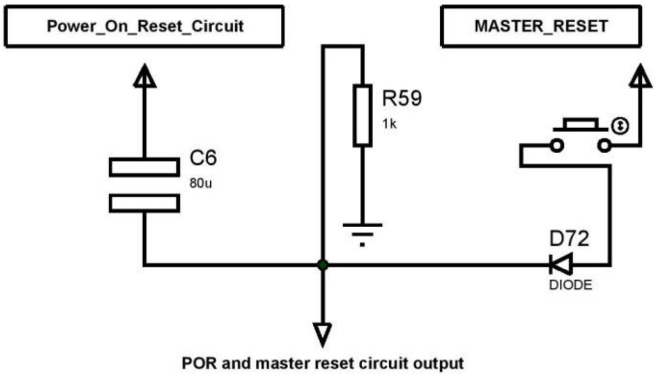

Fig 11: *Power On Reset circuit*

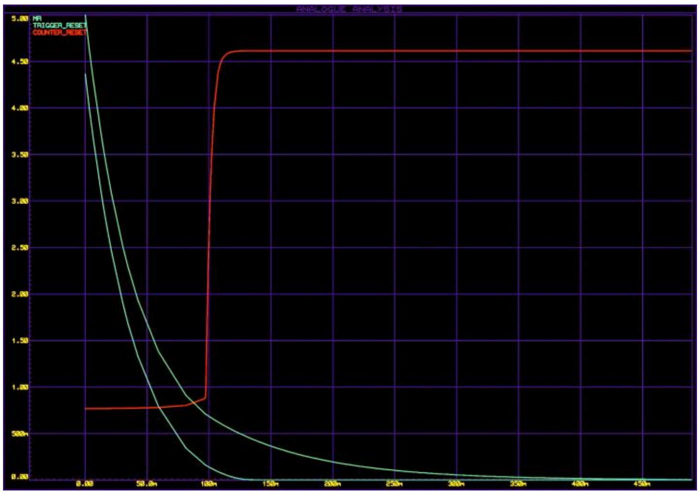

Fig 12: *Graph of POR circuit*

XII. OUTPUT

In order to give a visual alert of the detected voltage leak, alert lights are used in the circuit. The alert lights are made to flash by generating a square wave using a 555 timer in the output driver circuit. Fig 13 shows the graph of the overall output of the circuit after simulating a leak in pole number 1 and 5.

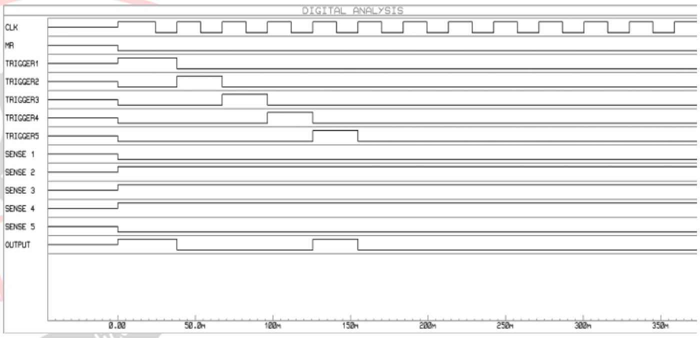

Fig 13: *Overall circuit output graph*

XIII. ESP8266 CIRCUIT

ESP8266 Wi-Fi module is used in the device in order to transmit the data from the circuit to the database. This is done so that the end user can fetch data from the app.

The module gets the pole number input from the 'counter' part of the circuit and with the detected voltage leak signal from the 'Input trigger' part of the circuit. The Wi-Fi circuit works by initiating the transfer of data (pole number) as soon as the leak signal becomes high. Thus, the pin input pin requirements of the circuit will be,

Number of required input pins = $\lceil \log_2 n \rceil + 1$, where 'n' is the number of poles.

This information then will be updated in the app so that the respective department's personnel can get notified to get the issue resolved.

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Reset	Output Mismatch Checker (Counter input, Input trigger stage 1)	Input Trigger Stage 2	WDT Reset Signal
1	x	x	0
0	0	0	1
0	0	1	1
0	1	0	1
0	1	1	0

XIV. WATCH DOG TIMER

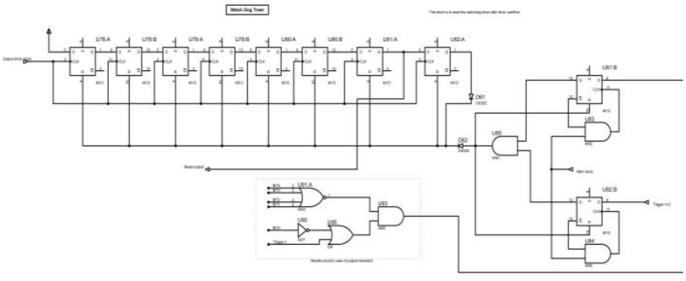

Fig 14: *Watch dog timer circuit*

Watch dog timer (Fig 14) for this circuit is a 7-bit timer designed using D-flip flops clocked asynchronously by a Low frequency oscillator that the output driver circuit uses.

It uses two stages of the ‘input trigger’ circuit as input to ensure the proper functioning of the system. Any malfunction on other sections of the circuit will lead to the counter overflow thus resetting the circuit after 3.37s.

Table 3: *Mismatch circuit output table*

It also has a ‘Output mismatch checker’ which is a reset mechanism to reset the circuit if a mismatch occurs in the outputs of the counter and the output trigger circuit. This part of the checking in the circuit is included since the ‘ESP8266’ Wi-Fi circuit uses the output of the counter and the input trigger circuit directly to determine the pole number of the faulty pole. The combinational logic can be expanded depending upon the pole count and the number of fault checks needed in a full cycle.

The last D flip flop in the circuit is to reset the WDT in an event of timer overflow in order to start it from its initial state after resetting the whole circuit.

$T_{Reset} = T_{Clock} * \text{Number of stages}$

$T_{Reset} = 0.482 * 7$

$T_{Reset} = 3.374\ \text{s}$

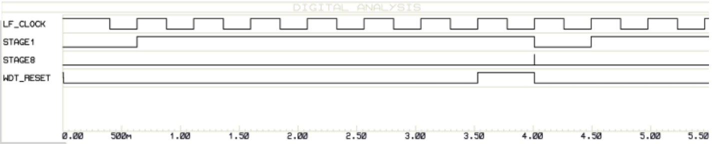

Fig 15: *Graph of WDT circuit*

XV. FULL CIRCUIT DIAGRAM

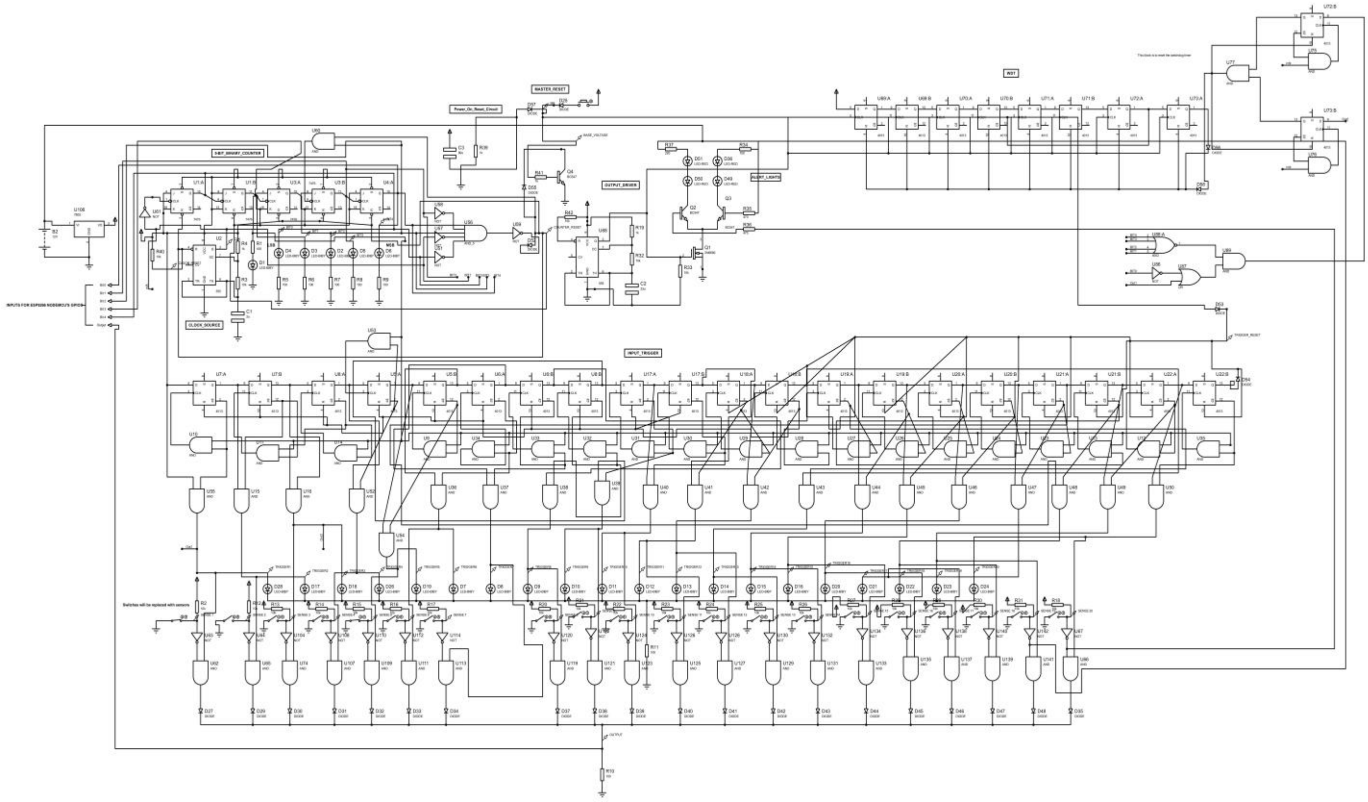

Fig 16: *Full circuit diagram*

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XVI. CONCLUSION

The overall aim of this paper is to design a detection and alerting device for electric leaks using simple digital systems. Though modern power transmission systems are equipped with switch gears and protection equipment, they have many limitations due to their mechanical construction and their high voltage handling capabilities. So, to overcome these limitations, the proposed smart digital system effectively addresses leaks in the power system.

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