



# An Innovative System for Full-Management of CB Using Current Injection Method

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## Abstract

In this article, an innovative supervision system will be proposed that can observe and analyze health of Circuit Breaker's trip coil. The proposed design also logs changes in the coil's quality and informs network supervisor in case of Circuit Breaker (CB) failure. This system injects small direct currents to the Circuit Breaker connections and the trip coil to compute CB's health and characteristics of trip coil. A large drift such as great change of resistance in coil, connections and switches characteristics can be determined as deflection of Circuit Breaker. This supervision system analyzes trip coil health with a microcontroller, logs trip coil condition changes (closed or tripped), failures and CB deflection in a multimedia card, shows condition of system via LEDs and LCD and sends needed information for network supervisor via SMS, Telephone line and also applies desired controls to the other appliances through three power relays. Besides, a number of these supervision systems can be networked via Ethernet to be observed and supervised with a web service program or webpage from a control room.

*Keywords:* Circuit Breaker, Trip Coil, Current Injection, Microcontroller, Ethernet.

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## 1. Introduction

The Circuit Breaker (CB) is an essential part in power systems. CB acts like a fuse in power networks while it is reversible. In case of overcurrent, fuses disconnect power network with fusil of a metal, but in circuit breakers overload current activates a magnetic coil that releases connection between tow terminals. This trip condition opens network power and prevents probable damages to wirings and appliances in network. User should manually reconnect terminals of CB after deletion of overload cause, and system will work normally [1].

Protective relay is the important device which detects abnormal conditions and sends a tripping signal to the circuit breaker. After receiving tripping command from the relay, the circuit breaker isolates the faulty part from the power system. For opening and closing the circuit, the contacts are presents. These contacts are placed in the closed chamber containing a fluid containing medium (either liquid or gas) which quenches the arc formed between the two contacts [2]. If trip

coil does not work correctly in condition of overload power source, network and consumer appliances may harm excessively. Aging and inconvenient ambient conditions can cause corruptions in application of CB trip coil [1]. Fig. 1 depicts a typical schematic diagram for a CB, used in a single-phase network. Current Transformer (CT) is designed to activate relay contacts only in condition of over-current. Activated relay contacts energize trip coil via battery and it releases CB terminals.

This procedure occurs in a fraction of second and network will be disconnected [3]. Circuit Breakers have a wide variety of types and designs. A properly-designed CB management system can be extended for working with all variety of CB's with some minor changes. In this paper, we will describe details of an innovative solution for fully-management of the circuit breaker presented in Fig. 1.

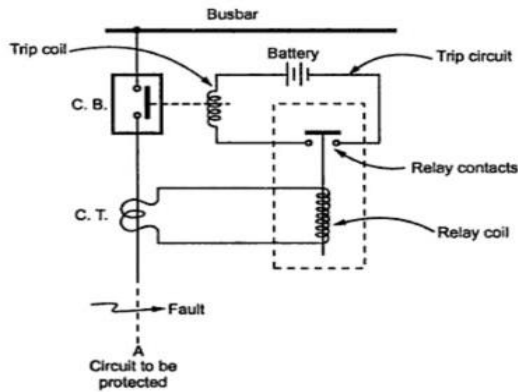


Fig. 1. A typical schematic diagram of a single-phase CB  
[3]General Block Diagram of Designed System

The following section presents an overall block diagram of the proposed system. Then, the third section describes the interior circuits for each block of the proposed system. Then, it will be continued with the details on the software and program code employed in the microcontroller processor and its flow chart. Standards and communication protocols will be described in the fifth section. Finally, the comparison results will be discussed in the last section.

This system needs five connections to the CB. Each checker block produces a small precise current and injects it to the CB in specific intervals. While the produced direct current is injecting to the trip circuit and its connections, microcontroller unit collects voltage drops at five connections  $Us_1$ ,  $U_a$ ,  $U_b$  and  $Us_2$  (shown in Fig. 2) and analyzes the TC, the CB contacts, the trip circuit connections and also the station DC power supply. An overall block diagram of the proposed system is illustrated in Fig. 2. This system has an internal power supply that uses auxiliary power to produce essential voltages for all the units inside the TCS. Auxiliary Power could be selected as network supervisor prefers. 24 VDC, 30 VDC, 48 VDC, 110 VDC, or 110 VAC, 220 VAC can be chosen for the input power source.

This system has an internal Real time Clock & Calendar (RTCC) that preserves time and date. Microcontroller uses time and date for logging the CB conditions and its faults. Additionally, microcontroller calculates probable large drifts in the TC characteristics over time passing to check the TC defection. Changes and controls can be applied to system via peripheral interfaces (RS232, USB or Ethernet) or using four push-buttons on the device panel. CB condition, time, date and other user-determined settings can be seen on the device panel (character type LCD). Four color LED's are predicted for illustration of faults, disconnection, trip condition and station power drifts. Three output relays are predicted for external controls in case of fault and warnings

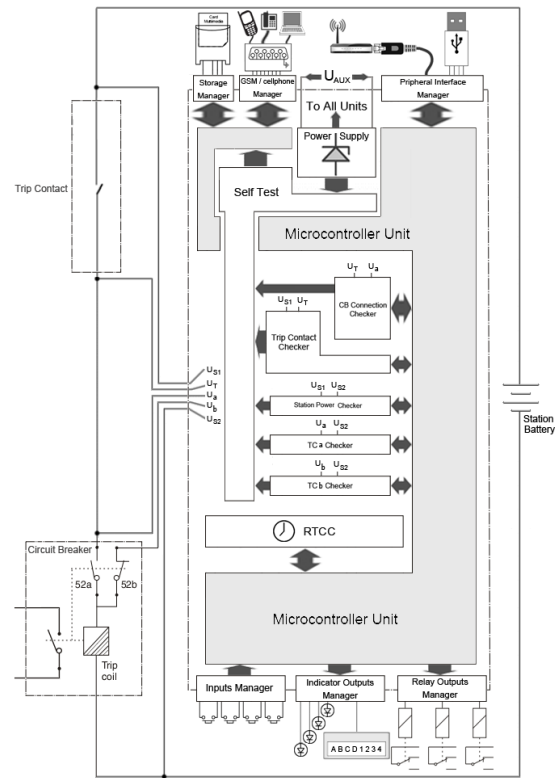


Fig. 2. An overall block diagram of designed system

occurrence, which can be programmed as the user prefers. TC electrical characteristics, CB conditions, faults and other defined settings will be stored in a multimedia card connected to device using storage manager block.

Designed supervision system uses self-test procedures to ensure its own health. Two self-test procedures are predicted for this system. A LTC1727 integrated circuit is predicted for the power supply supervision. In addition, one of microcontroller's analog inputs is reserved for checking the test currents produced in checker blocks. An Ethernet interface is implemented in the system that can be connected to station's local network or to another wireless network using a wireless access point. A remote web service can be installed in station's control room to pool data from all CITCS devices all over the power network, so user can observe all CITCS data and apply control signals to every CITCS node remotely. Five individual procedures are implemented in this system to analyze trip contact condition, TCa, TCb and trip coil electrical characteristics, station's battery and connection between trip contact and trip coil.

## 2. Designed Circuit for System

In this section, the proposed circuit for each block (Fig. 2) will be described in detail. Fig.3 shows designed circuit for power supply. This is a

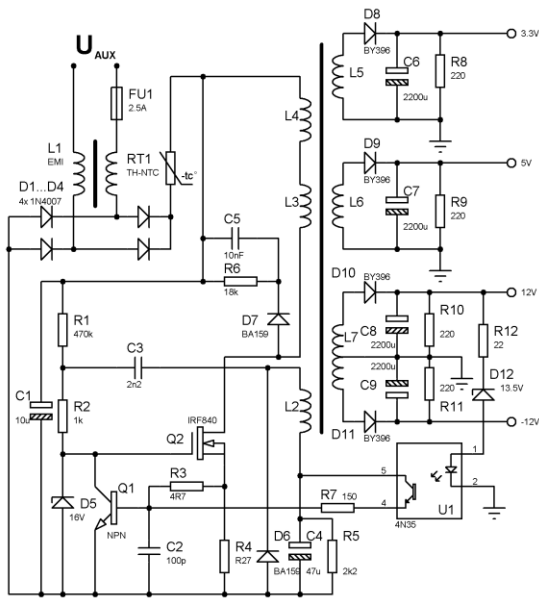


Fig. 3. Designed circuit for power supply

simple switch-mode power supply with a wide range of input voltage. This circuit produces four stable voltages (3.3V, 5V, 12V and -12V) that system needs.

The RTCC circuit is shown in Fig.4. U1 integrated circuit is an extremely accurate I2C type RTCC with integrated crystal and data RAM. DS3232 is a very accurate (1 ppm/V Frequency Stability), low-power-consumption (120µA @ 3.3v power supply), temperature-compensated (±2ppm Accuracy from 0°C to +40°C), coin-cell battery backed, Fast I2C Interface integrated (400 kHz) real-time clock and calendar (RTCC) made by MAXIM company. Microcontroller communicates with DS3232 chip via I2C interface and through SCL, SDA, and RST pins. R1 and R2 are pull-up resistors. When main power to the device is interrupted, DS3232 maintains accurate timekeeping using BAT1. With a 1000mAH battery, time can be preserved for 60 years without main power [4].

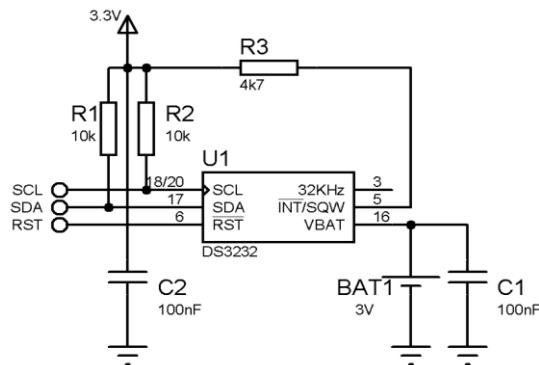


Fig. 4. Real Time Clock and Calendar circuit

The Ethernet interface circuit is shown in Fig.5. In this circuit, U1 is an integrated pulse-transformer. U1 operates as an isolator, to protect internal circuit from probable network problems, and on the other hand, it increases common-mode rejection ratio (CMRR) to suppress noise interference in communications.

Fig.6 presents the indicator outputs manager and input push-buttons circuits. LCD1 is a tow-line character type LCD with parallel interface. D1 to D4 LED's are user-programmable indicators for showing warnings and errors. Four input keys (OK, Up, Down, Cancel) are implemented for applying user controls to systems. B1 to B4 pins are connected to microcontroller's PORTB input and PORT\_CHANGE interrupt routine is enabled for reading the keys situation.

Fig.7 shows the relay outputs circuit. Three user-programmable relays are implemented for other external controls in condition of warning or failure, as user prefers.

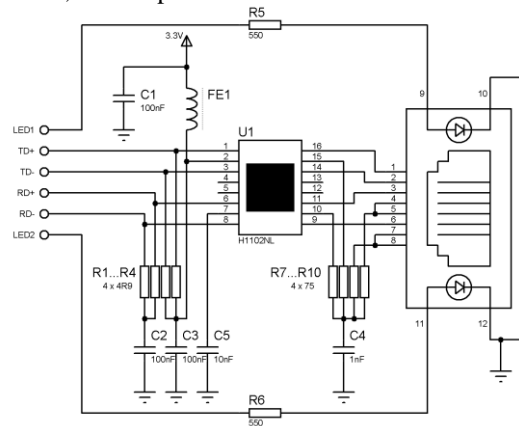


Fig. 5. Ethernet interface circuit

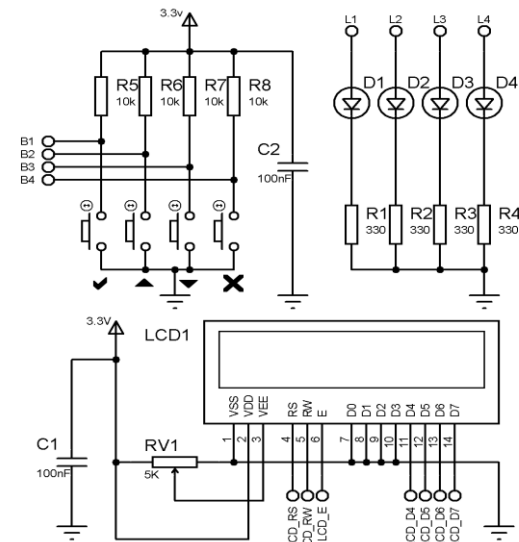


Fig. 6. Indicator outputs manager and input push-buttons circuits

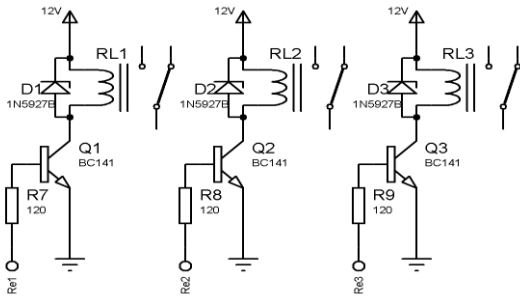


Fig. 7. Relay outputs circuit

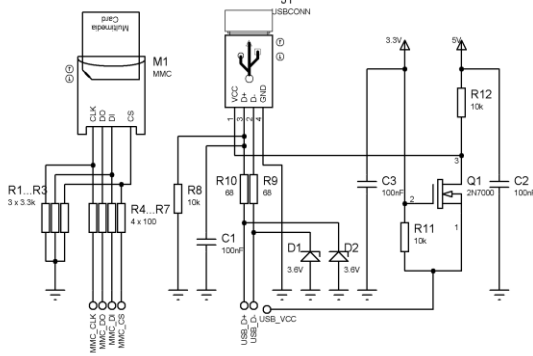


Fig. 8. Storage manager and USB interface circuit

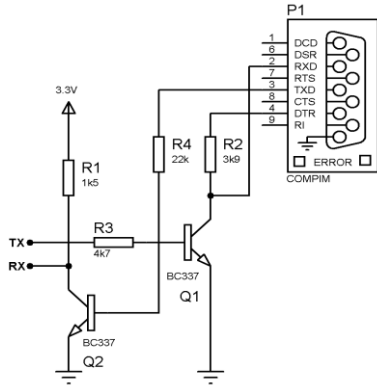


Fig. 9. RS232 Interface circuit

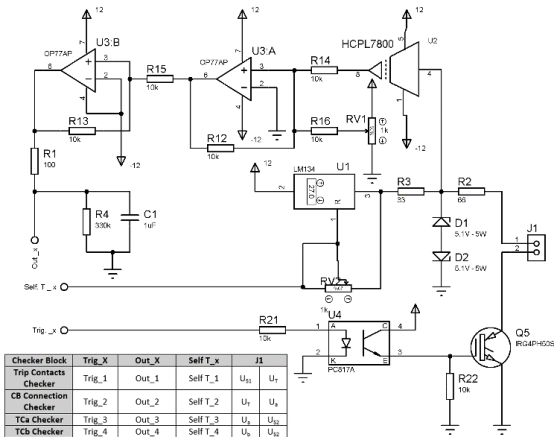


Fig. 10. Designed circuit for checker block

Fig.8 shows storage manager and USB interface circuit. M1 multimedia card (MMC) is suggested for recording CB conditions and probable warnings and faults. A 1GByte MMC can preserve 400 Million of characteristic changes and 100 Million of events along with date and time of occurrence. This amount of data capacity is enough for preserving data for approximately 500,000 years of working. A USB interface is implemented in this system for easier access to the recorded data through a user-friendly supervisory software. User also can change user-programmable settings and observe trends of CB characteristics using supervisory software.

Fig.9 describes the RS232 Interface circuit. RS232 interface has implemented in this system with two different usages. It can be used either as an interface for supervisory software or as an interface to connect this system to a GSM module or a cellular phone. CITCS system can be programmed to send a predefined message or make a call with a pre-recorded message to the phone numbers that user sets in case of warnings or failure occurrence. Microcontroller is programmed to communicate with GSM module or cellular phone using standard AT&T commands; therefore this system can be connected to all communication devices that support AT&T commands. Predefined message can be formatted with a “sprintf” command and can be written as the following:

Sprintf(gsm\_msg, “Node Number: %i %c CB Status: %s %c Date: %i / %i / %i – Time: %i : %i”, node\_id, char\_cr, status, char\_cr, date\_yy, date\_mm, date\_dd, time\_hh, time\_mm);

where “gsm\_msg” is output string that will be sent via GSM module, “node\_id” is user-defined id that holds identification number for circuit breaker, “char\_cr” is ASCII character (0xD) for carriage return(<CR>), “status” is a string holding current status of CB, “date\_yy”, “date\_mm” and “date\_dd” are integers holding current year, month and day respectively. Moreover, “time\_hh” and “time\_mm” are integers holding hours and minutes of current time respectively. Designed circuit shown in Fig. 10 does the checking procedure for four blocks of checkers (Trip Contacts Checker, CB Connection Checker, TCa Checker and TCb Checker). The table on the bottom of Fig. 10 shows signal-tag-names for each checker block. In the circuit which is shown Fig.10, U1 is a three terminal adjustable current source, with 0.0 2%/V current regulation, and Programmable range of current from 1µA to 10mA [5]. The isolated-op-amp U2, U3:A and U3:B Op-Amps are isolated-amplifiers for input voltage that falls across measuring junctions. U4 and Q5 are floating ground selector switch. Q5 is an “IRG4PH50S” with maximum IC of 57A and

maximum VCE of 1200V [6]. Microcontroller changes selected floating-ground in this system via activating Trig\_ x signals. D1 and D2 are power Zener diodes for clipping measured signal if it goes over 5.7V. Fig. 10 circuit uses LM134, which is a reliable steady current source for this application. As we know, set current for LM134 can be calculated from Formula-1 [5].

$$I_{set} = \frac{(227\mu V/^\circ K)(T)}{R_{SET}} \quad (1)$$

Where “T” is temperature in degrees of Kelvin and RSET is RV2 (in Fig.10 circuit) in Ohms. By setting RV2 multi-turn-potentiometer to 13.5Ω and holding LM134 temperature around 25°C (298.15 °K), ISET could be adjusted on 5mA. At this condition voltage across “Self\_T\_ x” and ground (V0) will be 0.5V (VSelf T\_X=0.5V). “VSelf T\_X” is used for checking health of current source and its temperature-independence-performance.

Fig. 11 shows the supervision circuit. U3 integrated circuit is a reliable triple supply monitor for supervising three supply voltages provided by Fig. 3 power supply. “RST OUT” signal is a common open-drain reset output that remains low until all three supplies have been in compliance for 200ms. U1:A Op-Amp is working as an analog adder that collects Self-Test currents from checker blocks, and its output will be sent to microcontroller unit. Microcontroller checks “Self T\_Out” and if it drifts more than 1% from its reference value microcontroller will shows it as a warning, drift more than 5% will be an error for this system. U2 is a HCPL7800 integrated circuit, used for optically-isolating high voltage section of circuit from low voltage section. HCPL7800 is a general purpose analog signal isolator with over 1000V input-to-output-insulation-voltage and 15 kV/μs common-mode rejection over 100 kHz bandwidth [7]. Fig.12 shows designed circuit for checking station power supply (Station Power Checker Block). Microcontroller checks station power in specific intervals by activating Trig\_5 signal and reading Out\_5. If station power falls lower than its nominal Voltage, system considers it as a fault. Fig.13 Shows designed circuit for Microcontroller unit. Main processing unit of this system is U1. The U1 is an 18fXX family of PIC microcontroller made by MICROCHIP. The PIC18f67J60 is chosen with a 64-pin PIC 168 Kbyte of code space, 3.8 Kbytes of data RAM with 10.5 Million Instruction per second and speed with 2V to 3.3V working voltage. PIC18f67J60 has IEEE 802.3™ Ethernet controller, fully compatible with 10/100/1000 Base-T networks. This microcontroller has two enhanced USART interface modules that support RS-485 and RS-232 and Two Master Synchronous Serial Port (MSSP)

modules supporting SPI (all 4 modes) and I2C™ Master and Slave modes. PIC18f67J60 has 16 channels of 10-Bit Analog-to-Digital Converter module (ADC) with auto-acquisition capability [8]. This processor unit is running with a 20 MHz crystal oscillator and has an output reset source from supervision circuit shown in Fig. 11 [8].

### 3. Software and Program Flow chart

The selected PIC microcontroller is programmed with 418 lines of codes in C language with MikroC compiler. Fig. 14 shows the overall flow chart for designed software and keypad interrupt for reading procedure of Fig. 6 input push buttons. In initializing procedure, microcontroller configure its peripheral interfaces (Ethernet controller, USB, USART interface modules, SPI and I²C Master mode) and sets six channels of ADC module using appropriate “ADCON0,1,2 Control Registers” for reading analog data from checker blocks and self-test circuit. Then microcontroller activates corresponding “TRISX” registers for direction of ports and it communicates with char-LCD and shows startup routine while it is initializing.

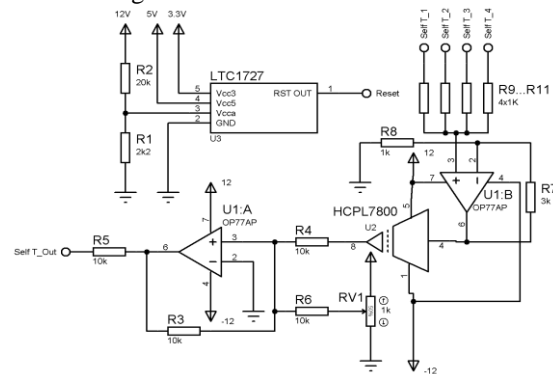


Fig. 11. Supervision Circuit

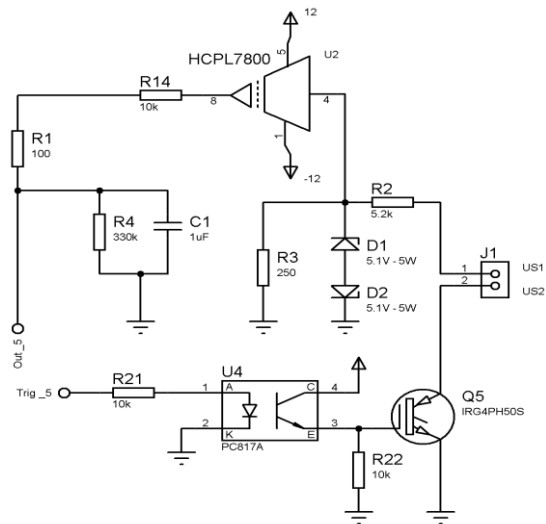


Fig. 12. Station Power Checker Block

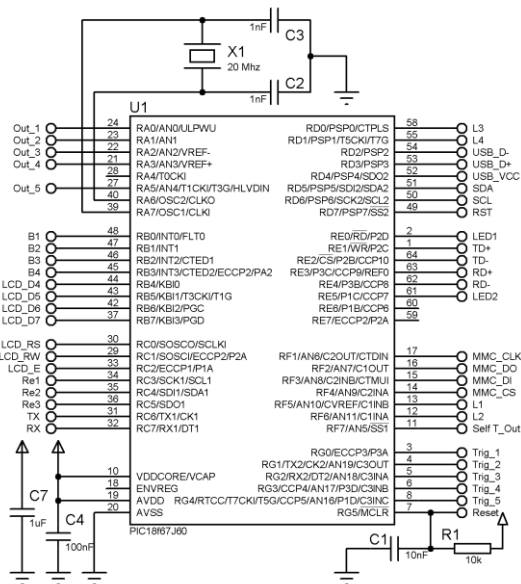


Fig. 13. Microcontroller unit circuit

Every “Send XXX Check Sig.” procedure is deactivation of all “Trig\_X” signals and activation of corresponding “Trig\_X” signal for triggering of floating-ground switching IGBT (Q5 in Fig.10 circuit) appropriate with “XXX” checker block. Every “Gather Data” is procedure of reading 2-bytes-result-registers that holds ADC conversion results (ADRESH and ADRESL) and storing them in their corresponding variables, defined in microcontroller’s RAM. It should be mentioned that required acquisition time ( $T_{ACQ}$ ) for this ADC is  $2.4\mu s$ . Constant delay required by procedure of reading every ADC channel is calculated using equations presented by manufacturer. The  $T_{ACQ}$  is calculated by:

$$\begin{aligned} T_{ACQ} &= T_{AMP} + T_C + T_{COFF} \\ &= 0.2\mu s + T_C + 1.2\mu s \quad (2) \\ &= 1.4\mu s + T_C \end{aligned}$$

Where “ $T_{AMP}$ ” is amplifier settling time ( $T_{AMP}=0.2\mu s$ ), “ $T_{COFF}$ ” is temperature coefficient ( $T_{COFF}=1.2\mu s$ ), “ $T_C$ ” is holding capacitor charging time, and the  $T_C$  is calculated by:

$$\begin{aligned} T_C &= (C_{HOLD})(R_{IC} + R_{SS} + R_s) \ln\left(\frac{1}{2048}\right) \mu s = \\ &= (25\text{ pF})(1\text{ k}\Omega + 2\text{ k}\Omega + 2.5\text{ k}\Omega) \ln(0.0004883) \mu s = \\ &= 1.05\mu s \end{aligned} \quad (3)$$

Where  $C_{HOLD}$  is holding capacitance of ADC module ( $C_{HOLD}=25\text{ pF}$ ) and ( $R_{IC} + R_{SS} + R_s$ ) is addition of serial resistance of sampling loop ( $1\text{ k}\Omega + 2\text{ k}\Omega + 2.5\text{ k}\Omega$ ). Acquisition delay time for each sampling is programmed at  $10\mu s$  to ensure correct conversion of ADC module. So, The  $T_{ACQ}$  can be calculated as:

$$T_{ACQ} = 1.4\mu s + T_C = 1.4\mu s + 1.05\mu s = 2.45\mu s \quad (4)$$

In “Read Self-Test Current” procedure, microcontroller reads “Self T\_Out” signal from Fig. 11 circuit via ADC channel 5 (AN5). As it has been described in section-III, “VSelf T\_X” in healthy condition of Fig. 10 performance should be around  $0.5\text{V}$  for each checker block. In addition, “VSelf T\_Out” from Fig. 11 should be addition of “VSelf T\_1 + VSelf T\_2 + VSelf T\_3 + VSelf T\_4 =  $2\text{V}$ ”. It is calculable via (1) in which voltage-drift more than 10% ( $0.2\text{V}$ ) of nominal “VSelf T\_Out”, is equal to “ISET” current-drift of 10% ( $0.5\text{mA}$ ). Since this current-drift can cause error in calculation of CB characteristics, microcontroller consider this amount of drift in “VSelf T\_Out” voltage as a fault.

In “Read RTCC” procedure, microcontroller reads minutes (address  $0x01$ ), hours (address  $0x02$ ), date (address  $0x04$ ), month (address  $0x05$ ) and year (address  $0x06$ ) from DS3232 registers, converts them to equivalent integers and store them in “time\_mm”, “time\_hh”, “date\_dd”, “date\_mm” and “date\_yy” respectively.

In “calculate Status” procedure, microcontroller compares ADC conversion results, stored in variables with their nominal values stored in EEPROM, and calculates the status of the CB. For example, nominal value for “Trip Contact Checker” (Out\_1 in Fig. 10 circuit or ADC channel 0 in Fig. 13 circuit) in open condition of CB should be equivalent to “Station Battery” (Out\_5 in Fig. 10 circuit or ADC channel 4 in Fig. 13 circuit). In a close condition, it should be equal to zero. After every calculation of “status”, one of bitwise variables corresponding to status of CB will be activated.

Microcontroller will send digital-low signals on relay pin-ports (Re1, Re2 and Re3) for activating relays, if needed. In addition, it sends digital-low signals on indicator LED pin-ports (L1, L2 and L3), and sends other predefined messages via USART and Ethernet interfaces as well. Calculated status of CB will be shown on char-LCD along with Time and Date for in-site-user observation. At the end, microcontroller will save status and Date and Time to the multimedia card via SPI protocol and checking procedures will be started over from beginning.

#### 4. Protocols and Standards

In this system, three standard communication protocols are implemented for sending needed data to user. RS232, TCP/IP Ethernet and telephone line can be defined as preferred communication method to inform user in case of status changes or fault occurrences. In addition, this device could be connected to cellphone or GSM modem with AT&T commands. Device will send predefined SMS's or make alert calls for status changes or fault

conditions occurrences. I<sup>2</sup>C and SPI protocols are used in inter-circuit communication level. I<sup>2</sup>C with 40 KHz clock speed is used for communicating with RTCC chip, and SPI is used for MMC data communication. Also, USB protocol is used for user maintenance check and status data storage observation.

Another option integrated in this system is Web-service networking. A numbers of CITCS devices can be connected to a server via TCP/IP protocol. User can watch all CB's Statuses and conditions, and also check TC coil health and its characteristics deviations over time passing.

## 5. Conclusion

There are many designs for TCS (Trip Coil Supervision), but in none of the existing systems, full management of CB is accomplished as the prototype that has been described here. The designed system uses more simple method for analyzing CB trip coil, have more options in controlling and fault finding in compare with existing CB management systems [9-12]. The designed method has five important advantages compared to existing CB management systems. 1) Designed system can log and show tripping coil behavior over total period of CB's lifetime, this helps power network supervisor to choose a proper CB in different conditions and finds source of probable faults in CB. 2) This system can communicate with user and network supervisor with multiple methods and protocols. 3) Using low power consumption techniques makes this system to work with smaller power consumption. 4) The designed system can be networked over Ethernet. Numbers of CITCS devices could be installed in multiple stations and be watched in a single web-server. Because of the above benefits, this design is a good candidate for full supervision of Circuit Breakers.

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