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SCADA-Based Monitoring and Remote Control of Circuit Breakers

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Authors' contributions

This work was carried out in collaboration between all authors. Author OCO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author OAE review and vet the analyses of the study. Author LOA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This paper presents a descriptive analysis of automated supervisory control and Data Acquisition (SCADA)-based monitoring and remote control of circuit breakers. The automated supervisory control and Data Acquisition (SCADA) system architecture has two main parts – The Hardware and The Software. The hardware comprises the circuit breaker monitor (CBM), the personal computer (PC) concentrator and the Global Positioning System (GPS) clock receiver. The circuit breaker is made up of the intelligent electronic devices (IEDs) which are found in the breaker cabinet in the switchyard. The global positioning system (GPS) receiver and the personal computer (PC) concentrator are also found in the control house. A point to multipoint (wireless) connects the personal computer concentrator with the intelligent electronic device. This kind of arrangement work as master-slave architecture. The circuit breaker monitoring slave unit is positioned at each breaker in the switchyard and are wired together to achieve the signals from controlled circuit breaker.

Keywords: SCADA; remote control; circuit breakers; CBM; point-to-multipoint; power system.

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1. INTRODUCTION

SCADA stands for supervising control and DATA Acquisition. The SCADA system became popular in the 1960's in order to monitor and control remote equipment. The early SCADA systems used mainframe technology and required human operators to make decisions, take actions and maintain the information system. Due to the high human labour cost, early SCADA systems were very expensive. Today, SCADA is much more automated and consequently more cost-efficient. The SCADA is the foundation for the distributed automation system. The use of the SCADA system in electrical utility companies started in the USA in 1962 [1]. The circuit breaker which is part of a power system, their functions are critical in continuously providing power supply. The circuit breaker are used to control the load flow in power system are used to disconnect the faulty parts of the system and they are have a life spam of say 40 years. Its method of operation change infrequently unless it is located in a power station were switching is intense. A breaker is been operated by protective relays as it has no memory or intelligent of its own. These relay helps to detect faults and help to identify the particular circuit breaker that is needed to be open, i.e. isolating the faulty part from the healthy part so as to enable the system operate normally [2]. However, a breaker can also be operated manually by the maintenance personnel or through command. There can be a time were the breaker may not open or close on command, this may lead to an incomplete action thereby allowing the fault to exist longer than expected or than the system can hold without damage.

Improper operation of the circuit breaker can lead to unwanted changes in the power system functioning as well cause an abnormal potential state which will eventually lead to power outage.

In the monitoring of circuit breaker status/operation, the use of Remote Terminal Unit (RTUs) of a supervisory control and Data Acquisition (SCADA) is use to ascertain the status of the circuit breaker. This will improve the reliability of the system. On-line and Real time monitoring seems to be a better solution for status monitoring and to ascertain the condition of the circuit breaker.

Supervisory Control and Data Acquisition (SCADA) was first use to introduce the on-line monitoring of circuit breakers, this schemes monitors the status of circuit breaker mechanical contacts and transfer its information in real time to the central house (SCADA house). The condition monitoring aspect is more recent and this is as a result of recent development in electronic sensor and on-line data acquisition equipment which has also made the system to be more feasible, economically attractive and technically achievable.

2. LITERATURE REVIEW

During the mid-1930s [3], Remote control switching, providing status and control was done using the telephone lines.

In 1960's [3], Digital communications has spread all over most developed countries, as at that time, data acquisition system (DAS) has been installed to automatically collect measured data from the substations or from switchyard. As development increased, analogue and digital data points was now available in single intelligent electronic device (IED) and there was no limiting factor of bandwidth as the need for messages, transmission times and other criteria were properly defined [3].

According to [4], Power flow can be justified technologically and economically for the need as well as power system during current operating state can be determined by the connectivity of the substation [4,5].

(Smith and Modzelewski, 1999), Describe the Remote Terminal Units (RTUs) as an advance features which can be used to enhance Energy Management System (EMS) capabilities to upgrade and this will lead to an ever growing role of the Remote Terminal Unit (RTU).

(Williams J. Ackerman, 1990), Says the use of intelligent electronic device (IED) in switchyards or substations will introduce the changes on the design and implementation of supervisory control and data acquisition (SCADA) and in distribution management system (DMS) which will lead to a more accurate reliable application program such as contingency analysis, load flow, state estimation etc.

(Hoppe et al, 1999) Says using existing utility communication schemes, operating personnel, maintenance and in the presentation of real-time rating, forms the integration process. He also describes the real-time monitoring and dynamic rating system as being used on-line by system operations.

(Wu et al, 2003), Says that the supervisory control and data acquisition system as a control system are used for the smooth operations, maintenance of energy infrastructure grids and monitoring of power system. Furthermore, those theoretical values are used in the computations of estimated parameters.

A well comprehensive literature review of many papers from international journals indicates that, it is important to research on developing an efficient data acquisition and processing scheme in other to improve the operations in power system.

3. STATUS MONITORING OF CIRCUIT BREAKER

As development civilization and the demand for a stable and a more reliable electric power increases, technologies known as supervisory control and data acquisition (SCADA) were developed in other to remoting monitor and control the important part of the power system.

Supervisory control and data acquisition, (SCADA). It's limited to monitoring and control of only critical parameters in the substation / switchyard. Its limited task includes reactive power monitoring, voltage, current and circuit breaker status assessment as shown below in Fig. 1.

Substation RTU's are connected and wired to the circuit breaker auxiliary contacts (52a and/or *52b),* which are used to monitor the status of the circuit breaker and they operate only when the breaker mechanism changes state. 52a and 52b contact signals represent the voltage across auxiliary switches that specify the open or close status of the circuit breaker – Fig. 2. Contact 52a opens when the breaker opens and closes when the breaker closes. It is also called 'a contact". Contact 52b has opposite logic: it opens only when the breaker closes and closes when the breaker opens. It is also called "b contact".

4. CONDITION MONITORING OF CIRCUIT BREAKER

In other to keep circuit breaker in a perfect condition below are some of the maintenance programs that must be carried out [6].

- ❖ Optimizing maintenance activities
- ❖ Determine the condition of a specific breaker.
- ❖ Determine the cause of failures/reducing the failure rate.
- ❖ Facilitating circuit breaker utilization.
- ❖ Improving the economics of equipment operations
- ❖ Understanding the condition of a larger population of circuit breakers acting in similar circumstances.

4.1 Design

In the design and simulation model, it is been characterized using some mathematical formulations. This formulation involves a step by step method or block by block design [7,8]. These individual block designs will be simulated and characterized.

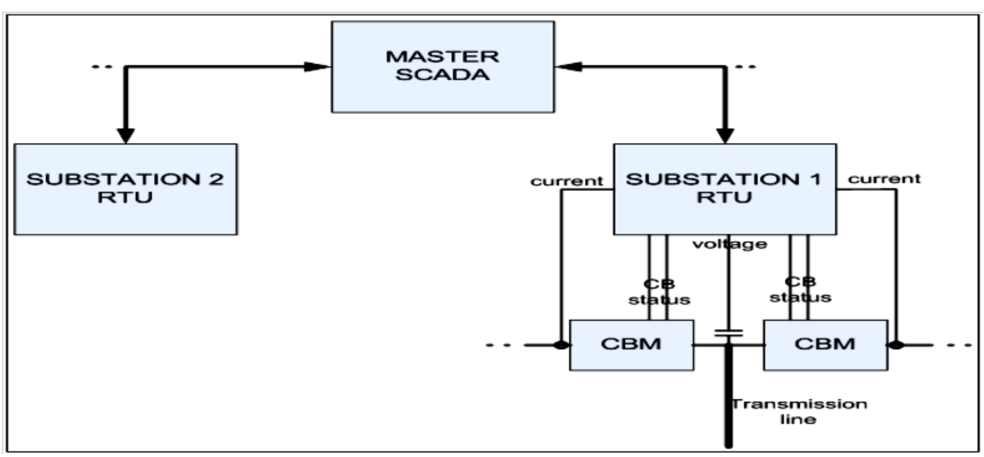

Fig. 1. SCADA topology

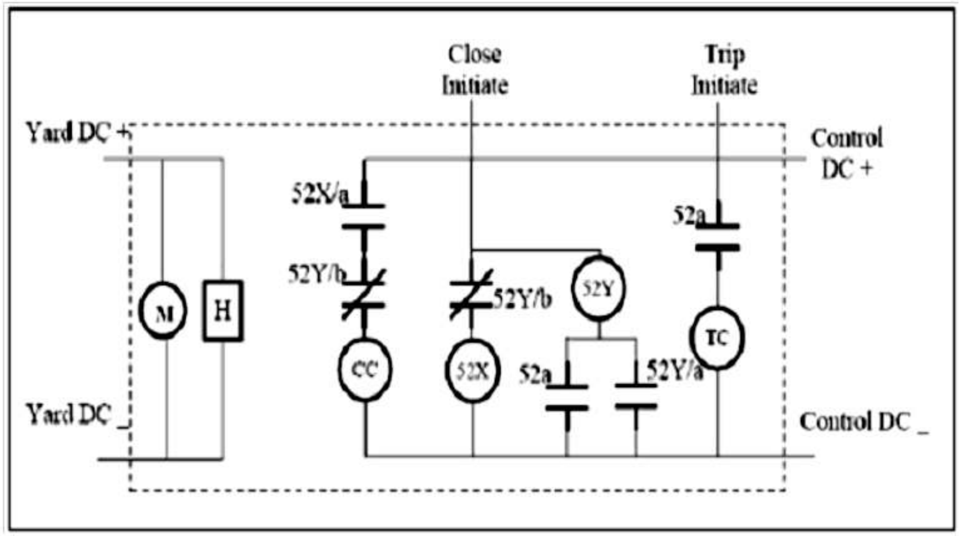

Fig. 2. Control circuit of a circuit breaker

Table 1. Parameters and signal selection of circuit breaker

Component	Parameters	Signal Measured
Control circuit	Trip timings (slow/fat)	Trip Coils (all poles)
	Close timings (slow/cast)	Close Coils (all poles)
	Sequence of operation	Backup Trip/Close Coils
	Auxiliary switch condition	Auxiliary contacts (52a, *52b)*
	Maladjustment of coils	X, Y coil status
	Battery status	Supply voltages
	battery charger status	
Operating mechanism	Contact travel curve	Trip Coils (all poles)
	Contact velocity	Close Coils (all poles)
	Deterioration of linkages	Auxiliary contacts *(52a,* 52b)
	Friction and binding	Heater (Cabinet) Temperature
	Heater status	Ambient Temperature
Main contacts	Contact erosion	Phase currents (a, b, c)
	Interrupter wear	Auxiliary contacts (52a, *52b)*
	Arcing time	Tank temperature
	Cumulative interrupted current	Number of operations
	High contact resistance	
Other	Circuit breaker status Circuit breaker interruption time	Phase currents (a, b, c) Auxiliary contacts *(52a, 52b)*

5. TOOLS USED IN THE DESIGN

- Proteus 7.8 Isis
- Program Description Language (PDL)
- MATLAB

5.1 Proteus 7.8 Isis

It was the primary simulator used in this design, which is the platform whereby components at gate level are logically connected together under an ideal environment. It is used to develop a simulation model that can visualize the intended system or design. It has tool boxes from which electronic solid state or logical components can be brought together and logically connected to give us the appropriate result.

5.2 Program Description Language

It is a part of C# and can be implemented into any programming language. It can be translated into system on chip language pr VERILOG or VHDL or VLSI for field programmable Gate

Arrays (FPGA) or complex Logic Device (CPLD). It is also use for implementation of algorithm code.

5.3 MATLAB

This research work makes use of MATLAB SIMULINK modelling tools for modelling the substation section in a distribution system by making use standard power block set elements in SIM POWER in the SIMULINK environment. It is in the MATLAB Simulink environment that the control signals for optimization of substation operation are generated.

6. SUBSTATION MODELLING

The simulation of the data acquisition and processing section of a substation in a distribution system would be effectively achieved using Proteus Isis 7.8 to produce a characterization of real time operations of the system.

MATLAB Simulink would be used in this research to give a detailed block by block representation of the substation model with the standard key block-set elements and functions.

The substation model is designed to constantly generate raw data that simulate information obtained from the physical substation in reality. This data is communicated in predetermined intervals for further processing by other software components. Several major blocks are implemented in order to model important elements and functions in the substation.

The distribution (location) of analogue and digital measurements in the substation model is determined considering following rules:

- Each circuit breaker has two current measurements (one at each side).
- Each transmission line has one current measurement, one voltage measurement, and calculated active and reactive power measurements.
- All switch elements have contact status measurements.

All measurements are single-phase measurements.

Four main Simulink blocks are developed for the substation model to describe different elements:

- equivalent source block,
- switching element block,
- measuring unit block
- Triggering block.

7. MATHEMATICAL CHARACTERISATION OF THE DATA ACQUISITION AND PROCESSING SYSTEM

During normal operation of the system, there is continuously processing of data samples taken from the measurement of instantaneous voltages and currents.

Using sequential samples, the algorithm can extract information about the measured values, such as amplitude and phase angle. Faulted or other system conditions can be determined by comparing the measured values to predetermined settings.

If the assumption is made that the voltage and current maintains sinusoidal form under varying conditions; amplitude and phase of the signal can be obtained using a limited number of samples.

Samples obtained from the sinusoidal signal can be described as

$$V'(t) = V_1 \sin(\omega_0 t) \quad (1)$$

Then the first derivative of the signal is

$$v'(t) = \omega 0V1\cos(\omega 0t) \quad (2)$$

Where: v'(t) = d/dt [v(t)]

From Eqns. 1 and 2, we have

$$[v(t)]^2 = V1$$

$$2[\sin(\omega_0 t)]^2 \quad (3)$$

$$[v'(t)]^2 = (\boldsymbol{\omega}_0)^2 V_1^{\,2} [\cos(\omega_0 t)]^2 \quad (4)$$

$$\frac{[v'(t)]2}{\omega_0} = V_1^{\,2}[\cos(\omega_0 t)]^2 \quad (5)$$

The peak value of the sinusoidal signal can be expressed as:

$$V_1 = V_1^{\,2}[v(t)]^2 + [\frac{[v'(t)}{\omega_0}]^2)^{0.5} \quad (6)$$

The above equations are valid for any instant. The derivative of the signal can be obtained if, between two consecutive samples, the signal is considered linear. This research work makes a modelling assumption that the derivative will be the slope of the linear segment of the signal and can be represented as

$$v'[k] = \frac{v}{t} = \frac{v[k+1]-v[k]}{t} \quad (7)$$

Where Δt is the time interval between instances when the two samples were taken.

The amplitude and the phase angle of the signal can therefore be calculated after each new sample using the following two equations:

$$V[k] = (v[k]2 + [\frac{v[k+1]-v[k]}{0\omega\Delta t}]^2)^{0.5} \quad (8)$$

$$\Phi[k] = \tan^{-1}(\frac{v[k]\omega 0\Delta t}{v[k+1]-v[k]}) \quad (9)$$

The above operations performed on instantaneous voltage are equally performed on instantaneous current.

$$I[k] = (i[k]2 + [\frac{i[k+1]-i[k]}{0\omega\Delta t}]^2)^{0.5} \quad (10)$$

$$\Phi[k] = \tan^{-1}(\frac{i[k]\omega 0\Delta t}{i[k+1]-i[k]}) \quad (11)$$

By leveraging first and second derivatives, it can reduce errors due to the decaying DC component (Russel, 1978). Using the same notations as for the previous mathematical formulations in Eqn. 3.7, the second derivatives of the sinusoidal signals

$$V'''[k] = \frac{vk+1 - 2vk + v[k+1]}{(\Delta t)^2} \quad (12)$$

$$I'''[k] = \frac{ik+1 - 2ik + i[k+1]}{(\Delta t)^2} \quad (13)$$

Thus, the amplitude and the phase angle of the sampled signal can be obtained as:

$$V[k] = \frac{1}{\omega 0}(v'[k]2 + [\frac{v''[k]}{\omega 0}]^2)^{0.5} \quad (14)$$

$$\Phi[k] = -\tan^{-1}([\frac{v''[k]}{\omega 0 v''[k]}) \quad (15)$$

$$I[k] = \frac{1}{\omega 0} (i'[k]2 + [\frac{i''[k]}{\omega 0}]^2)^{0.5} \quad (16)$$

$$\Phi[k] = -\tan^{-1}([\frac{i''[k]}{\omega 0 i''[k]}) \quad (17)$$

The mathematical formulations from eqns. (8) – (11) and eqns. (14) – (17) are extremely sensitive to deviations of the apparent sampling rate and as such this research further adopts Least Square Error (LSE), [9] algorithm to effectively handle any remaining decaying DC component and odd harmonics.

The wave form with decaying component and odd harmonics can be expressed as

$$v(t) = K_0 e^{-(t/\tau)} + K_1\sin(\boldsymbol{\omega}_1 t + \boldsymbol{\theta}_1) + K_3\sin(\boldsymbol{\omega}_3 t + \boldsymbol{\theta}_3) \quad (18)$$

Where τ is the time constant describing the decaying exponential.

Considering the first three element in the Taylor series expansion of a DC component, invoking the previous equation as it can be written as:

$$v(t) = K_0 - K_0\frac{t}{\tau} + K0\ \frac{t^2}{2\tau^2} + K_1\sin(\boldsymbol{\omega}_1 t + \boldsymbol{\theta}_1) + K_3\sin(\boldsymbol{\omega}_3 t + \boldsymbol{\theta}_3) \quad (19)$$

Using the fact that

$$\sin(\boldsymbol{\omega}t + \boldsymbol{\theta}) = \sin(\boldsymbol{\omega}t)\cos(\boldsymbol{\theta}) + \cos(\boldsymbol{\omega}t)\sin(\boldsymbol{\theta}) \quad (20)$$

Eqn. (19) can be written as:

$$v(t) = K_0 - K_0\frac{t}{\tau} + K0\ \frac{t^2}{2\tau^2} + K_1\sin(\boldsymbol{\omega}_1 t)\cos(\boldsymbol{\theta}_1) + K_1\cos(\boldsymbol{\omega}_1 t)\sin(\boldsymbol{\theta}_1) + K_3\sin(\boldsymbol{\omega}_3 t)\cos(\boldsymbol{\theta}_3) + K_3\cos(\boldsymbol{\omega}_3 t)\sin(\boldsymbol{\theta}_3) \quad (21)$$

The above equation is valid for any value of t. With the following notations:

$ak_1 = 1$
$ak_2 = \sin(\boldsymbol{\omega}_1 t_k)$
$ak_3 = \cos(\boldsymbol{\omega}_1 t_k)$
$ak_4 = \sin(\boldsymbol{\omega}_3 t_k)$
$ak_5 = \cos(\boldsymbol{\omega}_3 t_k)$
$ak_6 = t_k$
$ak_7 = t_{2k}$ (22)

and

$x_1 = K_0$
$x_2 = K_1\cos(\boldsymbol{\theta}_1)$
$x_3 = K_1\sin(\boldsymbol{\theta}_1)$
$x_4 = K_3\cos(\boldsymbol{\theta}_3)$
$x_5 = K_3\sin(\boldsymbol{\theta}_3)$
$x6 = \frac{-K0}{\tau}$
$x7 = \frac{-K0}{2\tau^2}$ (23)

Eqn. (3.21) can be written for consecutive values $t_1, t_2. . . t_m$ as:

$S_1 = \sum_{n=}^{7} 1^a 1nxn$
$S2 = \sum_{n=}^{7} 1^a 2nxn$
$S_m = \sum_{n=}^{7} 1^a mnxn$ (24)

The values of $x_j$can be obtained using the pseudo-inverse of matrix A = [aij],

Where i= 1, 2, . . . m and j = 1, 2, . . . 7. The matrix format of Eqn. (3.24) is:

$$S = AX \quad (25)$$

Where X= [x_j], with j = 1, 2, 3.4 5. . 7. It can be subsequently written that:

$$A^TS = A^TAX \quad (26)$$

$$(A^TA)-1A^TS = (A^TA)^{-1}A^TAX \quad (27)$$

As a result:

$$X = (A^TA)^{-1}A^TS \quad (28)$$

Considering the above values of X, the third harmonic, DC component, phase angle of the fundamental and the amplitude can be obtained.

In summary the mathematical process describes the substation data collection and processing of the power system.

8. SYSTEM ARCHITECTURE

The architecture of the complete SCADA system can be divided into two parts.

a. Hardware
b. Software

8.1 Hardware Architecture

The hardware consists of the Circuit Breaker Monitor (CBM), Global Positioning System (GPS) clock receiver, the concentrator personal computer (PC) [10].

The circuit breaker monitor; this consist also of an intelligent electronic device which is housed in the cabinet of the circuit breaker in the switchyard. The global positioning system clock receiver and the concentrator personal computer (PC) are also housed in the control room and are both connected together through a wireless point-to-multipoint network. The above configuration is been design to work as a master slave arrangement.

The slave circuit breaker monitoring units are arranged at each breaker in the switchyard and are wired together to achieve the desired signal for a smooth and appropriate circuit breaker control.

The concentrator personal computer (PC) which is the master unit is housed in the control house in other for it to gather all collected data by all the slave unit in the switchyard, store and process it.

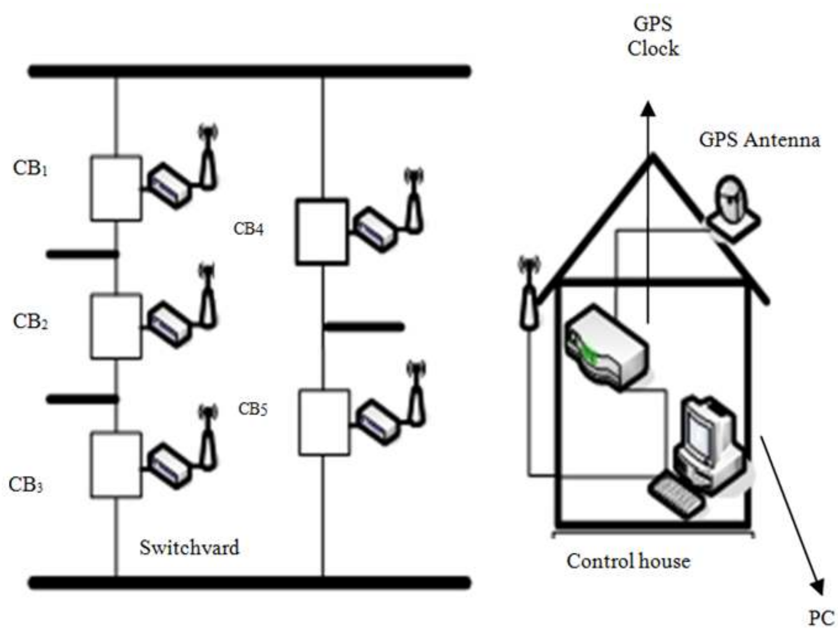

Fig. 3. CBM hardware architecture

When a breaker operates, the CBM records control circuit waveforms and transmit recorded files to the concentration personal computer (PC) using wireless communication. A list of signals recorded waveforms are given in Tables 1 and 2. From the listed tables, it may be observed that in order to monitor breaker operations closely, 15 signals are recorded including the phase currents through dedicated sensors wired inside the breaker. The obtained information is far more elaborate than what is acquired through breaker monitoring using typical wiring practice for remote terminal units (RTUs) of a SCADA.

8.2 Software Architecture

Circuit breaker monitor software performs data analysis and output information for different uses. Fig. 4 represents software architecture. The application enables customized views for various types of users since they may have different interests regarding breaker performance, sequence of breaker operations and network topology status. For some users it is important to know the precise topology of the systems and the status of CBs in every moment and for group of CBs after fault was recognized and cleared.

Table 2. Control signals of circuit breaker

Signal name	Channel	Type	Nominal range
Control Voltage	Voltage	Contact	*l25V*+15V
Light Wire	Voltage	Contact	- l25V±15V
Aux. Contact B	Voltage	Contact	*125V*± 15V
Yard DC	Voltage	Contact	l25V± 15V
Aux. Contact A	Voltage	Contact	*125V*± 15V
Close Coil Current (3 phases)	Current	Shunt	<10A(IV)
Trip 1 Coil Current.(3 phases)	Current	Shunt	<10A(IV)
Trip 2 Coil Current(3 phases)	Current	Shunt	<10A(IV)
Phase A Current	Current	Shunt	-5A (1V)
Phase B Current	Current	Shunt	-5A (1V)
Phase C Current	Current	Shunt	-5A (1V)
Close 1nitiat	Status	Contact	125V± 15V
Trip Initiate	Status	Contact	125V± 15V
‘X’ Coil	Status	Coil	l25V± 15V
‘Y’ Coil	Status	Coil	125V± 15V

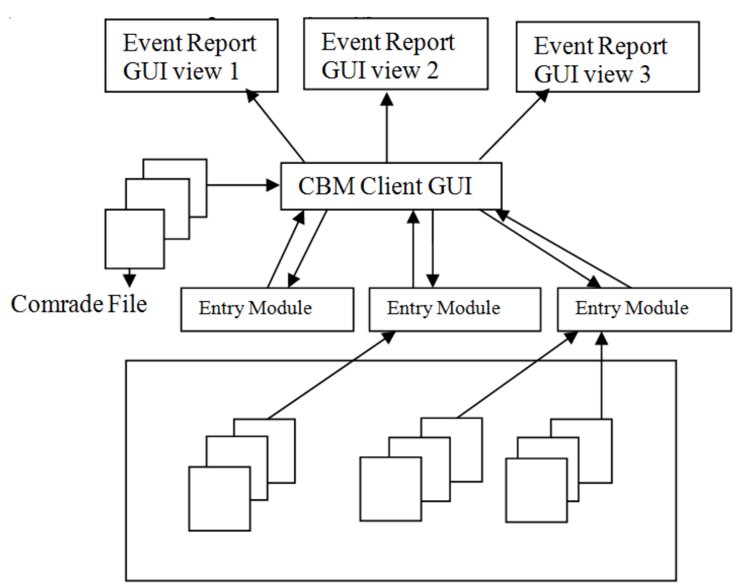

Fig. 4. Software Architecture of Circuit Breaker Monitor.

8.3 Hardware Functions

The circuit breaker monitoring and control (CBM) device is designed to perform two main functions:

8.3.1 Data acquisition

The input signals must be synchronously captured and converted to digital form whenever CBM is triggered.

8.3.2 Transfer to central place

The data gathered by CBM units at breaker must be transferred to a central location for further processing and analysis.

The wireless transmission solution was found to be cost effective and easy to implement. If the data acquisition system were to be set at each breaker in an entire substation, it would be very expensive to layout the wires to connect the units to a control house in the substation. The CBM unit connected to each CB consists of four (4) important components.

i. Signal conditioning
ii. Processing
iii. Analog to digital conversion
iv. Wireless Transmission Modules

8.4 Signal Conditioning Modules

The input signals shown in Tables 1, and 2 must be scaled appropriately before converting them into digital form for processing and storage. Most analog to digital converters require the input signals to be in the ±10V or ±5V range.

Systems, every node samples analogue signals A signal conditioning circuit must scale the signals to be in the range required by the A/D converter. This signal conditioning board should protect the rest of the device from high voltage transients generated during trip or close coil operation.

In other to be to run a breaker operation data analysis, all monitoring circuit breaker devices must be synchronized. This will enable the signal processing to incorporate multiple breaker to monitor. This solution will be designed as signal processing system as shown in Fig. 6.

The distributed and transmitting signal system, all analogue node samples signals will be controlled by their clocks signals and they are not synchronized. In other to synchronize their smooth operations among the processing node in the system, the drift and the jitter of the sampling must be handled properly.

For analysis of multiple breaker operations and system-wide applications, online circuit breaker monitoring solution should be designed as distributed signal processing system, which comprises numerous acquisition nodes which are interacting with the central processor to perform data acquisition and signal processing. The nodes should perform online data acquisition and signal pre-processing. The input data for this system arc digital samples of a discrete signal, usually sampled at the same clock rate.

Central processors and data acquisition units have separate clocks, which may violate data consistency constraints, due to their jitter and drift. This system should have event based data transferring and pre-processing so all samples should be time-stamped to enable signal alignment before processing in a central place. This problem does not exist in centralized, one-processor. One-data acquisition systems, as generally these have only one master sampling clock that schedules and controls the sampling processes.

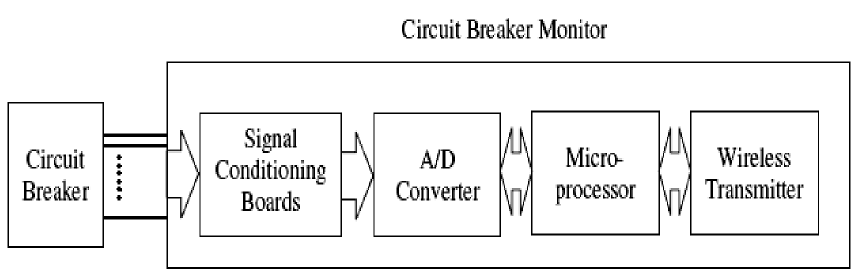

Fig. 5. Hardware architecture of circuit breaker monitor

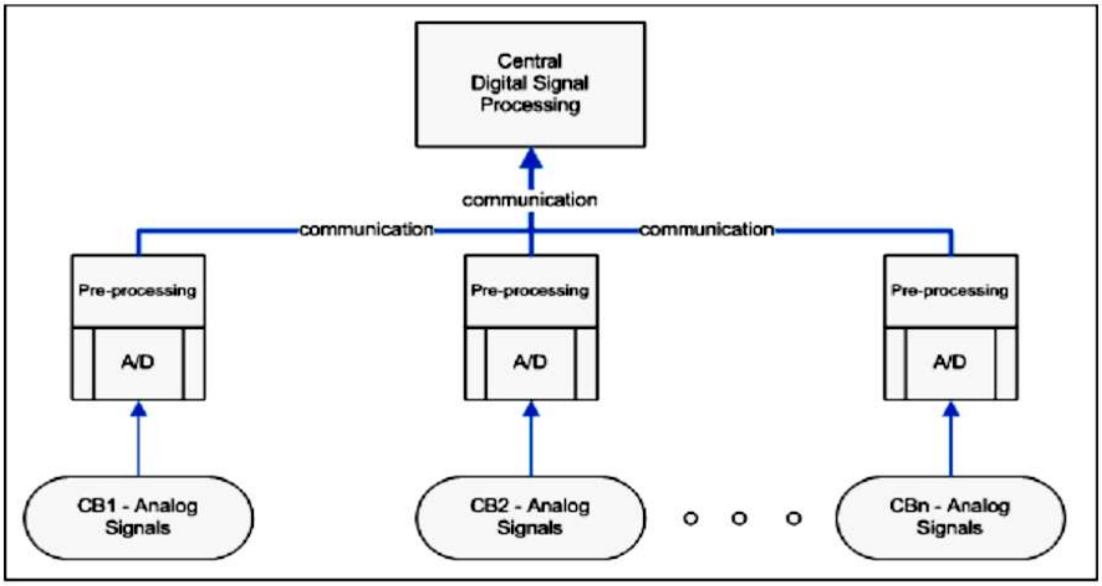

Fig. 6. Multiple circuit breaker monitor as distributed signal processing system

The field of distributed signal processing is not a well-explored area, so after the examination, of this complex problem, the most cost-effective solution is proposed. This system uses GPS clock signal to synchronize all the processing nodes in the system. Every sample taken around the system speeds to be sampled at the same time and stamped with common time stamp [11].

The overall signal processing and analysis is been performed by the central processor with all signals been aligned using the time stamp. Expensive real time data transfer network can be avoided using this method. The nature of the task (monitoring) is that the response time is not a major problem as the application does not require data transmission in real time. It is the even based recording process that requires the synchronization time. One of the advantages of this technique of signal alignment is that it meets the requirement and allow for quality time analysis. The remote data acquisition node, (Pre-processing), is used to carry out event recognition arid time stamping, this recognition is used to capture every events.

Similarly, monitoring of a circuit breaker, event recognition means determination of either close signal or the breaker trips operations which are indicated by sending all two signals and the signal status are recorded before the breaker operations as shown in Fig. 7. This captured waveform is called pre-event recording and is used to know the breaker status and the conditions of the control circuit before pre-event recording is usually done.

Every sample is stored temporary in a circular data, which therefore overwrites the oldest samples when it gets to the last or end pf the free space. When an event takes place all the data and new samples are stored to a memory. The length of time is fixed to some fundamental frequency cycles. The total number of length will be large enough to capture all information necessary at the same time. Circuit breaker in the high voltage transmission system needs two (2) to three (3) cycles to operate the breaker. Low and medium breakers needs up to 10 cycles to interrupt current. During reclosing operations, event signals will be initiated, device will be monitored and captured and the recording will be taken.

8.5 Analogue to Digital Conversion Module

The analog signals must be converted to digital form with a resolution high enough to allow an accurate analysis. A resolution of 12-16 bits is sufficient for most applications. The sampling rate must be high enough to enable accurate reconstruction of signals needed for the analysis. Sampling rate of 10 KHz is sufficient for most applications. To make sure that the recorded data may be combined with data from other CBs and other IEDs installed in a power system all signals must be sampled synchronously and then converted to digital form.

8.6 Time Synchronization Module

This is implemented using a global positioning system clock receiver and wireless transceiver for time distribution to intelligent electronic device located in the substation. The circuit breaker monitoring slave units are synchronized to the global positioning system time, with all their recordings accurately time- stamped. The global positioning system synchronization signal is shared from the master transceiver that is house in the control room to the circuit breaker slave unit at each breaker and as a result only one global positioning system receiver per substation will be needed. Time stamp transfer from global positioning system to circuit breaker monitoring system will be implemented using a circuit breaker communication protocol as shown in Fig. 8 and its time accuracy is 10 microseconds and this satisfy the needed requirements for the applications. The local clock has a small time drift between the two pulses so that the sampling accuracy will not be affected. The time stamp received from the concentrator personal computer is used to determine the date, second, minute and hour while the resolution is determine by the local timer which is synchronized with the global positioning system seconds.

8.7 Microprocessor Module

Besides time synchronization, microprocessor module performs the following functions.

- Controls data acquisition parameters of the A/D converter
- Sets the signal sampling frequency and scaling factors for digital signals.
- Detects events and record data for specified duration in memory
- Transmits data to concentrator PC using communication protocol and wireless transceivers
- Receives and execute commands sent from concentrator PC.

8.8 Wireless Communication Module

The concentrator PC gathers data from A/D slave units through wireless communication. The wireless transmission system enables data transfer from multiple points to the central storage system via a wireless modem employing frequency hopping spread spectrum technology unit in the control house. The transceivers work in a point -to- multipoint mode. In this mode, the slave units communicate with the master unit and vice versa but there is no communication between the slaves. In this mode the slave to master data link is usually robust, ensuring reliability of data transfer. The communication is controlled using custom point-to-multipoint protocol.

8.9 Software Functions

The CBM software analysis application is designed to perform three main functions:

- Automated analysis of individual circuit breaker operation in real time.
- Automated analysis of an operation of a group of circuit breakers.
- Distribution of results through different GUI views and reports for variety of users.

8.9.1 Automated monitoring analysis

Availability of new data from CBs control circuit brings possibilities for new types of analysis. CBM device monitors signals from control circuit of CB as indicated earlier in Tables 2. The analysis applications developed in an earlier project at TAMU analyzes performance and determines current status and behavior of an individual CB. Detailed analysis of single circuit breaker behavior is of great importance for maintenance groups. Other utility groups like protection engineers are more interested in sequence of events associated with a group of circuit breakers. They are interested in knowing when the sequence started, what caused operations and finally whether the sequence is executed correctly. In order to meet the foretasted requirements it was necessary to provide automatic retrieval of synchronized data from a group of circuit breakers to the central repository. This enables new feature of company control circuit signals from different circuit breakers on the same time scale. CBM architecture is designed to uphold these features.

8.9.2 Topology and sequence of events analysis

As mentioned earlier, automated analysis of CBM data has more information available through existing tools. Since CBs track the topology change (connectivity of various components in power system) with more details, better information about the topology is available.,

[12]. Knowledge about the current state of the system topology is very important for many power system applications like state estimation, fault location and alarm processor, which demonstrates the importance of the proposed architecture for future improvement of existing tool [13].

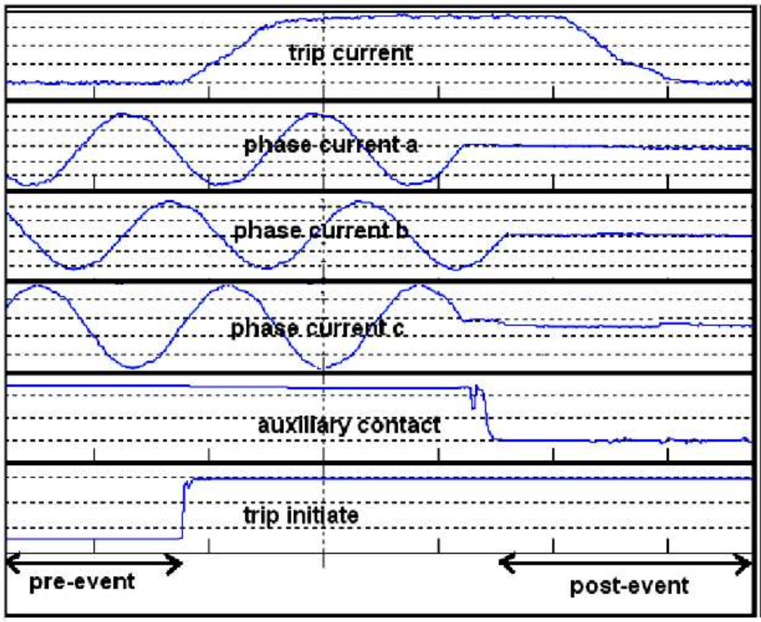

Fig. 7. Pre and post event recordings

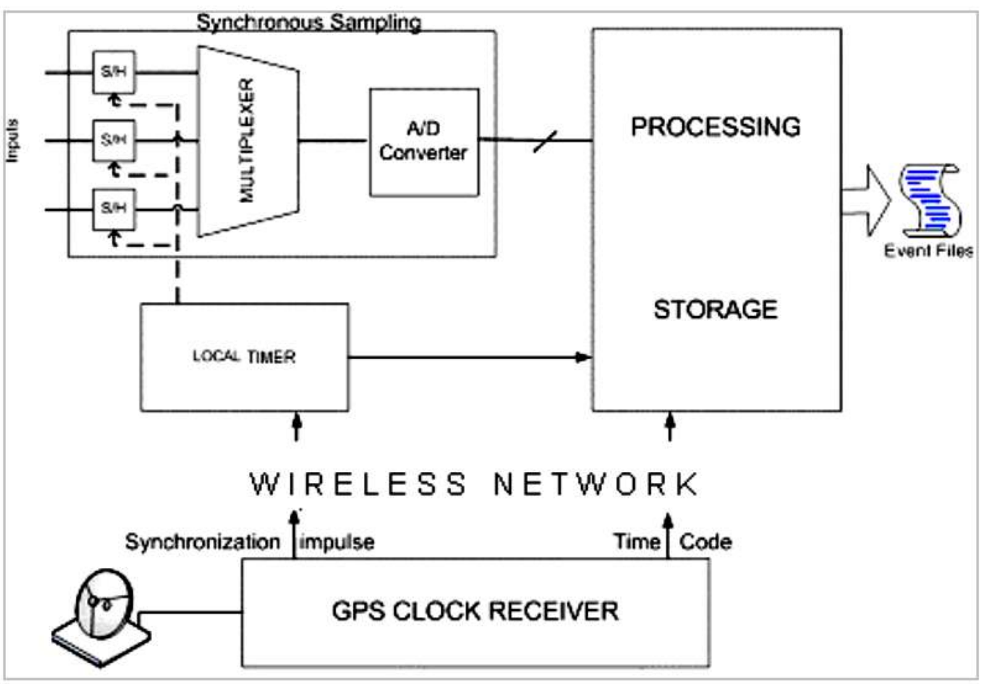

Fig. 8. Synchronization sampling

In general, CBs have the purpose to automatically connect or disconnect different parts of the power system in order to isolate the faults and/or re-route the power flow. In most cases they operate as a group in order to switch on/off some power system parts. To demonstrate this behaviour we will consider small part of the network as shown in Fig. 9.

In case that fault is present on line 4, corresponding breakers CB1, CB2 and CB3 as shown in Fig. 5 should open and de-energize faulted line. After some time they will be re-closed automatically in order to check whether the fault is cleared. Process of reclosing can be repeated a couple of times and it is initiated in order to determine whether fault, is cleared. Process of reclosing can be repeated a couple of times and it is initiated in order to determine whether fault, which caused opening of breaker is still present. Sequence of events in case of a temporary fault present on line 3 seen from the left hand substation from Fig. 9 is shown in Fig. 10.

9. APPLICATIONS AND BENEFITS

The advantages of maintaining power system equipment, specifically the transmission, distribution, circuit breaker and medium voltage equipment has increased due to the aging assets problem these include: [14,15].

1. The Circuit breaker monitor system will improve CB condition monitoring performing online monitoring of all available signals in the breaker control Circuit.
2. This system should provide data for condition assessment.
3. Identification of problems and in some cases
4. Prediction of failures and operating problems before they become critical.
5. Without making changes on existing data acquisition units, implementation can be done using from multiple circuit breaker monitors.
6. Circuit breaker can provide only information about the states of the individual breaker and its operations.
7. Data from multiple breakers can enable implementation of substation and system wide monitoring and control applications.
8. Decrease in the down time and increase in reliability and availability of the circuit breaker.

Based on data availability three level of analysis applications are possible.

1. Applications are using data from multiple circuit breakers across the system.
2. Operation of single breaker and condition analysis can be performed, based on present and historical data available.
3. Analysis of a switching sequence that involves multiple breakers uses time-correlated data from multiple circuit breakers form single substation.

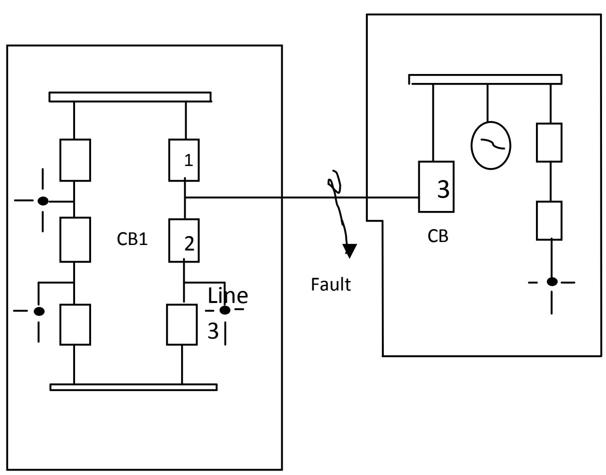

Fig. 9. Example of fault present on transmission line

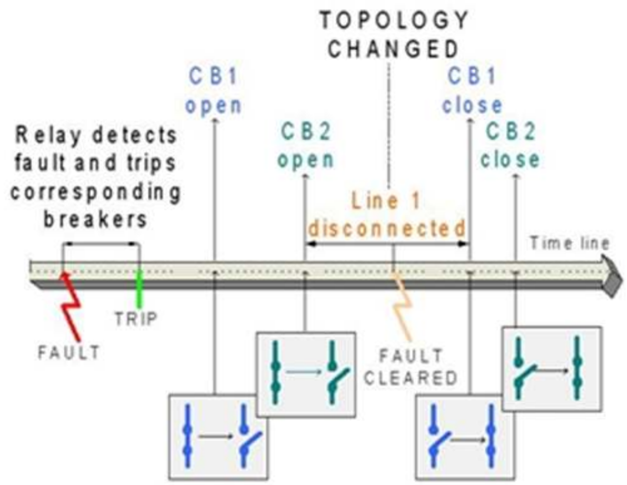

Fig. 10. Sequence of events in case of temporary fault

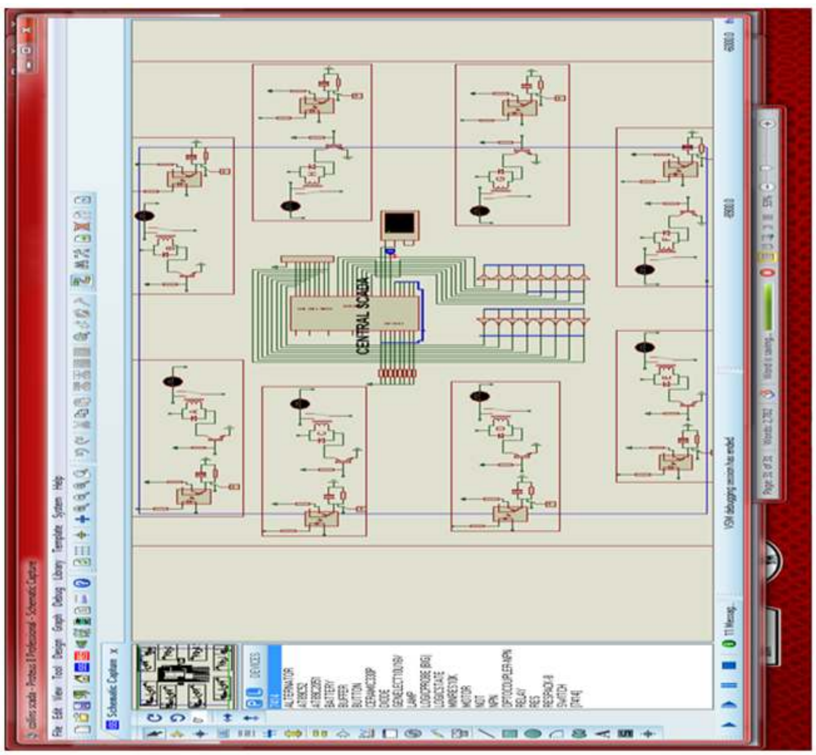

Fig. 11. Design simulated analysis using Proteus 7.8 Isis.

10. SUMMARY AND CONCLUSION

It can be easily concluded that by monitoring the CBs status changes and recognizing operational bag groups of CBs using synchronized data, one can infer what the reason for initiation of the sequence was and if it was executed as expected. A detailed analysis of possible sequence of events for the case of breaker –and-a-half bus arrangement was performed using automated software developed for this purpose. The automated SCADA system as presented in this study makes data readily available for electrical power system operation and maintenance as it grants remote access to operation and maintenance data. It permits fewer employees to be more productive thereby reducing operation and maintenance cost and increasing the efficiency of process.

11. FUTURE WORK IMPROVEMENT

All collected data or information that has been gathered by the circuit breaker monitor should be included in the switchyard or substation control center database in other to provide simple data access in the future. This can only happen through data integration following the data modeling standards. It is also well known that some of the results can be available for different kind of system wide analysis. Future work should be focused on the problem how to combine row data from circuit breaker monitor, as well as how to process information from online circuit breaker monitoring system. This can be available at both the substation and system wide levels. Availability of data in a suitable form such as the central database will provide improvement in the existing system analysis application and improvement of new applications.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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