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Real-Time Detection of Interruptions and Associated Equipments in Electric Power Distribution Substations in Nigeria

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Abstract

Real-time detection of interruption and affected equipment in electric power distribution system in Nigeria is repositioned to overcome the challenges posed by non-ability to detect outages in distribution substations whenever protective devices operate. This research initiative was undertaken to develop indigenous real-time detection of outages using current signature analysis. Software driven hardware positioned at remotely located sub-station monitors the state of the network in real-time. It analyzes the results and initiates communication with the Distribution Control Center (DCC) whenever outages conditions occur for analysis and diagnosis. Additionally, it generates a restoration code whenever corrective measures initiated are successful. The response of the installed sensors was analysed at the DCC to determine the affected equipment. The resultant system limits the effects of unplanned outages and increases power availability by reducing the down time. The system not only provides network wide status and health monitoring, but also strengthen engineering and management capabilities.

Key Word: communication, current, substation automation and voltage

Introduction

The distribution system is one of the three components of an electric power system. The others are generation and transmission [1]. A distribution network connects all loads in a particular area to the transmission lines. Hence, the distribution network design, planning and operation are of great importance in the quest towards the provision to customers of a continuously stable electric power. Notwithstanding the protective measures in distribution networks, faults do occur that cause serious damages to equipment and safety hazards to personnel [1]. Generally the effect of these faults manifest in so-called power events interruptions, Sags and Blackout [2]. Substation outages have a considerable economic impact on the operation of an electrical network. The direct effect is further amplified by the indirect impact of outages on the consumers which explains the importance of substation in the delivery of power. Therefore it is the aim to ensure an accurate assessment of the primary equipment condition. Traditionally, human beings are employed to monitor the performance of the networks particularly at the distribution level, but this solution is costly, unreliable and time consuming. Also distribution networks are not manned and only receive attention once an outage has occurred and been reported by the consumers. The relatively poor availability experienced at the distribution level when compared with what obtains at the transmission and generation stages where communication facilities are provided is not unconnected with the non-provision of communication infrastructures and the very large number of components that provide the path to the plethora of consumers [3]. When considered that distribution lines experience faults more often than the faults experienced by other power system facilities **[4],** real time detection will offer quick detection and reporting of outages. Unfortunately, presently EPDSs in Nigeria do not support quick fault detection and or a rapid response to outages.

In a developing country, where the generating stations are not adequate, an improved distribution network will enhance the delivery of power. Faults and failures of components in distribution system may cause interruption of power supply to customers. Since distribution systems in general encounter high frequency of outages caused by weather, component wear and tear, accident and other reasons, the need to reduce outage time is evident for two reasons [5]:

a) the growing customer requirement for high quality of service;

b) the growing demand recover the cost of generating electricity.

The most direct impact of faults on the profit is the loss in customer billing due to undelivered kWh, as well as maintenance expense [5]. The concern is how to reduce the outage detection and repair time.

To improve the performance of the EPDS, automation of monitoring and diagnosis needs to be widely adopted to bring the practice closer to that encountered in smart-grid systems moving the power substations to unmanned, automated monitoring systems. The emergence of reliable and affordable information communication technology (ICT) devices provides a unique opportunity for integrating real-time monitoring of infrastructure with other relevant decision-making features to facilitate efficient system management. This detector installed in the secondary side of distribution transformer will continuously detect the voltage. Outage signal is sent from the Remote Terminal Unit (RTU) if outage occurs. The RTU will be operated with battery, even if the power is cut. The detector also returns restore command back to distribution control center (DCC) if the power is restored. This paper focuses on the design of outage detector for distribution substation. [6], [7] discuss the outage management.

Justification for Real-Time fault Diagnosis and reporting in Nigeria

Generation Scenario in Nigeria

The efforts at addressing the availability of power by increasing the Installed Capacity are expressed by Fig. 1and Fig. 2. However, the daily generation was in the order of about 30% of the installed capacity. Therefore, an efficient approach by targeting the Distribution level becomes inevitable.

Delays in Fault Reporting and Clearing

Associated with the Akure EPDS is delay in fault reporting as this depends on occasional reporting of faults by consumers and by the patrol team. The direct consequence of disturbance is reduction in power availability. Availability means that a system is on-line and ready for access. A variety of factors can take a system off-line, ranging from planned downtime for maintenance to catastrophic failure. The goals of high availability solutions are to minimize this downtime and/or to minimize the time needed to recover from an outage. Availability, A, of power is defined by the equation [8]:

$$A = \frac{MTBF}{MTBF + MTTR} \dots\dots\dots\dots\dots\dots.1$$

Where:

MTBF= Mean time before failure; and

MTTR= Mean time to repair

Peculiar to the network under investigation, the MTTR is determined by the detection time, reporting time, diagnostic time, location time and restoration time.

$$MTTR = \sum_{i=o}^{n} \int_{0}^{t_i} A_i \, dt \dots\dots\dots\dots\dots.2$$

Where, A_i represents the various n components which are time dependent.

A reduction in the time of associated MTTR components will increase the availability of power supply to consumers A high availability solution focuses on both preventing and avoiding problems that might lead to an interruption of service. Also it should focus on recovering quickly and minimizing the impact from any outages that do occur

Development of Indigenous Real-time Monitoring System

To detect the various faults and outage on the distribution network, a methodology that properly differentiates normal operating conditions from those of fault operating conditions was developed. The first step was to establish a baseline of normal operating conditions. Then the next step was to develop a method of differentiating fault operating characteristics from baseline characteristics. Outage detection of distribution transformer is shown in Figure 3

Supply Power Quality (PQ)

The quality of the supply is used to determine outages and sustained interruptions. According to [2], both the magnitude and duration of the quantities recorded by the sensors at the substation terminal defined the status of the substation. The investigation of the recorded data supplies information to determine outages, interruptions and associated equipment [12](Primary and secondary equipment).

(i) Outage

$0 \leq V_{rms} \leq 0.1V_n \dots\dots\dots\dots\dots\dots\dots .3$

(ii) Sustained Interruptions

$V_{rms} \leq 0.1V_n \dots\dots \dots\dots\dots\dots\dots 4$

(iii) Under voltage

$0.1V_n \leq V_{rms} \leq 0.7V_n \dots\dots\dots .5$

(iv) Overvoltage

$0.1V_n \leq V_{rms} \leq 0.7V_n \dots\dots .6$

Where V_n represents the nominal voltage values of each phase

Outages/Interruptions Boolean algebra

To establish the logic expression for the three phase system, the truth table was developed with a low representing outage and a high for normal operation. The quality of supply was assumed to be within the normal operation range in developing the interruption Boolean expression.

$Y1 = ABCD' + ABCE' + ABCF'$………….. 7

Similarly, the outage Boolean algebra as obtained from the truth table is given by Boolean expression below

$Y1 = A'B' C'$ ……………..….. 8

Where the two set of output sensors {A,B, C} and {D,E,F} stand for R,Y and B Phases as monitored before and after the fuse (feeder pillar).

b) Software implementation of outage detection

Software detector continuously monitors the input trigger signal using the boundary set above (based on the PQ). Outage is determined from the response of the sensors. This is illustrated below in Table 1 with a 0 corresponds to the condition in equation 1.

Table 1: Using power supply quality in outage and equipment detection

Voltage before fuseV_1	Voltage after fuseV_2	Equipment	Remarks
0	0	J&P/shedding	Outage
1	0	Fuse	Phase-off
0	1	fuse open	Distributed Gen**
1	1	No fuse open	Normal state*

* Normal state but the following may require attention

** An abnormal situation when a phase is off and distributed generator feeding the line from the consumer end.

The upriser is tested for open circuit: The non-detection of current in the upriser cable as recorded by the current sensors suggests the presence of open circuit at the nearest node to the pole. This was implemented to address the problem associated with Nigeria EPDS. Table 2 illustrates the algorithm

Table2: Detection of open circuit fault in upriser cable

V_1	V_2	I_a	Fuse	Remarks
1	1	1	Close	Normal
1	1	0	Close	Upriser open

The outage detection method is broken down as follows:

a) Hardware implementation of outage detection

i). The transformer secondary phase voltage is monitored before and after the feeder pillar fuse using voltage sensor.

ii). The sinusoidal output signals of the sensors are rectified by full wave active rectifier.

iii) The zero crossing point is detected to trigger the microcontroller to initiate ADC operation of bandlimited signals.

iv). The RMS values the sampled signals are calculated.

c) Software restored detection

i). Software continuously monitors the input trigger signal after outage.

ii). The restored flag becomes true if electricity is restored.

HARDWARE IMPLEMENTATION

The hardware architecture as shown Figure 2 was based on the European standard (adopted for Nigeria) consists of three levels [9,10]. These are Process level, the Bay level and the Station level. The process level monitors the voltage on both the primary and secondary sides of the Substation Transformer as shown in Figure 4 and Fig. 5. Both transformer and Potential divider method served as the voltage sensor. A complete design of a Remote Monitoring System for Akure EPDS that comprises of the process unit, where the Network parameters are measured; the RTU where the harvested data is processed and used to take decisions for communication over the mobile Network to the DCC for diagnosis and analysis was considered. Since effective performance of remote monitoring depends on the sensing units, the design of this unit was addressed.

OUTAGE INFORMATION PROCESSING SYSTEM

Outage Information Processing System (OIPS) is software that installs at distribution control center. The software analysis the remote data based on the quality of supply as recorded by the sensors. The result is presented in graphic user interface

Field Implementation

The system was installed in Akure distribution network, Nigeria. The RTU monitors both the phase voltage and phase current using voltage sensors which consist of Voltage Transformer and Potential Divider while the current sensor is Rogowski coil. The Rogowski coil was chosen to overcome saturation and shunt capacitance effects that limit the applications of current transformer and shunt resistance respectively [12]. However, the output requires further processing using integrator and filters.

Remote Terminal Unit for Data Collection

The set-up for collecting data from the selected substation is shown in Fig. 6. The RTU detect interruption and communicate the DCC via text message. The DCC received the data for further analysis

Distribution Network Faults Log

According to [13] remote measurements can be obtained in three different ways. These are:

Cyclic polling, Polling on demand and Threshold trespassing.

Threshold trespassing was implemented because cyclic polling requires ubiquitous network which is expensive to operate in the environment under consideration using Mobile communication. Similarly, polling on demand involves two way communications which translates to additional transfer cost. The RTU also responds to outages and interruption by forwarding the data to the DCC OIPS software for further processing. To reduce cost of transfer, a page which contains 160 characters was used. Hence, the message format is presented in hexadecimal.

Diagnosis and Analysis

The data received from the RTU after processing produces the results presented in window forms as sown in Fig 7 to Fig. 11.

Case 1: The response of the system to outages is investigated in this experiment.

Received Data
$100173737400000161D2614080000000000000
00000000000000000C120C000F160F000D130D
00141D14000D130D001A261A

Case 2: The voltage on the primary side of the substation transformer was present but interruption was noticed in one of the phases.

Received Data
$100173737473737300161D2614080000000000000
00000000000000000C120C000F160F000D130D
00141D14000D130D001A261A

Case 3: The voltage on the primary side of the substation transformer was present but interruptions were noticed in two of the phases. The Diagnostic software receives the data and gives the result presented in Figure 7.

Received Data
$10017373747300000161D2614080000000000000
00000000000000000C120C000F160F000D130D
00141D14000D130D001A261A

Case 4: Phase Voltages are available at the primary and secondary terminal of the transformer but the upriser cable of one of the phases disconnected. The result is shown in Fig. 8

Received Data:
$1001737373737373001D2614080000000000000
00000000000000000C120C000F160F000D130D
00141D14000D130D001A261A

Case 5: No voltage on the primary side of the transformer
$100100000000000161D2614080000000000000
00000000000000000C120C000F160F000D130D
00141D14000D130D001A261A

CONCLUSION

Outage detector of substation in Nigeria Electric Power Distribution was implemented in Akure Distribution Network. In addition, the system was able to identify associated equipments by analyzing the state of the installed sensors. The hardware and software for outage detection performed to design specification and were not affected by the operation of both the primary and secondary equipment at the substation. The response of the system to outages or restoration of service was within 2sec. In contrast to the traditional outage detection, the system eliminates detection time, reporting and diagnosis time. The system ensures that outages are reported promptly and hence reduces the downtime.

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Figures:

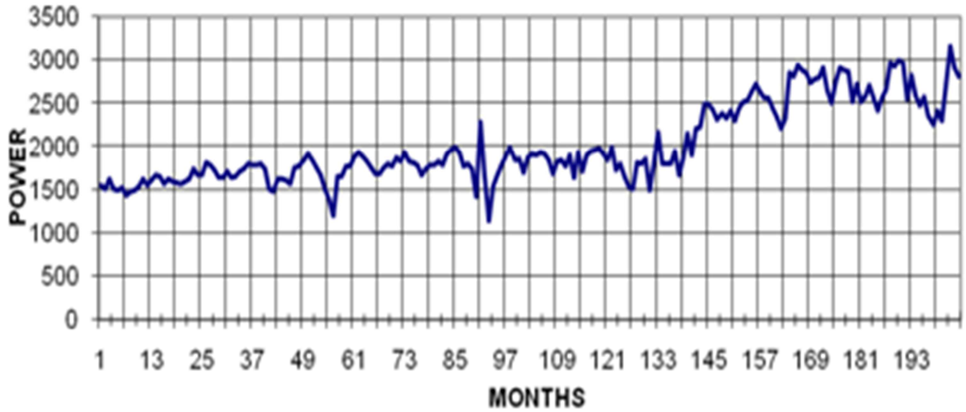

Figure 1: Generation Scenario in Nigeria

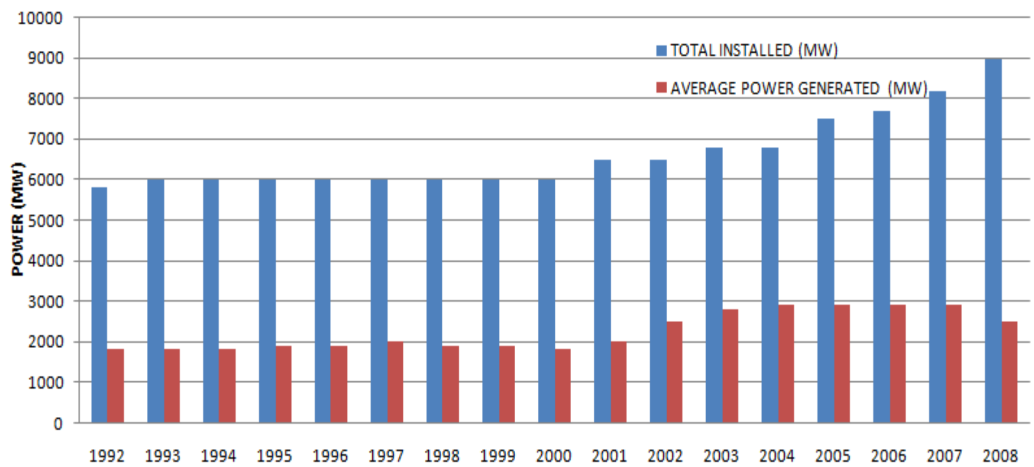

Figure 2 Average yearly Available Power Vs Total Yearly Installed Capacity

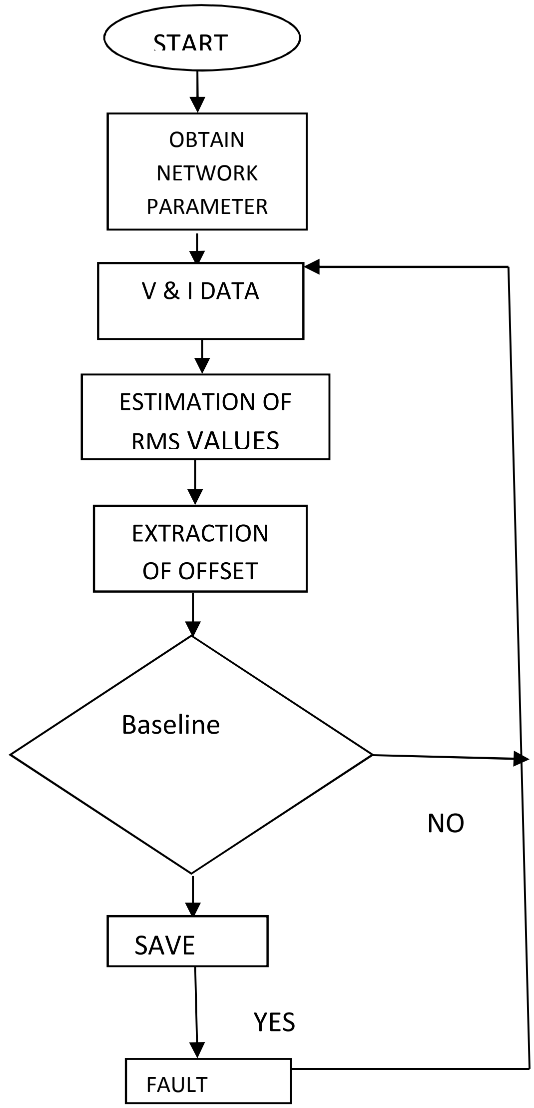

Figure 3: Flow Chart for Outage Detection

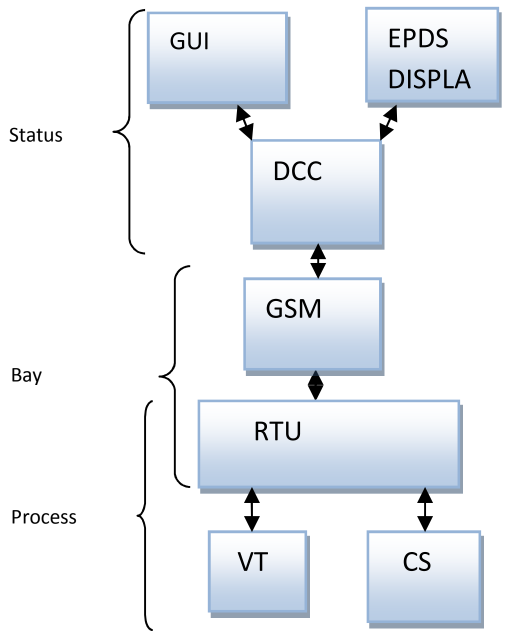

Figure 4: Block diagram of distribution network remote monitoring system

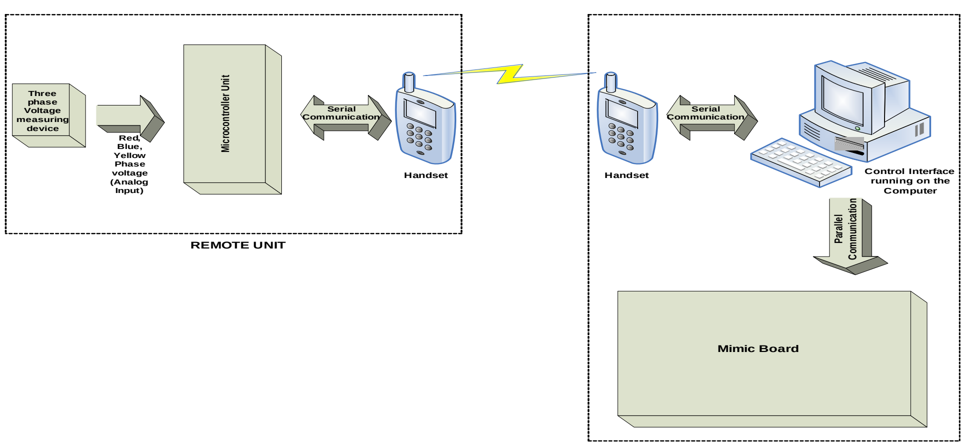

Figure 5 Outage Detection Architecture

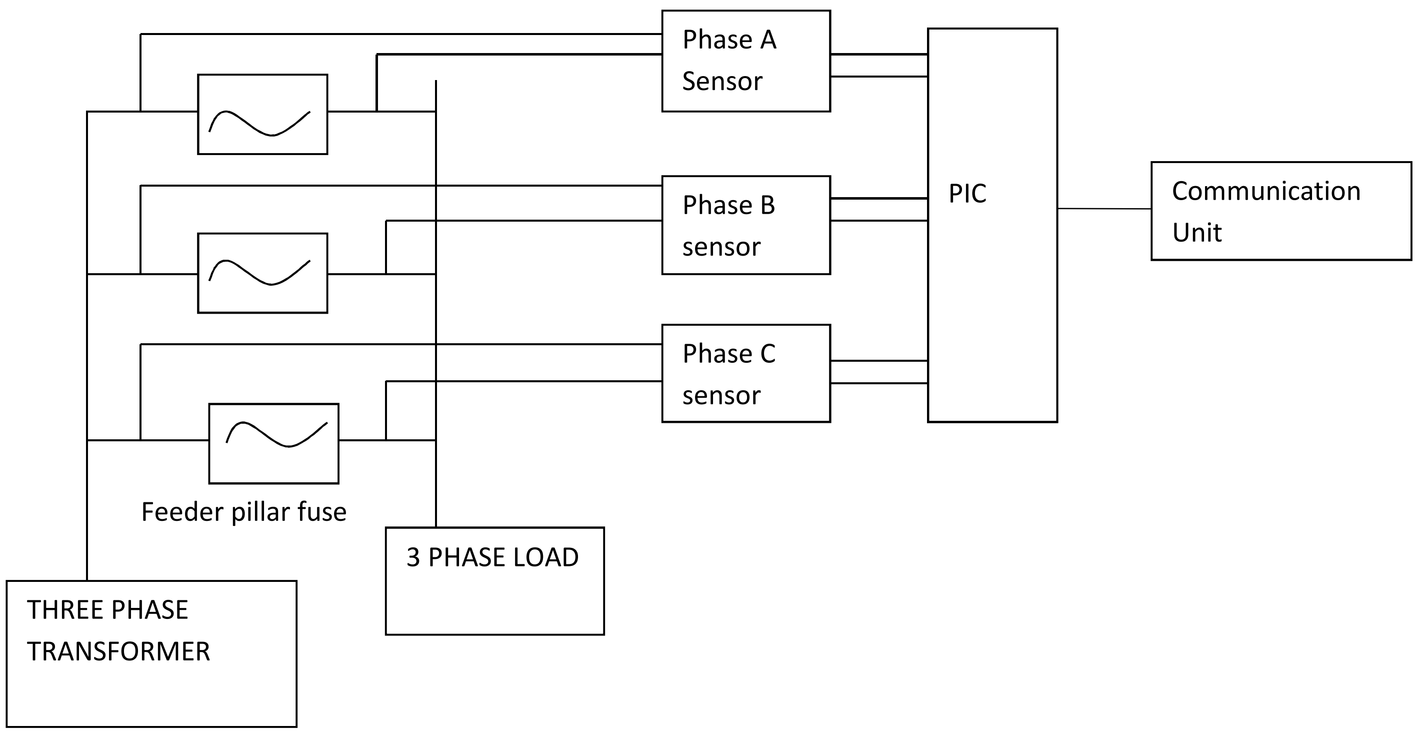

Figure 6: Block Diagram of Remote Terminal Unit

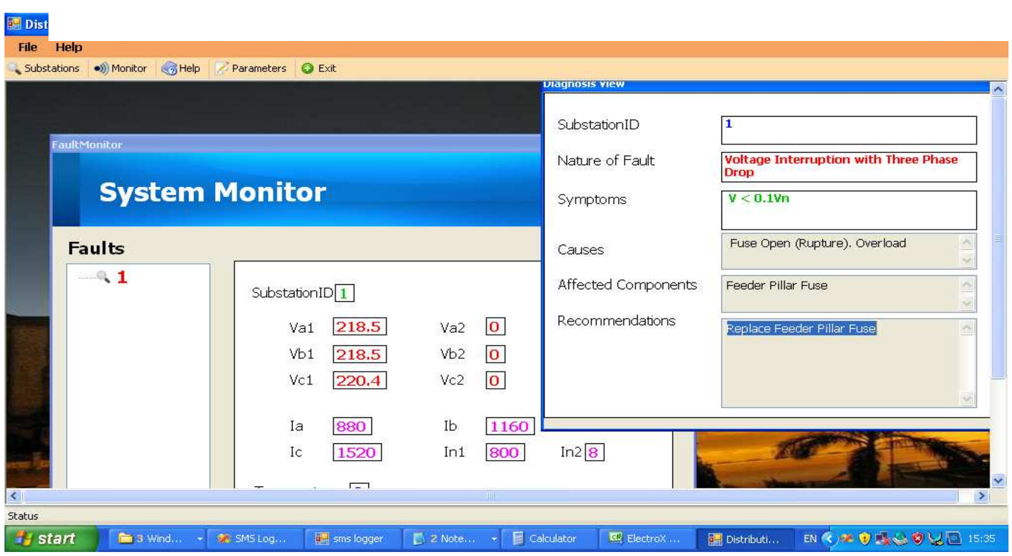

Figure 7: Interruption detection and diagnosis

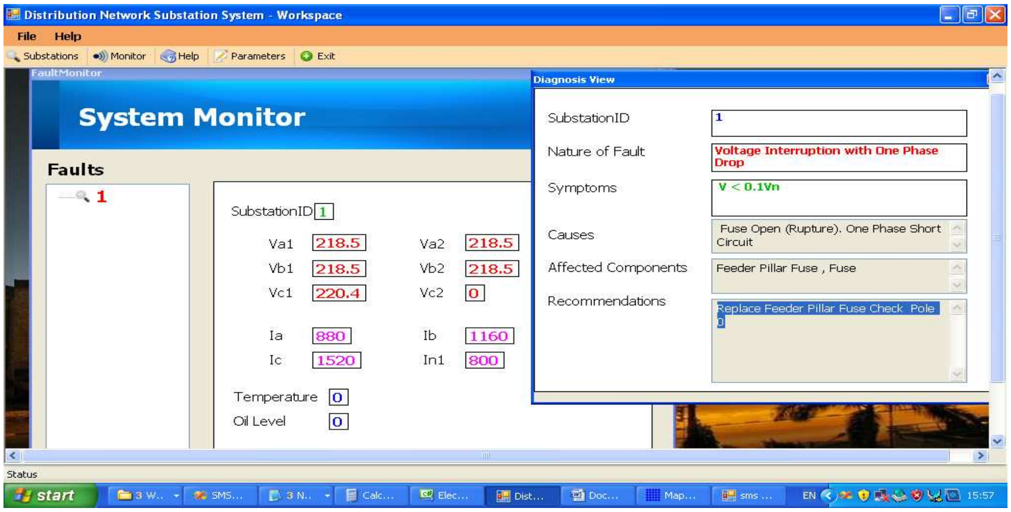

Figure 8: Interruption detection on one phase

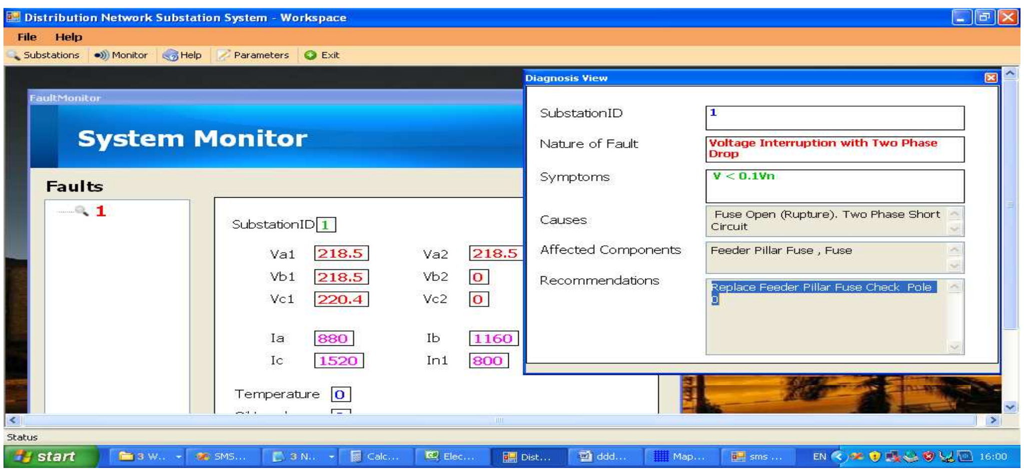

Figure 9: Voltage Interruption on two phases

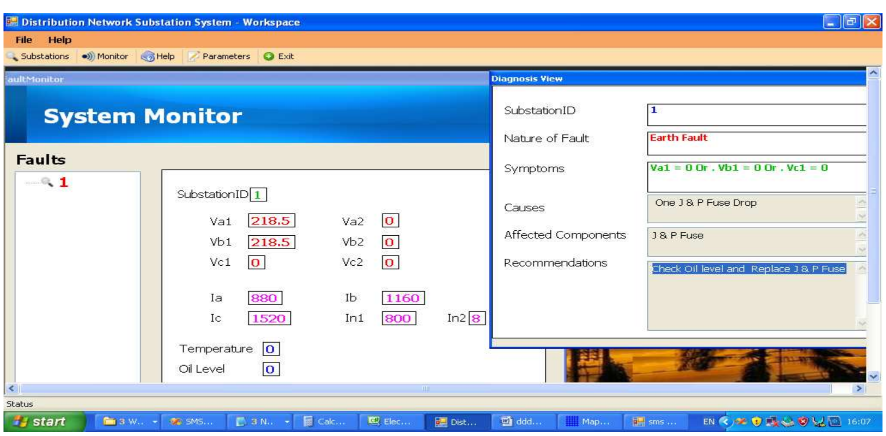

Figure 10: Open J&P Fuse

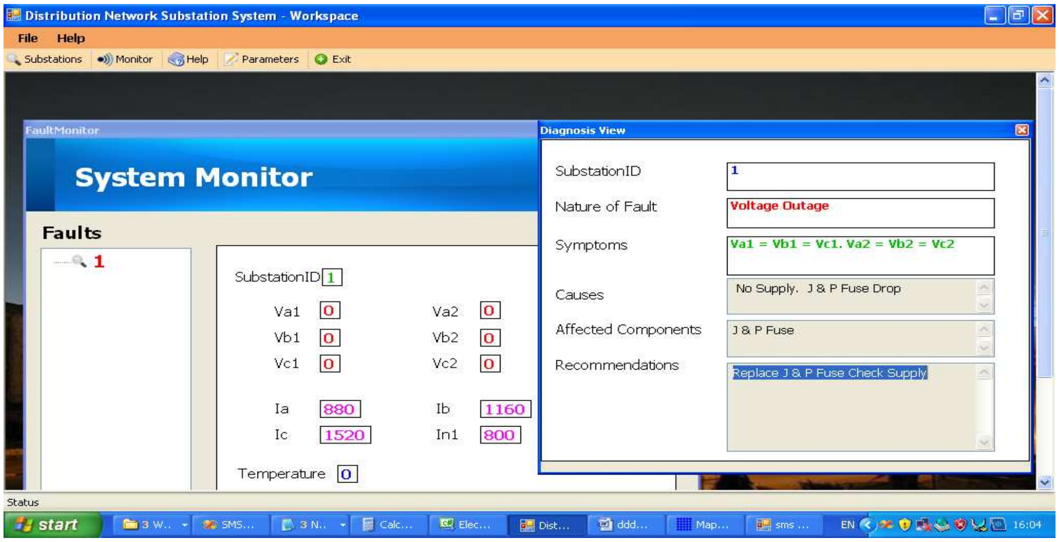

Figure 11: Outage