Innovative Systems Design and Engineering
ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)
Vol.4, No.8, 2013

Development of Substations Emulator for Akure Electric Power Distribution System in Nigeria

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Abstract
The paper describes the development of substation Emulator for Electric Power Distribution System (EPDS) in Nigeria using Akure as the case study. The line diagrams of Akure EPDS were transformed into a PC-based Distribution Network with each node representing the various substations. The geo-information attributes of these substations were captured and integrated with the digitized map of the network. To facilitate real-time data gathering, Remote terminal units were connected to the substations to monitor the status of the substations using threshold passing algorithm and communicate the distribution control centre whenever changes are observed. The information is used by the developed engineering software to update the digitised network. The system provides the opportunity to study the dynamic behavior of Akure EPDS
Keywords: Current, Electric Distribution, Distribution Automation and voltage

1. Introduction

The demand for electric power is on the increase in Nigeria, particularly in Akure since the city became a state capital. This has resulted in considerable increase in the number of substations and distribution lines in operation. However, Electric power distribution is an important function of electrical power systems in the delivery of electricity to consumers but experience faults more often than the faults experienced by other power system facilities [1] as experienced by distribution networks in Akure occasioned by wind storms, lightning, rain, insulation breakdown, overloading and short circuits. This is not unconnected with the fact that the distribution systems have generally grown in an unplanned manner.[1] [2]. According to [3], the Nigerian electric power distribution system (EPDS) as a developing one is horizontally characterized by very long radial circuits, under sized distribution conductors and numerous other factors that affect reliability. In Akure, the power distribution network consists of a number of distribution substations located over a vast geographical area. Associated with efficient power delivery in Akure EPDS is the type of topology deployed, protection equipment in-use coupled with maintenance and repair response. Issues involving reliability and availability are therefore very important in the assessment of networks. To improve the performance of the EPDS, automation of monitoring and diagnosis needs to be widely adopted. 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 [4]. Consequently a spatially distributed system such as an EPDS can be better appreciated by operations personnel when provided with a visual aid representing its condition. In this regard, a relational digital map of the locality can play a very important role in clarifying and providing a prompt and concise summary of the system condition at any given time. Real-time data gathering is essential for the efficient management of power distribution. The wide spread use of global system for mobile communication (GSM) [5] with provision for short message service offers a possible solution for linking between remotely located distribution equipment and the control center.

1.1 Review of PC-Based Distribution System

Electricity Distribution Networks are normally spread over large geographical areas corresponding to the dispersion of the consumers. Such distribution networks consist of a large number of similar elements that facilitate the delivery of the energy to the user. To keep up-to-date information about the dynamic behavior of this complex system, technology deployment is the only visible solution. Therefore, to an operations engineer, feeding visual aid representing some or all of the features of the network is indispensable. Such an aid may include one line diagram, animated graphics and in the limit closed circuit images. Most of the existing systems employ simple schematic one line diagrams with the status of the substation being represented as an object which may be a lamp or an entity in a software managed graph. Herrell proposed a method of modeling of distribution systems in PCs.[6]. Wainwright presents an electric power distribution Geographical Information System (EPDIGIS) as a major program of network information data capture at all voltage levels. Xing Weiguo et al [7] (2003) presented a report on a proposal for a PC-based visual aid for electrical power distribution system. When this is integrated with the GIS it provides the positional attributes of the equipment in the network. A GIS system contains a model of the circuit topology. It is a computerized tool for capturing, storage, checking, integrating, manipulating, analyzing and displaying of geo-information [8]. According to [9], the ever increasing numbers of subscribers to the services of electricity call for the re-engineering of the electricity distribution strategy using the appropriate technology – GIS

1.2 The Structure of Akure Electrical Distribution Networks

Akure EPDS consists three 33/11 kV injection stations which are described as follows:

(a) Six 11kV feeders which are fed by two 15 MVA transformers supplying power to the main city. The feeders are Ijapo, Ondo road, Oyemekun, Oke-eda, Ilesa road and Isikan.

(b) Two 11 kV feeders connected to 15 MVA transformer serving Obale and Alagbaka.

(c) A 7.5 MVA transformer dedicated to the Army cantonment, Akure.

1.2.1 Development of Line Diagrams of Akure EPDS

A distribution network System is a collection of circuits consisting of primary stations, 11kV feeders, hundreds of substations (distribution), hundreds of switching stations and thousands of overhead poles all linked via switches and overhead lines or cables [10]. The development of line diagram for Akure was developed on the information obtained from the Utilities-PHCN using the standard symbols. The diagram defines the interconnection of the injection stations to the 11kV feeders which convey power to the 11kV/0.415kV substations. The line diagrams for the entire network were developed. Figure 1 illustrates the transmission station while atypical feeder is shown in Figure 2

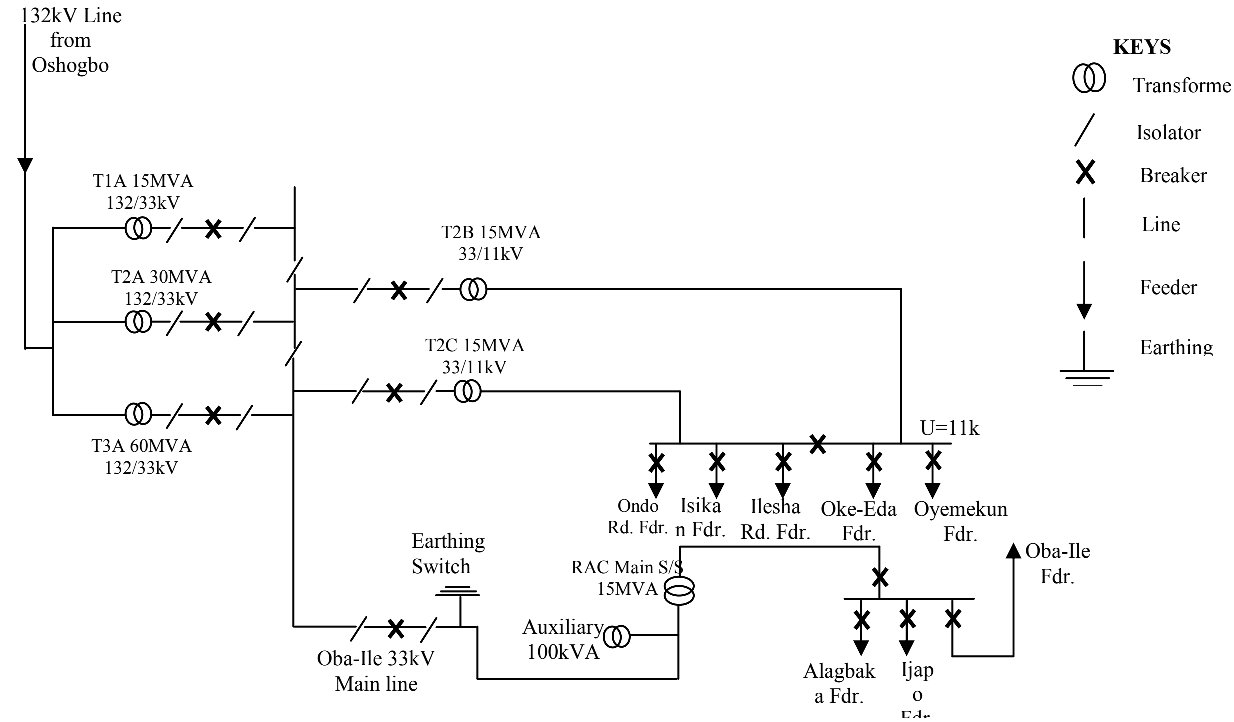

Figure 1: Schematic diagram showing 132/33/11kV network in Akure district

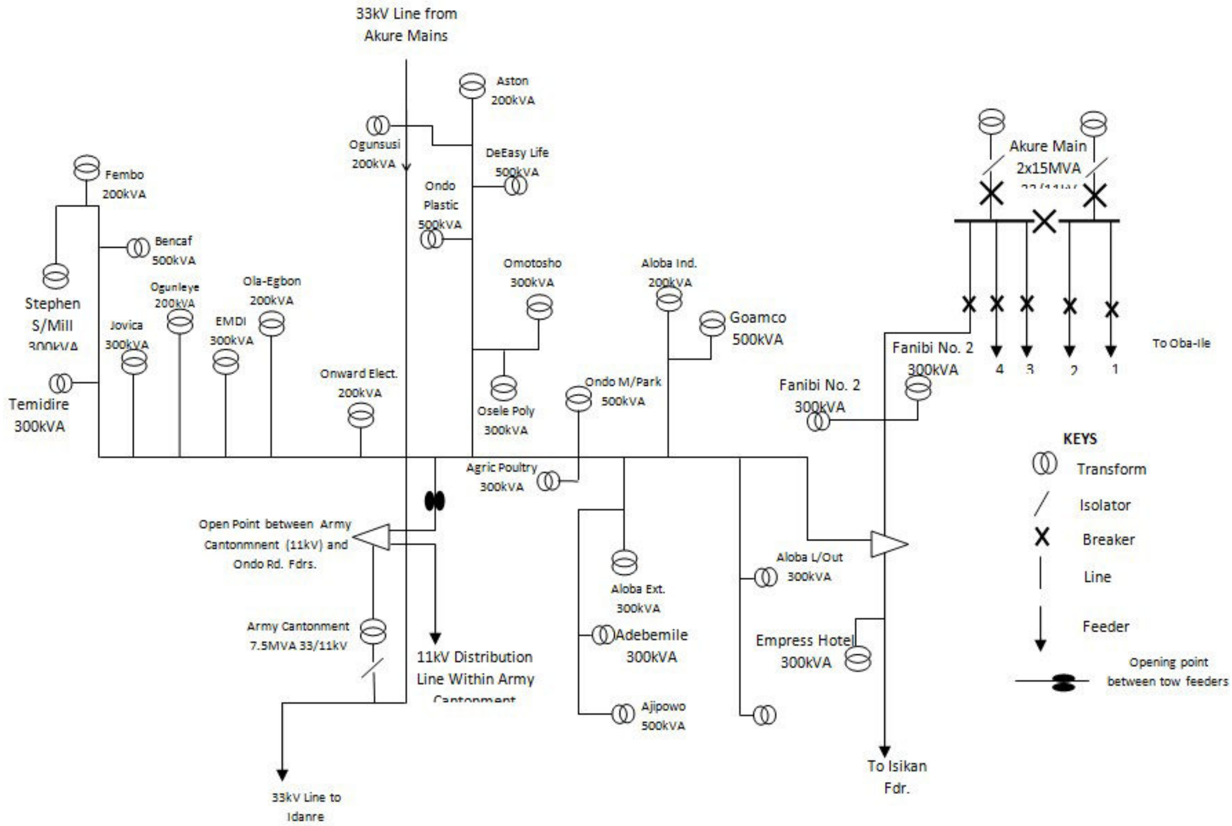

Figure 2: Ondo Road 11kv feeder network diagram

Summary of 11/.415 kV substation for Akure is shown in Table 1

Table 1: Analysis of Akure EPDS Feeders

11kV Feeder Description	100kVA	200kVA	300Kva	500kVA	Number of 11/0.415kV Substations	Total allowed Substations	ID number
Oke-eda road	2	7	10	12	31	255	000-FF
Oyemekun road	3	4	8	7	22	255	100-1FF
Ilesa road	3	8	15	11	37	255	200-2FF
Isikan	1	3	6	13	23	255	300-3FF
Ondo road	1	7	13	6	27	255	400-4FF
Ijapo	1	14	8	3	26	255	500-5FF
Obale	1	1	5	5	12	255	600-6FF
Alagbaka	12	19	11	12	54	255	700-7FF

1.2.2 Digitisation of Akure EPDS

According to [9], the ever increasing numbers of subscribers to the services of electricity call for the re-engineering of the EPDS using the appropriate technology – GIS. The procedure includes:

a) data acquisition phase
b) data Processing Phase
c) database design and implementation
d) implementation of Substation emulation

The geometric data was acquired using ANTARIS 4 GPS Receiver. The GPS was placed at the substations to capture the longitudes, latitudes and the altitudes (geometric attributes). The PC-based EPDS - EDMS was developed using C# and using Microsoft window as the external data storage. Graph is a collection of interconnected nodes -was modeled using line diagram developed for Akure EPDS. Each node in the graph holds substation records.

1.3. Integration of Distribution Automation System

Real-time updating of the developed emulator was made possible through the integration of the PC-based EPDS with Distribution Automation System (DAS). The DAS was developed using the European standard which consists of three levels as shown in Fig. 3 [11,12]. These are the Process level where the voltage and current are measured. Whenever the threshold window is crossed an error text message is sent from the Bay level at the Remote Terminal Unit (RTU) and the station level at the Distribution Control Centre (DCC) for diagnosis and updating the affected substations.

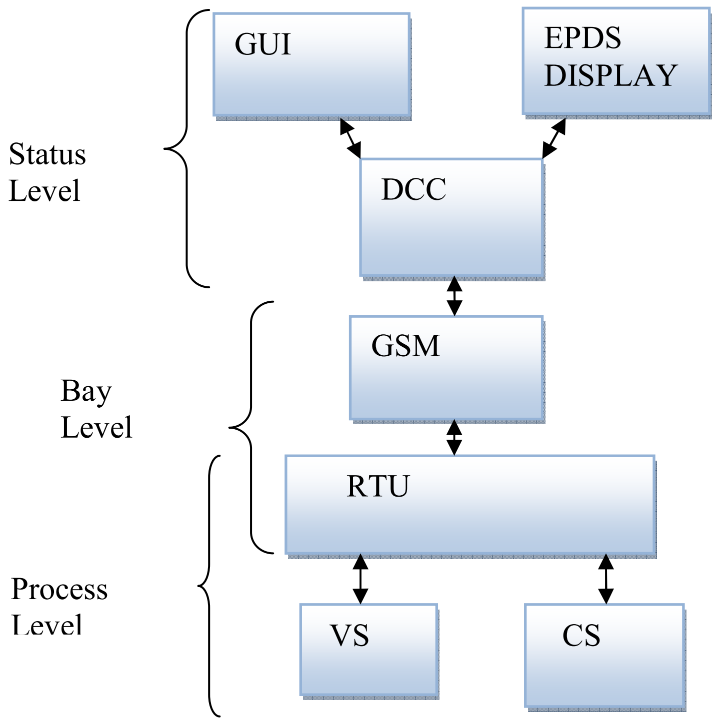

Figure 3: Block Diagram of Conceptual Distribution Network Remote Monitoring Model

Where:

CS- Current Sensor, VS- Voltage Sensor, GUI- Graphic User Interface. RTU- Remote Terminal Unit, GSM- Global System for Mobile Communication, DCC- Distribution Control Centre.

The general Architecture for the real-time gathering of substation data which include terminal current and voltage is shown in Fig. 4

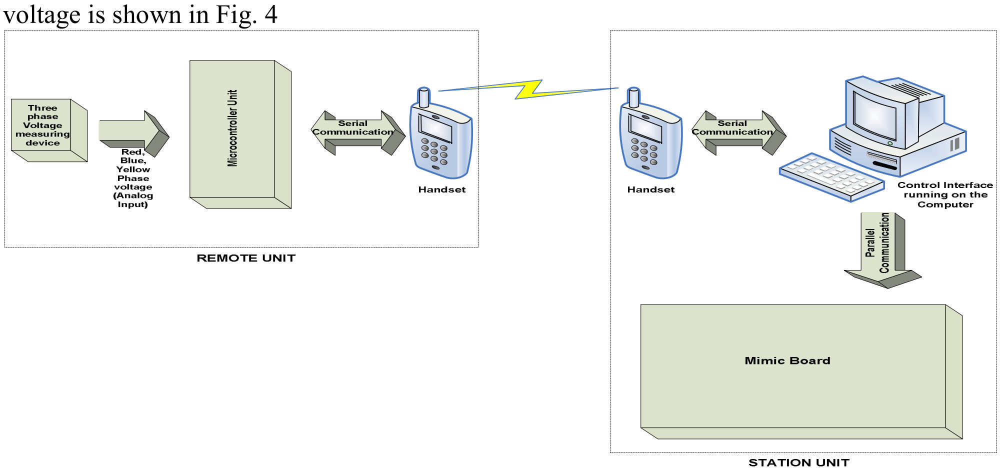

FIGURE 4: Architecture of System Emulator

1.3.1 Design of Instrumentation Units

The design of process Unit where two variables are monitored is considered in this section. The effectiveness of the entire monitoring system depends on the process unit. Sensors were developed for two variables, namely phase voltage and current.

a) Current Sensing Unit

Rogowski current transducers comprise a Rogowski coil, integrator, analogue filter and ADC (Figure 5). The coil is connected to the integrator by a co-axial cable to reduce interference. Rogowski coil processes some attributes suitable for the work which include: non-saturation and simplicity [13]

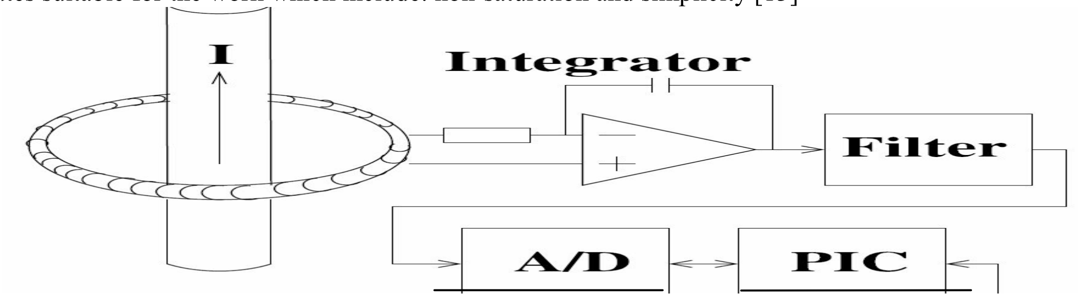

Figure 5: Current instrumentation block diagram

The construction of circular cross-section sensing winding is shown on the Figure 6.

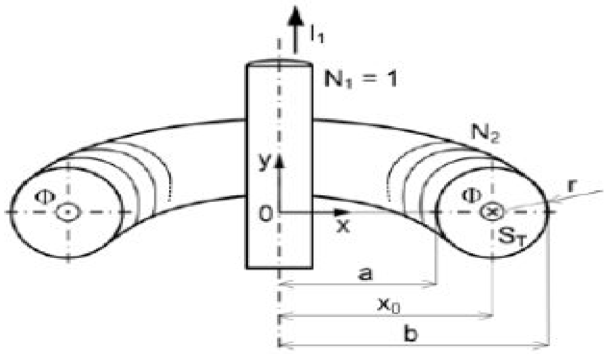

Figure 6: Circular Cross-Section Toroid

According to [13],mutual inductance M_{21} between the sensing winding N_2 and the conductor with measured current I_1, in arrangement according to Figure 6, is:

$$M_{21} = \frac{\mu_0 N_2}{2(a + b - 2\sqrt{ab})} \quad \ldots (1)$$

While the self inductance L_2 of the sensing winding with circular cross-section of the toroidal core is:

$$L_2 = \frac{\mu_0 {N_2}^2}{2(a + b - 2\sqrt{ab})} \quad \ldots (2)$$

and the Impedance magnitude of sensing winding N2 is calculated by:

$$Z = \sqrt{(R^2 + (wL)^2)} \quad \ldots (3)$$

Where μ_o is the permeability of the free space, taken as $4\pi x10^{-7}$ and M is taken as 400nH.

The geometric characteristics of the circular cross-section Rogowski coil obtained from the equations above for the construction are given in Table 4.1. A coaxial cable of length 50cm was stripped of the outer insulation. A 24 SWG copper conductor was connected to the solid copper at one end of the coaxial cable. The copper conductor was wound on the cable based on the parameters obtained and shown on Table 2. The end Bends over and laid into a loop.

Table 2: Rogowski coil parameters

Coil Parameters	Specification
Inner diameter	12cm
Outer diameter	16cm
Self inductance	22MH
Mutual inductance	18 MH
Resistance	2.8Ω
Number of turns	600
Length of coil	10cm

The output voltage of the coil is integrated and lowpass filtered to obtain the current flowing through the conductor. The output of the integrator is expressed by equation 4

$$i = v_{out} = \frac{1}{R_1C_1}\int E_{in}(t)dt \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

The transfer function for the integrator is given by Equation 5.

$$\frac{V_{int}(s)}{E(s)} = \frac{R_2}{R_1(R_2C_1\ s+1)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (5)$$

High frequency effects of the Rogowski coil are not significant at the frequencies of interest and are removed by a low pass filter. The filter is a two-pole active filter Butterworth filter. The integrating pole is placed at *0.3Hz* and the active filter poles are placed at *160Hz*. This design gives a bandwidth of 0.3 Hz < *f* < 160 Hz with a magnitude error of less than 1.5%, and a phase error of less than 10°. At 50 Hz the magnitude error is less than 0.3%, and the phase error less than 4°.

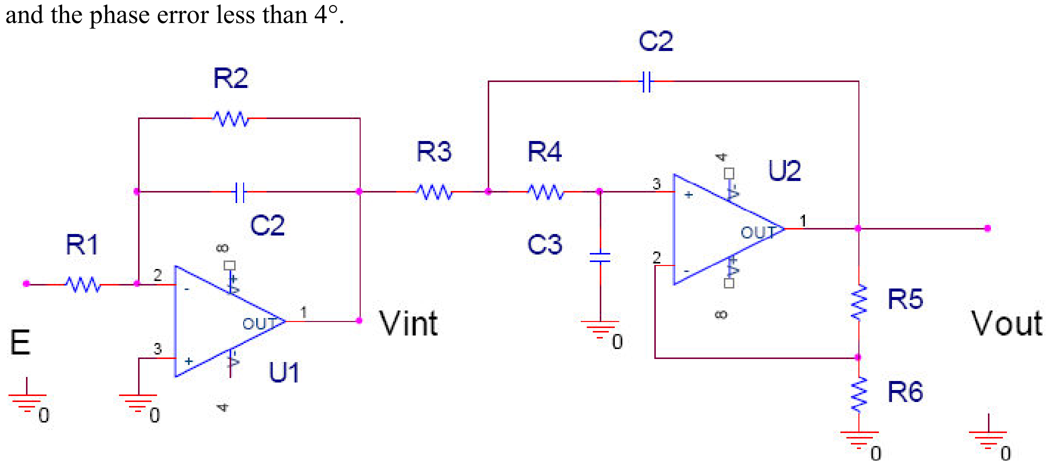

Figure 7: Current Processing circuit diagram

b) Voltage Sensing Unit

The combination of potential divider and voltage transformer was used for the sensing unit of the voltage instrumentation units. The transformer provides galvanic isolation. Two sensors were installed per phase given a total of six sensors. The phase voltage on both ends of the protective device was monitored continuously to detect the response of the protective device to disturbance on the LT side of the transformer. In addition, the sensors also response to changes on the HT side of the transformer. The output voltage of the device is expressed by equation 9.. The advantages of this method compared to using magnetic VT's. include: .Non saturable; Linear and Small and lightweight. [14]. Fig. 8 shows the Potential divider arrangement.

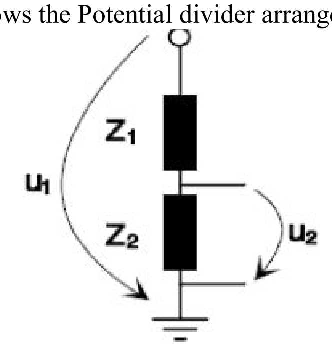

Figure 8: The Principle of the impedance voltage divider

$$U_2 = \frac{Z_1 U_1}{Z_1 + Z_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

1.3.2 Remote Terminal Unit (RTU)

The block diagram of RTU is shown in Fig. 9. This includes ADC, the communication unit, microcontroller and external memory. The microcontroller ADC was used. The microcontroller receives the analogue signal from the instrumentation units and calculates the rms values for voltage and current channels. The values are compared to the preceding cycle to establish if fault has occurred. This unit also perform arithmetic algorithm based on the outage detection algorithm using the quality of power supply to the consumer as monitored at the substation to establish outage and interruptions

4.4.2 Arithmetic Using Microprocessor

Three phase voltages and currents are fed to RTU from Current Instrumentations and PTs at the substation's terminal of the feeder. These voltages and currents are instantaneous values, and the effective value was made from this instantaneous value using RMS arithmetic method at RTU.

$$V_{rms} = \sqrt{\frac{\sum_{i=0}^{N} {V_i}^2}{N}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (7)$$

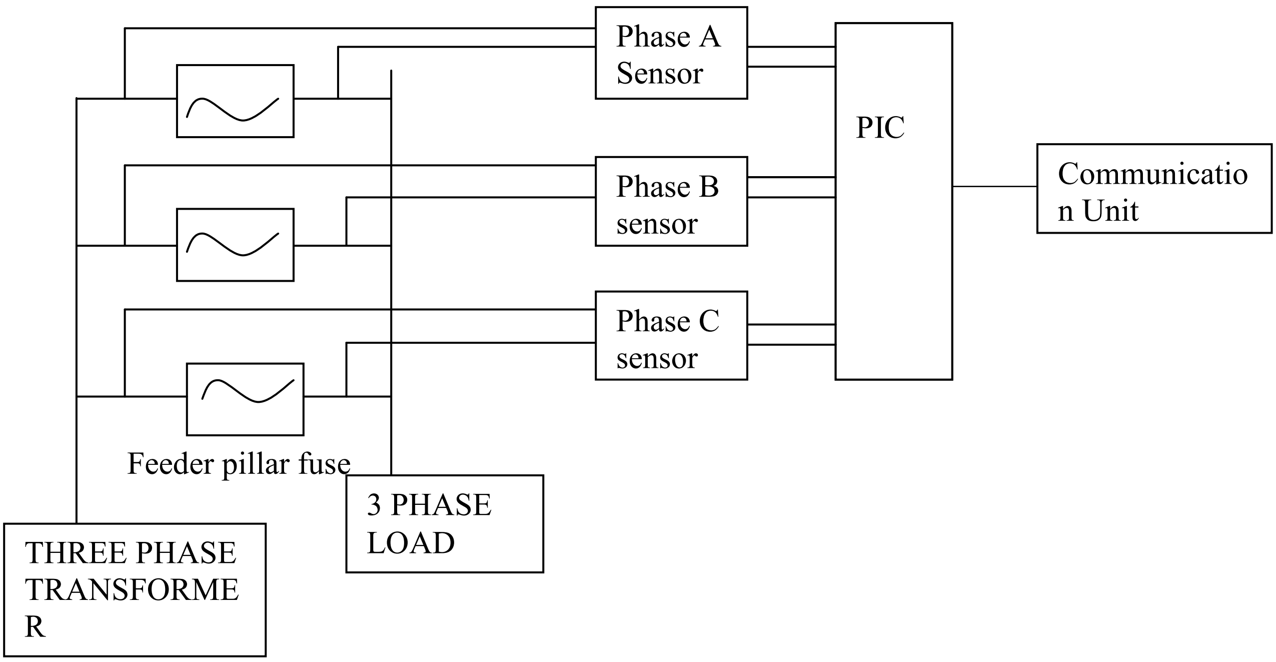

Figure 9: Block Diagram of Remote Terminal Unit

1.3.3. Choise of Communication Link between RTU and DCC

The choice of which of the GSM operators to be considered depends on some factors:

a) SMS Rate (bulk)
b) Network coverage
c) Teledensity
d) Growth Rate

The Telecoms providers in Nigeria with which include operators on fixed wired/wireless CDMA platform as shown in Figure 10

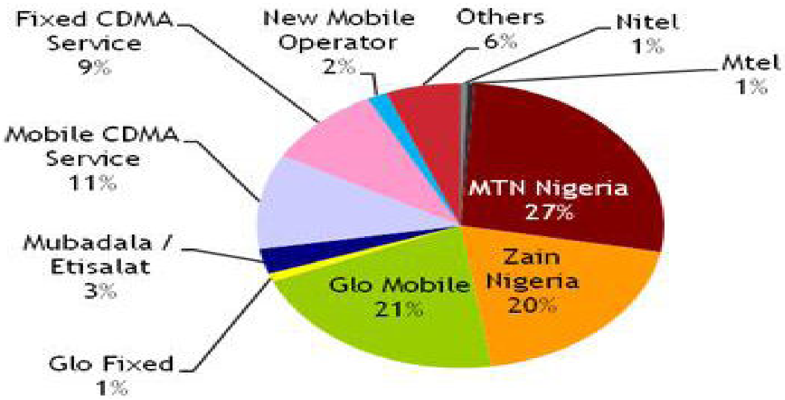

Figure 10.: Telecommunication providers' distribution in Nigeria

1.3.4 Substation Health Status Determination

Using threshold passing algorithm, the status of each substation is remotely determined. The measured voltages and currents are fed into the algorithm to establish a faulty or healthy state. The result of the status is sent to the distribution control centre (Station Level) where the developed engineering software accepts it for analysis and EPDS Emulator updating

1.4. EPDS Emulator Implementation

For normal operation, the substation state of health stays green (healthy state) while abnormal status changes to red. The system was developed through a system based on hardware/software that monitors the data received from the remote terminal units. A change in the status from a low to a high simulates the required change on the map base on the substation identification. A typical feeder is shown in Figure 5.20. The substations in green stand for those operating normally while those in red are faulty.

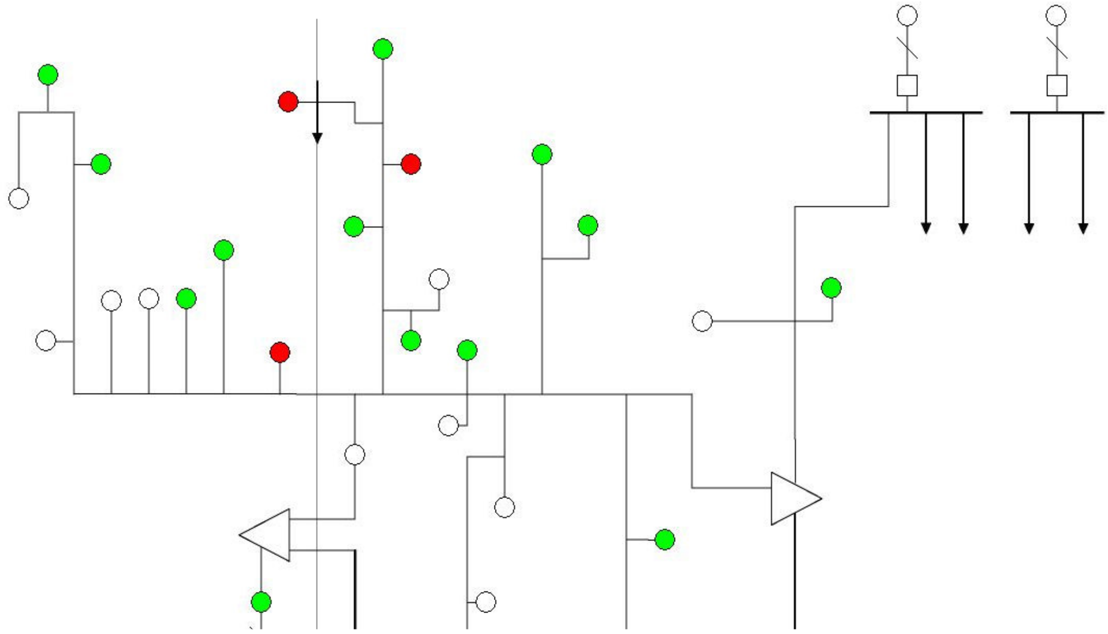

Figure 11: Emulation of Ondo Road 11kv feeder network diagram

1.5. Conclusion

The visual tracking of the wide spread substations in Akure EPDS was made possible by the developed emulator which gives up-to-date information about the status of all the substations. This was achieved by transforming the line diagrams of the network into a PC based distribution network integrated with the geo-information attributes of the substations. The implementation of DAS provides the platform for remote harvesting of the network quantities that were used to update the map. Hence, the system dynamic behavior was investigated in real-time. The response of the system to changes in the Network was also considered in the design objective resulting in updates of the map every 2 sec

References

[1] H.A Boknam, S. PARK, C. SHIN, S. KWON and S. PARK,'' Power Quality Monitoring on Distribution Network using Distribution Automation System'', 19th International Conference on Electricity Distribution Vienna, Paper 0426,2007
[2] B.L Theraja., A..K.,Theraja''A Textboobook of Electrical Technology', ,S.Chand Ltd 24th Edition 2008.
[3] E.A. Ogujor, P. Otasowie and P.A Kuale, ''Fault Analysis of Electric Power Distribution in Benin City'', Journal of Electrical and Electronic Engineering vol 10, pp 27-34, 2006
[4] McDonald J. D., "Substation Automation: IED Integration and Availability of Information", IEEE Power and Energy Magazine, pp. 22-31, 2003.
[5] Nigeria Communication Website, www.ncc.nig.com , 24th June, 2008
[6] R. P. Gupta, and S. C. Srivastava, "Technology Development and Implementation for Power Distribution Automation", Water and Energy International Journal, Vol. 61, No. 4, pp. 40-47, 2004
[6] K. Brand, V. Lohmann and W. Wimmer, "Substation Automation Handbook", Utility Automation Consulting Lohmann, Bremgaten, Switzerland 2003
[7] Y Liu., R. A Discher., N.N. Schulz (2002), "Distribution system outage and restoration analysis using a wireless AMR system," in proc. IEEE Power Engineering Society Winter Meeting, vol. 2, pp.871-875, 27-31.
[8] N. Guven N. Oza. And E. Tunah (1996)., "GIS based outage analysis system for electric distribution networks," in proc. IEEE MELECON '96 Electrotechnical Conference, vol. 2, pp. 761-764, 13-16.
[9] S.S. Olaniyi Electricity Distribution Engineering and Geographic Information System (DeGIS) in Nigeria''. XXIII FIG Congress Munich Germany, October 8-13, 2006
[10] Glover J. D., Sarma M. S., (2002), Power System Analysis and Design. Third Edition. USA: Brooks/Cole Thomson Learning, p. 608-610
[11] IEC 61850, ''Communication Network and System in Substation'', ''Communication Networks and System in Substation'', Part 1, IEC 61850, 2003.
[12] R.P Pandey and N. Srivastava "Data Communication Architecture using IEC 61850 Protocol for Substation Automation", in the proceedings of International Conference on Distribution India, pp 113-121, 2004
[13] D. Estra1da, I.I. Maria and S.A.R. Macau, ''China Distribution Automation over Power Line Carrier Communication System'' in Macau 2008
[13] G. D'Antona,, E. Carminati, M. Lazzaroni, R. Ottoboni, and C. Svelto, "AC Current Measurements Via Digital Processing of Rogowski Coils Signal", Proceedings of the 19th IEEE, vol. 1, pp. 693-698, 2002.
[14] N. James, ''Control and automation of electrical power distribution systems'', CRC press Boca Raton, , pg292, 2007

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