

CHAPTER 29

Intelligent SCADA Based Monitoring Scheme for Low Voltage Distribution System

Abdullateef Ayodele Isqeel^a and Momoh Jimoh Eyiomika Salami

Department of Mechatronics, Faculty of Engineering, IIUM

^aabumukhtar2000@yahoo.com

29.1. Introduction

The demands for electricity for industrial and domestic purposes have increased rapidly since the middle of the last century because of industrial developments and expansion in population growth (Figure 1.1). Consequently, power utilities in various countries have attempted to bridge the gap between the demand and supply of electric power to the consumers. Most of these power utilities have shown concern for these challenges particularly the increase in power generation and optimization of distribution networks.

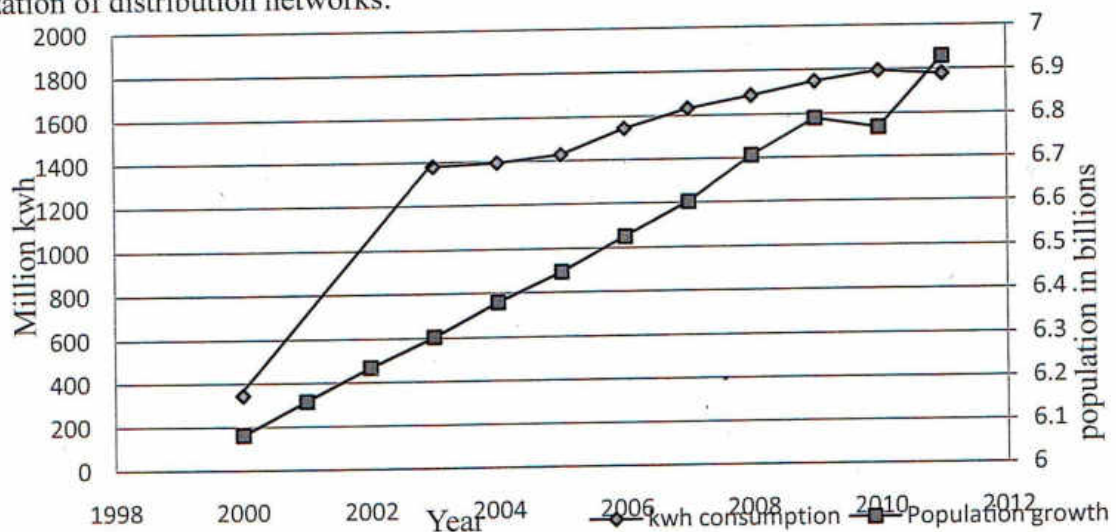


Fig. 1 World electricity consumption in (Million KWh) and World population in billion.

Distribution network is very significant in power delivery to the consumers, since it is the end link to the consumers, thus, it is essential to regular electric power supply. Unfavourable conditions would therefore affect power system operations and income generated by these utilities. Effective management of these distribution systems for continuous regular power supply is very essential for various reasons such as socioeconomic of a nation.

Generally, there are medium and low voltage distribution networks in a typical Power distribution system (Figure 2). Typical low voltage distribution systems include transformers, fuses, distribution lines and the consumer-end load, which is indicated in energy meter readings while medium include transformers, switches, isolators and distribution feeders.

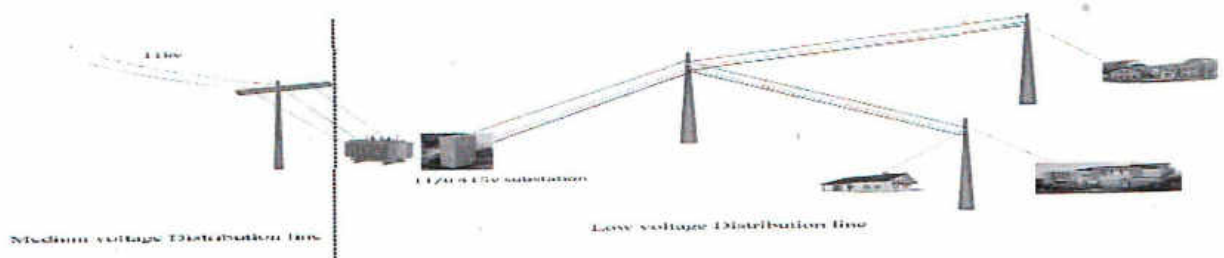


Fig. 2 Typical distribution system networks.

These distribution components serve different purposes in the distribution network. Transformer is the core and the most expensive equipment in the power system, therefore, it needs to be monitored and kept in good condition at all times, in order to prevent it from break down. Its effective operation is essential to network security, stability and reliability while its failure impedes the proper operation of the power system. In some cases, the transformer experienced fatal development such as burnt due to lack of monitoring (Figure 3). Previous studies show that monitoring and control is evident in studying the composition of the oil, oil temperature and vibration of the transformer. Besides the faults associated with transformer, the distribution feeders equally share a sizeable percentage in factors affecting power distribution system. Distribution feeders, overhead or underground, connect the substation with the consumers, thus activities on the network is necessary for onward power delivery.

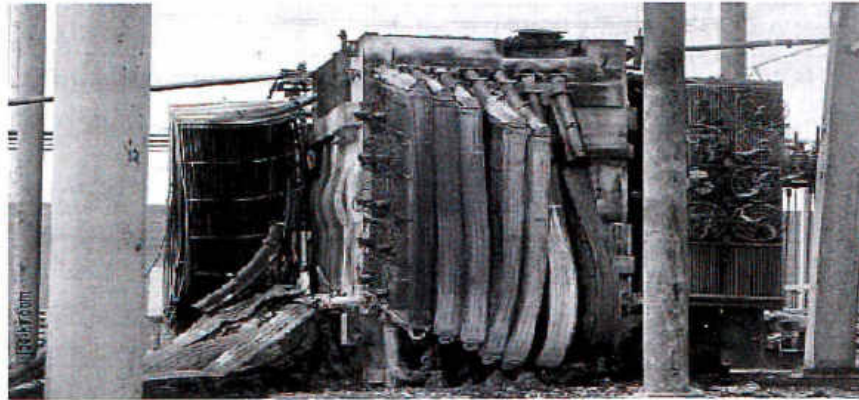


Fig. 3 Burnt transformer.

Common faults on the network include short circuit fault and open circuit fault, which generally hinder effective power supply to the consumers. The mode of fault detection, identification, and isolation is conducted manually via the use of phone calls, and physical presence of service personnel, however, these approaches are slightly slow, tedious, time consuming, labour intensive and are not suitable for real time operation. Moreover, quick detection, identification and isolation of faults done in real time will enhance power restoration process and hence, better operational service.

The consumers as well as the vendor can monitor the amount of power consumed with energy meters, which are installed at the consumers end and the amount of electricity consumed are read and recorded by a large number of operators who takes longer time to accomplish the task . Furthermore, the data recorded are not accurate, due to human error, and sometimes, the energy meter located at remote and inaccessible areas are left out. Similarly, other consumer-related interference, which includes electricity theft, such as billing irregularities, illegal connections and meter tampering, has, consequently, reduce the amount of income generated by the utilities.

Thus, there is need to monitor and control the low voltage distribution system in real time for enhanced services and optimum power delivery through the application of modern technology.

29.2. Existing System

The connection of distribution networks is generally overhead, where the conductors are wired from the substations via poles of different types to the consumer end and the network monitoring is usually carried out manually. However, this method of monitoring impedes regular power supply due to non-availability of real time performance and information about the components, such as transformers on the network. Without appropriate real time data, operational planning, such as maintenance, power restoration and fault detection, will be difficult. Consequently, this leads to increase in system losses and electricity theft such as meter tampering, and illegal connection, which affect revenue generation, and the power quality on the network and in addition, increases incessant power outage (Table 2.1).

Table 2.1 Revenue Losses Due to Electricity Theft in some Countries

USA Houston 2010 60 to 70 % of the meters have been tampered	\$6 bn	Electricity theft: Dangerous trend that's costing honest Houstonians money by Jeff McShan / 11 News khou.com Posted on April 29, 2010 http://www.khou.com/news/crime/Electricity-theft-a-dangerous-trend-thats-costing-honest-Houstonians-money-92450694.html
USA Florida 2009	\$1bn-\$2bn	Tampa Bay area sees rise in electricity theft cases By Kameel Stanley, Times Staff Writer In Print: Sunday, March 29, 2009 http://www.tampabay.com/news/publicsafety/article987938.ece
Canada 2010	\$100m	Electricity theft by B.C. grow-ops costs \$100M a year <i>Last Updated: Friday, October 8, 2010</i> http://www.cbc.ca/news/canada/british-columbia/story/2010/10/08/bc-hydro-grow-op-theftw.html
Malaysia Sabah October, 2011	1%=RM11m RM150.48m	Sabah Elecctricity Sdn Bhd reduces it electricity theft loss to 13.68% http://www.bernama.com.my/bernama/v5/newsindex.php?id=617926
2010	RM500m	Tenaga Nasional Berhad (TNB) Cheng N.Y, Zuhrein A.A &Raman A. TNB losing RM500mil a year to electricity theft The Star Newspaper, Malaysia(2010 December, 31).
2004	U.S.\$229 m	Tenaga Nasional Berhad (TNB), (Nagi, et al., 2010)
Venezuela 2005	US\$7m	Electricity theft cost govt US\$7mn in lost taxes last year Wednesday, November 23, 2005, http://www.bnamericas.com/news/electricpower/Electricity_theft_cost_govt_US*7mn_in_lost_taxes_last_year
South Africa 2008/09	R2.5bn- R3.6bn	R4bn lost to electricity theft Mar 23 2010 http://www.fin24.com/Economy/R4bn-lost-to-electricity-theft-20100323
	R4bn	Gauteng has highest rate of electricity theft Eskom http://www.environment.co.za/south-africas-energy-crisis/gauteng-has-highest-rate-of-electricity-theft-eskom.html
Swazi	E136 m	SEC losing E136 million through theft of electricity 07 September, 2011 10:29:00Stories by Teetee Zwane http://www.observer.org.sz/index.php?news=29445
Dominican republic Santo Domingo	US\$50m	The rich and poor steal US\$50M in electricity http://www.dominicantoday.com/dr/local/2011/6/15/39894/The-rich-and-poor-steal-US50M-in-electricity
Lebanon	LL 250 bn	Beyond repair? Zahra Hankir, NOW Staff http://www.nowlebanon.com/Print.aspx?ID=29438

However, this could be avoided if the monitoring and control of the system were to be automated by applying intelligent paradigm. Intelligent monitoring and control are, therefore, expected to influence the operational planning, improve revenue generation, reduce technical losses, and improve the reliability of power distribution system, which eventually enhance power quality supply and reliability.

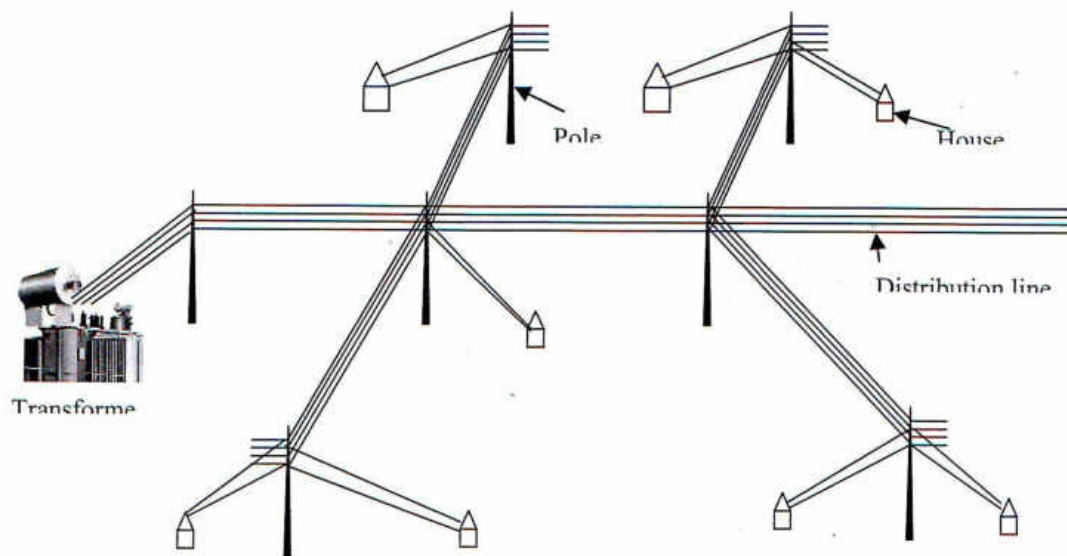


Fig. 4 Typical low voltage distribution network connection.

Recent advancement in technology in Electrical Electronic Engineering shows that real time data can now be sourced from the equipment on the network while remote control of switches are possible from a control centre where decisions are made, through the process known as 'distribution automation'. The Institute of Electrical and Electronic Engineers' (IEEE) defined 'distribution automation' as a system that enables an electric utility to remotely monitor, coordinate and operate distribution components in real-time mode from remote location[1]. Supervisory Control and Data Acquisition (SCADA) system arrangement has been employed in order to achieve better services and system optimization of distribution automation [2]

Several research works on distribution automation, based on SCADA system, generally focused on hardware configuration and benefits which are related to medium distribution network only [3-9]. Although, few works have been reported on automation of low voltage distribution network recently, however, it is limited to 11kv line but Ahmed [10-11] reported automation of low voltage distribution system, between the substation and consumers side, with special focus on fault restoration, which includes fault detection, identification and isolation.

The system developed in the study was based on SCADA technique and human machine interface provides graphical interpretation of the fault. The study further used open loop distribution system configuration and the connected loads fed from two feeders, which are divided into zones for easy fault identification and location. This is carried out by checking the zone, in succession, through the closing and opening of the relays. However, the system lacks the ability to indicate the causes and types of faults on the lines, and could not detect or monitor fault on transformers, above all, activities on consumers' end which lead to non-technical losses such as electricity theft have not been given adequate attention in the study.

Electric energy meter, usually installed at the consumers end, measures and indicates the amount of energy used by the consumers. Conventionally, the method of billing requires operator to visit and take data of power consumption at each consumer's house. This requires large number operators and long working hour to complete while the method is prone to reading error. In addition, adverse climate condition may hinder the process of reading the meter as at when due and sometime the houses locations are not easily accessible. This gives room for electricity theft such as

meter tampering, and illegal connection, which affect the utilities revenue generation and the power quality on the network.

To this end, an intelligent based monitoring and control scheme for low voltage distribution system using SCADA arrangement is proposed in this chapter. The system will be able to monitor and make intelligent decisions most especially on consumer interferences on the distribution network and this will lead to real time energy information acquisition, enhanced customer service, improve power outage management and good power quality monitoring. In addition, it will be able to monitor the effect of consumers' loads on the transformer to prevent overloading, detect and eliminate meter tampering, illegal connections and meter theft.

29.3. Proposed System

The propose system will be able to monitor real time equipment such as transformers, fuses and consumers' load on the network and SCADA arrangement will be operated with new algorithm to prevent electricity theft on the network. The monitoring and control scheme for the network equipment is discusses as follow.

29.3.1 Distribution transformer

Transformer is a significant and the most expensive component of power system. It could be referred to as power transformer or distribution transformer, depending on where it is connected. The latter is used in distribution substations, which involve stepping down of the voltage while the former is employed in transmission substation, which involves stepping up of the voltage. Its failure may cause permanent damages to the transformers' windings, the connected equipment and this may cause devastating effect on power systems, which could result in possible widespread power outages and huge economical losses. Therefore, adequate procedure should be taken to maintain it in good condition of service to prevent damages caused by faults.

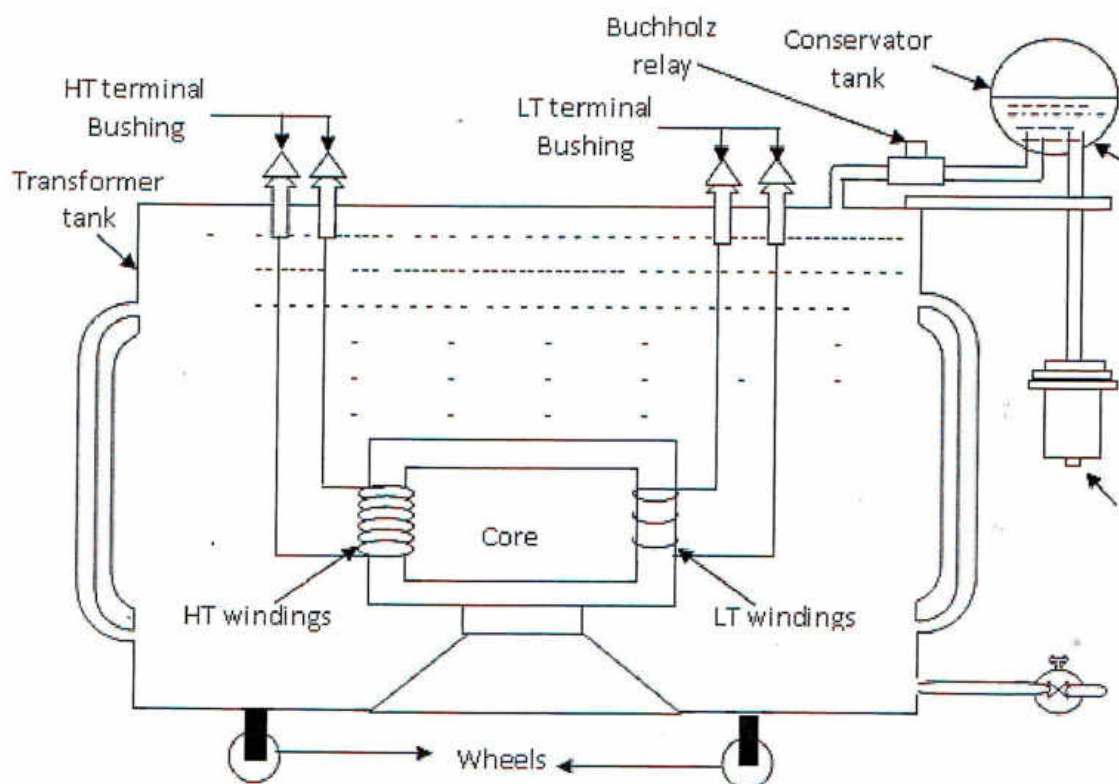


Fig. 5 Physical structure of transformer.

The two main types of fault that generally occur within transformer are classified as internal incipient faults, which develops gradually with time within the transformer, such fault include partial discharges, hot spots and arcing. These faults, if not addressed on time, could lead to the thermal degradation of the oil and paper insulation within the transformer and eventual short circuit of the transformer windings. However, the detection of these faults at earlier stage is paramount to the life expectancy of a given transformer, its efficiency and stability of power system in general. One of the methods of detecting these faults is Dissolved Gas Analysis (DGA) which involves evaluating the quantities of hydrocarbon gases, hydrogen and oxides of carbon present in the transformer oil [12] and the ratio of these gases indicates the type of fault developed in the transformer.

DGA is the most sensitive and reliable technique which gives an early indication of abnormal performance of a transformer. Several methods such as International Electrotechnical Commission (IEC) ratio, Roger's ratio, Doernenburg's ratio, the Key gas method and Duval Triangle method are used in interpreting DGA for fault prediction in transformer oil [13-14]. Furthermore, over the years, efforts have been made to improve the DGA result which has hitherto done conventionally off-line by applying intelligent paradigm [15-20]

Another approach of detecting incipient fault in transformer is through monitoring of the oil temperatures, which includes the top oil temperature and the hot spot temperature. The top oil temperature is the temperature of the oil measured at the top inside the transformer while the hotspot temperature is the highest temperature occurring in the winding insulation system and it represents the thermal limitation of the transformer loading. [21]. The conditions of transformers winding insulation and hence its useable life depend greatly on the hot-spot temperature therefore, knowledge of hot spot temperature during loading cycle is vital to the monitoring of transformer operation. Literature studies have shown that knowledge of heat transfer and thermal-electrical analogous can be used to calculate these temperature hence real time monitoring is possible [22-26]. Other possible methods from studies for detecting transformer fault include [27-30].

29.3.2 Distribution line

The proposed work will assume a perfect distribution line hence distribution line will not be focus in this study. However, the distribution line could be represented as a short transmission line, for future studies.

The distribution line feeder can be model as short transmission lines because of it length and operating voltage level. When the length and the operating voltage of the lines is less than or equal to 80Km and 20KV respectively the effect of shunt capacitance and conductance are negligible and hence, neglected. The equivalent circuit of a single-phase distribution line is shown in figure 3.2.

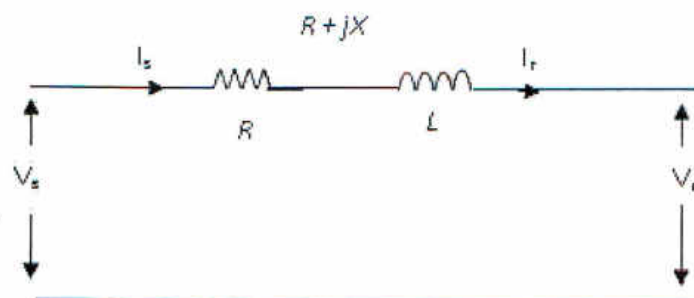


Fig. 6 Single-phase short transmission line model.

The single-phase short transmission line model consists of a series impedance Z , which is represented by the lumped resistance R and reactance X respectively. R is the resistance per phase while L is the inductance per phase of the entire transmission line. The line consists of two ends; sending and receiving end. The sending end voltage V_s and current I_s are located at the secondary of

the distribution transformer and the receiving end voltage V_r and I_r at the consumer terminal respectively.

From figure 3.2

$$I_s = I_r \quad (1)$$

The voltage at the sending end

$$V_s = V_r + I_r Z \quad (2)$$

29.3.3 Consumer end: electric meter monitoring and theft detection

Over the years, an improved mode of data collection and billing which involve the use of communication network has been proposed to overcome some of the problems encountered by manual method of meter monitoring and billing [31-33]. However, most of these studies are proposed and are yet to be deployed at large and it will be impracticable in rural areas such as in developing countries where no modern communication (wired or wireless) exists. Furthermore, where communication exists, additional communication network fees have to be paid by the consumers, which put more burdens on the consumer, in addition, the prototype designed creates an opportunity for consumer to connect to the distribution line illegally by bypassing the meter.

Application of intelligent paradigm such as Support Vector Machine (SVM), extreme learning machine (ELM) and online sequential-extreme learning machine (OS-ELM) as classifiers in the process of detecting electricity theft based on consumers load consumption pattern profile have been proposed [34-36]. However, the problem of proper theft identification in the selected consumers for onsite inspection in these works is yet to be solved.

The shortcomings in the present system and the proposed studies so far would be taken care off in the proposed distribution automation system by having an RTU station on the pole and with appropriate algorithm to detect and disconnect meter tampering and illegal connection. This system is hereby conjectured to eliminate electricity theft.

29.3.4 Overview of the proposed system

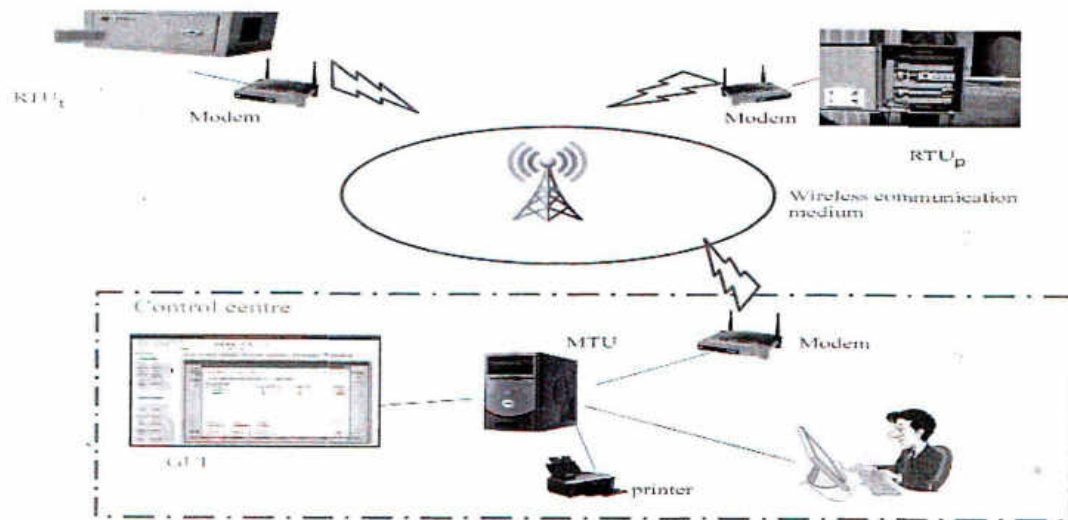


Fig. 7 Distribution system automation based on SCADA.

Remote Terminal Units (RTU) will be designed for the substation as well as consumer end with the capability of acquiring and processing data such as current, voltage, oil temperature and power

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output. These data will be used in the algorithm to be developed to monitor and control the transformer and consumer end in real time such that overloading of the transformer will be prevented at the substation. In addition, electricity theft will be eliminated or reduced to barest minimum. Furthermore, Main Terminal Unit (MTU) will be designed and parameters such as voltage, current, transformer oil temperature will be display graphically on the Graphical User Interface GUI, for monitoring and control of the system.

29.4. References

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