



UNIVERSITY OF NAIROBI

MSc Research Project

**TITLE: ELECTRICAL POWER SUBSTATION ENERGY AUDIT AND
THE COST- BENEFIT ANALYSIS OF AUTOMATING SWITCHING
OPERATIONS DURING OUTAGES AT THE KENYA POWER
COMPANY LIMITED.**

*A project report submitted in partial fulfillment of the requirement for the award of the
degree of Master of Science in Energy Management of the University of Nairobi*

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Date: April, 2012

I DECLARATION

A. Student’s Declaration

This MSc research project Report is my original work and has not been presented for a degree award in this or any other university.

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Reg. No. F56/76714/2009

Sign.....

Date.....

B. Supervisors’ Declaration

This MSc research project report has been submitted to the School of Engineering, University of Nairobi with our approval as supervisors:

Dr. N.O. Abungu

Dr. C. Wekesa

Sign:

Sign:

Date:

Date:

II DEDICATION

To my loving wife Christine and children, for their support during the entire project period. They demonstrated great patience and I salute them all.

III ACKNOWLEDGEMENT

I would like to express my gratitude to my supervisors, Dr. Nicodemus Abungu Odero and Dr. Cyrus Wekesa for their guidance and support that enabled me to complete this work.

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Mr Charles Maloba, the senior engineer in charge of system planning and operations in Kenya Power. He was so resourceful in the field of planning and operation of the system.

All system control staff for their unreserved ideas and assistance during the entire period of the project.

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V ABSTRACT

Substation automation has, its prime objective, the need to satisfy the increasingly demanding requirements of the power systems concerned. The most important requirement is to ensure that the power system, as a whole, is operated and controlled in the most effective, secure and economic manner possible. In High Voltage (HV) and Extra HV substations, decisions must be taken quickly and safely to achieve rapid restoration of supply and speedy return to normal operating conditions following a substation equipment fault or other substation abnormality [50]. The project intended to explore interactive techniques for substation automation by describing models and computational techniques that have been developed to model substation configuration and detect the available restoration operations following a fault in a substation equipment. These techniques should recognize the existing, at the time of fault, operational configuration of the substation by inputting the operating states of the breakers and isolators.

Simulation and especially computer simulation is a basic tool since it enables engineers to understand how systems work without actually needing to see them. They can learn how they work in different circumstances and optimize their design with considerably less cost in terms of time and money than if they had to carry out tests on a physical system. There is a wide range of commercial brands on the market offering products for electrical simulation. These are powerful tools, but require the engineer to have a perfect knowledge of the electrical field.

Energy efficiency brings health, productivity, safety, comfort and savings to consumers and beneficiaries, as well as local and global environmental benefits.

This project intended to study and explore the modelling of Intelligent Electronic Device (IED). These configurable IED models allow to easily build Substation Automation System (SAS) network model with different topologies for all kinds of substations so that the dynamic performance issues could be studied during the planning stage and network performance problem could be caught ahead of the deployment stage [50]. An example of using models to construct Substation Automation System network as well as the network performance simulation results was considered in this project.

CHAPTER ONE

1. INTRODUCTION

This report presents the results of an energy audit and computer simulation study performed on the 132000V to 66000V Juja road Substation, an Electrical Power Transmission facility located in the City of Nairobi, Kenya. This project study was completed as part of my masters degree program in energy management of the University of Nairobi.

Energy auditing is an excellent way to obtain energy savings through low cost improvements that optimize building systems so that they operate efficiently and effectively. In addition, an energy management system can improve occupant comfort, reduce indoor air quality problems and reduce operations and maintenance costs.

In developing countries, about 40 per cent of operational expenditure is estimated to be incurred in human settlements, and costs for supplying energy accounts for a significant portion of this expenditure. These costs place a severe strain on the national economy of almost all developing countries: hence, there is an urgent need for initiating sound energy management [1]. This calls for innovative approaches to management aimed at energy conservation. Energy users need to be convinced of the financial benefits they can derive through energy management: it is often not realized that resources spent on conserving energy and on reducing energy waste are sound investments and that there are several measures which can be undertaken at minimal costs.

Efficient functioning of any business organization would enable it to provide goods and services at a lower price. In the process of managing organizations, the managers at different levels should take appropriate economic decisions which will help in minimizing investment, operating and maintenance expenditures besides increasing the revenue, savings and such other gains of the organization. These can be achieved through Engineering Economics which deals with the methods that enable one to make economic decisions towards minimizing costs and maximizing benefits to business organizations [2].

Examples of possible savings that can be made by changing operating and maintenance procedures and, in many cases, by installing energy efficient equipment has been indicated in this project. Implementing the ideas and suggestions presented in this report will provide

energy savings for most substations, although the savings might not be the same as those cited in the examples.

After doing an energy audit, this project report proposes no-cost and low-cost methods for reducing energy consumption. Procedures and techniques to eliminate energy waste and to reduce energy use are also proposed.

The first part of the report – the Energy Audit report – is, as the name implies, devoted to the energy audit or survey of one of the Kenya Power substations, the Juja Rd substation.

Energy auditing is an integral part of any energy-management programme and an essential step in the process of energy-conservation, since it facilitates the optimum use of available energy resources [2]. It can be a valuable tool in developing countries like Kenya where emphasis is being placed on reducing consumption of commercial and non-commercial energy through energy-conservation measures. Some governments of developing countries have already adopted energy-conservation measures but not always in accordance with a systematic national policy on energy conservation which would bring benefits through

- (i) A reduction of the load on overall energy-supply systems;
- (ii) An increase in time available to develop new indigenous energy sources;
- (iii) A reduction of foreign-exchange demand; and
- (iv) A reduction in overall costs of operating human settlements.

A first step in undertaking an energy-management programme is to identify energy-consumption patterns, to determine:

- (a) Where energy is used;
- (b) How energy is used;
- (c) What forms of energy is used;
- (d) How much energy is used; and
- (e) When energy is used.

“Energy audit” therefore means the verification, monitoring and analysis of use of energy including submission of technical report containing recommendation for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption [3].

The energy audit will present a picture of the substation’s energy profile.

The second part of the report – the automation of the switching operations in substations – provides a suggestion and an example of possible savings as compared to manual operations in switching.

A necessary input into the performance of any task is energy, hence the importance of the study of its automatic transformation. Substation automation therefore has, as its prime objective, the need to satisfy the increasingly demanding requirements of the power systems concerned. The most important requirement is to ensure that the power system, as a whole, is operated and controlled in the most effective, secure and economic manner possible. In High Voltage and Extra High Voltage substations, decisions must be taken quickly and safely to achieve rapid restoration of supply and speedy return to normal operating conditions following a substation equipment fault or other substation abnormality.

1.1 PROBLEM STATEMENT

Energy exists in different forms in nature but the most important form is the electrical energy. The modern society is so much dependent upon the use of electrical energy that it has become a part and parcel of our life. Energy is the basic necessity for the economic development of a country. Many functions necessary to present day living grind to a halt when supply of energy stop. It is practically impossible to estimate the actual magnitude of the past that energy has played in the building up of present-day civilization. As a matter of fact, there is a close relationship between the energy used per person and his/her standard of living. The greater the per capita consumption of energy in a country, the higher is the standard of living of its people.

Electrical Power is a critical infrastructure for the growth of the Kenyan Economy. Acceleration in the economic growth will depend upon a financially and commercially viable power sector that is able to attract fresh investments. However, the financial health of the state owned utility company- The Kenya Power, has become a matter of grave concern considering the rate at which electricity tariffs are sky rocketing time and again.

The challenges facing the energy sector in Kenya today include among others a weak power transmission and distribution infrastructure due to limited investments in power system upgrading. As a consequence, the economy has been experiencing high electrical power system losses, extreme voltage fluctuations and intermittent power outages which cause equipment and material damage including losses in production.

With the foregoing in focus, the Kenyan electrical power transmission and distribution system has more than one occasion let down its customers in power failures. Blackouts and unexpected power interruptions have been and are a common punctuation phenomenon in the entire customer base of Kenya Power. These power system weaknesses coupled with the

high cost of power from independent power producer contribute to the high cost of power in Kenya.

In Kenya, for humanity's continued survival and improvement of quality of life, and just as developing countries become industrialized and their populations grow, the need for increasing amounts of energy is placing a heavy burden on energy-supply systems. Hence, there is an urgent need for maximum conservation of existing energy supplies and maximum efficiency in their use. The Kenya Power has to continue to improve its capacity to exploit opportunities to transmit and distribute a reliable and improved electrical power and avoid prolonged power outages if not blackouts to its customers as the case stands now. Unless this trend is halted with corrective steps, then the Kenya power as a utility Company in a developing nation would therefore have no option, but to improve its services for its continued survival in the market. If not, it would definitely loose to new upcoming utility companies given the current world trends of an increasing free competitive market in electrical power supply. This is because modern civilization being science and technology driven, a time will come when it would be suicidal to ignore even the smallest of energy saving opportunities and failure to embrace automation in switching operations.

1.2 RESEARCH OBJECTIVES

Most of the switching operations in most of the transmission and distribution substations in the Kenya Power Company are manual in nature. The principal goal of this research project was to analyze the cost-benefit of automating all the switching programmes during all manner and forms of operations be it load transfers, outages and breakdowns within the Kenya Power and Lighting Company as well as conducting an energy audit in one of the major transmission substations to check whether power is transmitted and distributed most efficiently and economically.

Thus:

1. To design a computer simulation method to model sequence switching in high voltage substations as a faster switching means and thus reducing the switching time and hence the overall outage time during both planned and unplanned outages in Kenya Power Company.
2. Conduct an energy audit as far as is practically possible to check whether there are any opportunities to save energy loss.

When met, these two objectives would indirectly to some extent reduce legal tussles between Kenya Power and its customers as entrenched in the new constitution as a result of

a more stable and reliable power system because the automatic switching would be faster and less prone to transients, a cause of equipment failure.

1.3 RELEVANCE/JUSTIFICATION OF STUDY

Most of the switching operations in the Kenya Power and Lighting Company are manual in nature. This in itself makes it a very lengthy exercise when the need arises to isolate and work upon a section of the interconnected transmission and distribution system. A process which would take less than a few minutes when automatically operated end up taking much time than it is necessary when manually operated. Therefore it is prudent to quantify the input cost and associated benefits in changing from a manually operated system to an automatically operated one.

Secondly, transmission and distribution substation systems are built up with electrical apparatus and equipment. These then become potential sources of electrical energy loss during the energy conveyance from one point to another. So carrying out an energy audit in one of the major substations within Kenya Power and Lighting Company would assist in establishing areas of energy saving opportunities which over time could turn out as great revenue savers for the utility company. Besides that, being the only monopoly in the area of transmission and distribution of electrical power, the company would more often than not tent to loose focus of the opportunities available to save on energy losses. A necessary input into the performance of any task is energy, hence the importance of the study of its transformation

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

Energy is the basic necessity for the economic development of a country. Many functions necessary to present day living grind to a halt when supply of energy stops. It is practically impossible to estimate the actual magnitude of the part that energy has played in the building up of present-day civilization. The availability of huge amount of energy in the modern times has resulted in a shorter working day, higher agricultural and industrial production, a healthier and more balanced diet and better transportation facilities. As a matter of fact, in their book, V.K Mehta And Rohit Mehta of the *Principles of Power Systems*, [4], there is a close relationship between the energy used per person and his/her standard of living. The greater the per capita consumption of energy in a country, the higher is the standard of living of its people [4].

The power sector has existed for over 100 years. Throughout this time, it has experienced waves of change in structure and regulatory approach driven by technical and economic developments. Power engineering being the oldest and most traditional of the various areas within electrical engineering, no other facet of modern technology is currently undergoing a more dramatic revolution in technology or business structure as it is. Perhaps the most fundamental change taking place in the electric utility industry is the move toward a quantitative basis for the management of service reliability. Traditionally, electric utilities achieved satisfactory customer service quality through the use of more or less “one size fits all situations” standards and criteria that experience had shown would lead to no more than an acceptable level of trouble on their system. Tried and true, these methods succeeded in achieving acceptable service quality[5].

But evolving industry requirements changed the relevance of these methods in two ways. First, the needs of modern electric energy consumers changed. Even into the early 1980s, very short (less than 10 second) interruptions of power had minimal impact on most consumers. Then, utilities routinely performed field switching of feeders in the early morning hours, creating 10-second interruptions of power flow that most consumers would not even notice. But where the synchronous-motor alarm clocks of the 1960s and 1970s

would just fall a few seconds behind during such interruptions, modern digital clocks, microelectronic equipment and computers cease working altogether. The key evolutionary stages are outlined below.

1870s - 1920s: Private ownership. Fragmentation. No universal grid.

1920s - World War II: Governments recognition of electric power as a "necessity". Public investment but industry remains fragmented.

World War II - 1960s: Sector viewed as a natural monopoly. Some governments consolidate and nationalise the power sector; others apply economic regulation; some exempt the sector from the application of competition law.

1970s: Oil shocks. Changes in fuel inputs to power generation and shift toward nuclear. Experience with independent power producers on the public grid and discovery that minimum efficient scale of generation may be smaller. Identification of economies of vertical integration between generation and transmission.

1980s - 1990s: Combined Cycle Gas Turbine development reduces minimum efficient scale in generation; coordination eased by falling information technology costs. Power sector reform in some countries involved the development of competition in generation and supply.[5]

According to R. E. Brown, G. Frimpong and H. L. Willis, Electricity, produced and delivered to customers through generation, transmission and distribution systems, constitutes one of the largest consumer markets in the world[6]. Engineers design transmission networks to transport the energy as efficiently as feasible, while at the same time taking into account economic factors, network safety and redundancy. These networks use components such as power lines, cables, circuit breakers, switches and transformers.

Electric power transmission or "high-voltage electric transmission" is the bulk transfer of electrical energy, from generating power plants to substations located near population centers. This is distinct from the local wiring between high-voltage substations and customers, which is typically referred to as electric power distribution. Transmission lines, when interconnected with each other, become high-voltage transmission networks. In the US, these are typically referred to as "power grids" or just "the grid", while in the UK the network is known as the "national grid." Historically, transmission and distribution lines were owned by the same company, but over the last few decades or so many countries have liberalized the electricity market in ways that have led to the separation of the electricity transmission business from the distribution business[7].

Electricity is transmitted at high voltages (110 kV or above) to reduce the energy lost in long distance transmission. Power is usually transmitted through overhead power lines to transmission or sub-transmission substations.

Despite the undisputed success of electrical power generation, transmission and distribution all over the world, many important fundamental problems and questions remain unanswered in many utilities dealing with electrical power. Without doubt, one of the most widely discussed of these in the present day is how to achieve both efficiency and reliability of electrical power. Like most fundamental issues in physics, this question leads to challenges at several levels of thought. At the philosophical level this issue poses questions about whether it is true or false that energy is lost or not. At the physical level we are forced to examine what equipment and apparatus in a system cause or cause not energy losses and at the mathematical level many questions are raised about the completeness and logical depth to which losses can be quantified. A key limitation in the distribution of electricity is that, with minor exceptions, electrical energy cannot be stored, and therefore must be generated as needed. A sophisticated system of control is therefore required to ensure electric generation very closely matches the demand. If supply and demand are not in balance, generation plants and transmission equipment can shut down which, in the worst cases, can lead to a major regional blackout, such as occurred in California and the US Northwest in 1996 and in the US Northeast in 1965, 1977 and 2003[8].

To reduce the risk of such failures, electric transmission networks are interconnected into regional, national or continental wide networks thereby providing multiple redundant alternate routes for power to flow should (weather or equipment) failures occur therefore as the reliable supply of energy, especially electric energy, continues to grow in importance, the potential impact of energy efficiency cannot be overstated. With the array of technologies and methodologies now available, efficiency stands ready to play a much larger role in the energy equation.

In the U.S, Department of Energy estimates that increasing energy efficiency could reduce national energy use by as much as 20% in 2020, with net economic benefits for consumers and businesses as a result.

The concept of energy efficiency has moved in and out of favor with the public over the years, but recently has gained renewed broad-based support. The confluence of economic, environmental and geopolitical concerns around reducing America's exposure to disruptions in the supply of energy has moved efficiency to the fore. As a result, a number

of initiatives are now underway to improve efficiency in a variety of areas, but much more can and should be done.

The US is not alone in these efforts. China presently has ten efficiency programs aimed at bringing the country's energy intensity—the amount of energy used per unit of GDP—in line with rivals such as the US and the European Union. The European Union likewise has taken steps to improve energy efficiency in its member countries by 20% over the next fifteen years.

Efficiency is a simple concept which can perhaps best be summed up with the cliché, “doing more with less.” Perhaps the best-known efficiency program among American consumers is the Energy Star program that helps them to identify appliances like dishwashers and refrigerators that use less energy than other similar models. Indeed, the term “efficiency” is typically associated with how energy is consumed at the point of end use, but the concept of efficiency can also be applied to how energy is produced and distributed.

Once electric energy is generated, it must be moved to areas where it will be used. This is known as transmission—moving large amounts of power over sometimes very long distances—and is separate from distribution, which refers to the process of delivering electric energy from the high voltage transmission grid to specific locations such as a residential street or commercial park.

The transmission and distribution or “T&D” system, then, includes everything between a generation plant and an end-use site. Along the way, some of the energy supplied by the generator is lost due to the resistance of the wires and equipment that the electricity passes through. Most of this energy is converted to heat. Just how much energy is taken up as losses in the T&D system depends greatly on the physical characteristics of the system in question as well as how it is operated. Generally speaking, T&D losses between 6% and 8% are considered normal.

2.2 Improving Efficiency in the T&D System

There are other initiatives at the distribution level, but if we focus our attention on the measures that have the greatest potential for improving efficiency, we inevitably must look to transmission. There are numerous technologies that are already being applied to boost efficiency in transmission, and still more that have yet to reach full commercial implementation. In the following sections, some of these technologies have been explored.

2.3 Energy Auditing of Substation Electrical Power flows

Energy auditing has been used as an integral part of any energy-management programme and an essential step in the process of energy-conservation, since it facilitates the optimum use of available energy resources. It can be a valuable tool in developing countries where emphasis is being placed on reducing consumption of commercial and non-commercial energy through energy-conservation measures[1].

An energy audit, sometimes referred to as an energy survey or an energy inventory, is an examination of the total energy used in a particular property. The analysis is designed to provide a relatively quick and simple method of determining not only how much energy is being consumed but where and when. The energy audit will identify deficiencies in operating procedures and in physical facilities. Once these deficiencies have been identified, it will be apparent where to concentrate efforts in order to save energy. The energy audit is the beginning of and the basis for an effective energy-management programme [9].

For example human settlements encompass a variety of buildings. Regardless of the building involved, the audit procedure is basically the same. If more than one facility is involved (as is the case of apartment buildings) an audit of each will be necessary.

“An energy audit may be considered similar to the monthly closing statement of an accounting system. One series of entries would consist of amounts of energy which are consumed during a month in the form of electricity, gas, fuel, oil, steam, and the second series would list how the energy was used: how much for lighting, in air-conditioning, in heating, in process, etc. The energy audit process must be carried out accurately enough to identify and qualify the energy and cost savings that are likely to be realized through investment in an energy saving measure.”[9]

With the purpose of examining the various aspects of energy conservation and energy management, the United Nations Centre for Human Settlements (Habitat) and the Regional Centre for Energy, Heat and Mass Transfer for Asia and the Pacific convened a Workshop on Energy Auditing in Human Settlements in Madras, India, in 1987. The Workshop noted that, in developing countries, per capita energy consumption is on the increase and that energy consumption in residential, commercial and public buildings constitutes a significant portion of total energy consumption in urban areas, thus justifying the implementation of energy-conservation measures. It concluded that there was scope for initiating energy-auditing procedures which would lead to energy conservation in these sectors and recommended, inter alia, the development of national and local-level energy-audit manuals,

both for the user and the auditor, applying, with suitable modifications where necessary, the experience already gained by developed countries in the field [1].

Elsewhere in the U.S, due to the recent economic downturn, which has hindered the construction industry world wide, Arches etc, a San Diego business, which specializes in the manufacture, distribution, and installation of custom designed doors, windows, mouldings, and hardware believed that an analysis and optimization of their energy usage would provide additional assistance towards their goal to lower overhead and maintain current operations. This was in a Senior Project submitted in partial fulfilment of the requirements for the degree of Bachelor of Science in Industrial Engineering entitled Energy Audit and Optimization for “Arches etc.” by Ross Dixon. To begin this task, a comprehensive energy audit was conducted to establish an initial state from which to base improvements [10].

With this energy audit as baseline to build upon, several aspects of their facility were analyzed, including: Manufacturing Processes, Equipment Capacity, Equipment Runtime, and Equipment Efficiency. After developing a collection of proposed improvements based upon these areas, the economic justification of each improvement was evaluated. Free energy saving improvements, or those that did not require an initial investment resulted in an estimated annual savings of \$2,000.

Hamilton Zanze of San Francisco, the owners of the properties at 140/160 Franklin – Oakland, California, and the adjacent corner property at 384 Embarcadero, commissioned 15000 Inc.[11] to evaluate the buildings for potential savings in energy usage based upon criteria “ASHRAE” (American Society of Heating, Refrigeration and Air Conditioning Engineers).

In short, the building was found to present multiple energy savings opportunities with varying degrees of payback, return on investment and capital outlay. In general, it was recommended to perform the high priority, low capital improvement projects first. Each practical measure proposed was weighted for priority based upon capital expenditure versus net energy effect and Energy Usage Index. (EUI).

Despite all this much work done in residential, commercial and industrial buildings, no much attention seem ever been dedicated to electrical power transforming substations in the field of energy auditing.

2.4 Flexible AC Transmission Systems (FACTS) Devices

A family of power electronics devices known as Flexible AC Transmission Systems, or FACTS, provides a variety of benefits for increasing transmission efficiency. Perhaps the most immediate is their ability to allow existing AC lines to be loaded more heavily without increasing the risk of disturbances on the system. FACTS devices stabilize voltage, and in so doing remove some of the operational safety constraints that prevent operators from loading a given line more heavily. In addition to the efficiency gains, these devices also deliver a clear reliability benefit.

2.5 Gas-Insulated Substations

Most substations occupy large areas of land to accommodate the design requirements of the given facility. However, each time power flows through a substation to step down the voltage, more energy is lost as the power flows through the transformers, switches and other equipment. The efficiency of the lower-voltage lines coming out of the substation is also markedly lower than their high-voltage counterparts. If power can be transmitted at higher voltage to a substation that is closer to where the energy will be consumed, significant efficiency improvements are possible.

Gas-insulated substations essentially take all of the equipment you would find in an outdoor substation and encapsulate it inside of a metal housing. The air inside is replaced with a special inert gas, which allows all of the components to be placed much closer together without the risk of a flashover. The result is that it is now possible to locate a substation in the basement of a building or other confined space so that the efficiency of high-voltage transmission can be exploited to the fullest extent.

ABB is a pioneer in developing gas insulated substations. In the year 1967, ABB delivered the first gas insulated substation in the world. Since that time, ABB has delivered more than 10,000 high voltage gas insulated switchgear bays[12].

GIS was first developed in various countries between 1968 and 1972. After about 5 years of experience, the use rate increased to about 20% of new substations in countries where space is limited. In other countries with space easily available, the higher cost of GIS relative to Air Insulated System has limited use to special cases.

For example, in the U.S., only about 2% of new substations are GIS. International experience with GIS is described in a series of CIGRE papers (CIGRE, 1992; 1994; 1982)[13]. The use of SF₆ gas as an insulating medium in switchgear reduces the clearance distance between active and non-active parts of a switchgear facilitating the following advantages of gas insulated applications compared to air insulated applications:

- Less space requirements - especially in congested city areas
- Less sensitivity to pollution, as well as salt, sand or even large amounts of snow
- Less operation & maintenance costs

More than 35 years experience in building turnkey gas insulated substations around the world has given ABB the expertise to handle all kinds of challenges in the construction of indoor and outdoor gas insulated substations without limitation due to site conditions or voltage levels.[12]

In Kenya the technology has been adopted at the Kenya Electricity Generating company Kipevu III station at the Coastal town of Mombasa.

2.6 Superconductors

Superconducting materials at or near liquid nitrogen temperatures have the ability to conduct electricity with near-zero resistance. So-called high temperature superconducting (HTS) cables now under development, which still require some refrigeration, can carry three to five times the power of conventional cables. The losses in HTS cables are also significantly lower than the losses in conventional lines, even when the refrigeration costs are included. A major vendor of superconducting conductors claims that the HTS cable losses are only half a percent (0.5%) of the transmitted power compared to 5-8% for traditional power cables. Superconducting materials can also be used to replace the copper windings of transformers to reduce losses by as much as 70% compared to current designs.

James Dewar initiated research into electrical resistance at low temperatures.

Zygmunt Florenty Wroblewski conducted research into electrical properties at low temperatures, though his research ended early due to his accidental death. Around 1864, Karol Olszewski and Wroblewski predicted the electrical phenomena of dropping resistance levels at ultra-cold temperatures. Olszewski and Wroblewski documented evidence of this in the 1880s. Dewar and John Ambrose Fleming predicted that at absolute zero, pure metals would become perfect electromagnetic conductors (though, later, Dewar altered his opinion on the disappearance of resistance, believing that there would always be some resistance). Walther Hermann Nernst developed the third law of thermodynamics and stated that absolute zero was unattainable. Carl von Linde and William Hampson, both commercial researchers, nearly at the same time filed for patents on the Joule-Thomson effect for the liquefaction of gases. Linde's patent was the climax of 20 years of systematic investigation of established facts, using a regenerative counterflow method. Hampson's designs was also

of a regenerative method. The combined process became known as the Hampson-Linde liquefaction process.

Onnes purchased a Linde machine for his research. On March 21, 1900, Nikola Tesla was granted a US patent for the means for increasing the intensity of electrical oscillations by lowering the temperature, which was caused by lowered resistance, a phenomenon previously observed by Olszewski and Wroblewski. Within this patent it describes the increased intensity and duration of electric oscillations of a low temperature resonating circuit. It is believed that Tesla had intended that Linde's machine would be used to attain the cooling agents.

A milestone was achieved on July 10, 1908 when Heike Kamerlingh Onnes at Leiden University in the Netherlands produced, for the first time, liquified helium, which has a boiling point of 4.2 kelvin at atmospheric pressure.

2.7 Wide Area Monitoring Systems

Much of the transmission system could feasibly be operated at a higher loading, were it not for reliability concerns. However, if operators were given the ability to monitor grid conditions more precisely and in real time, some of these constraints would be removed. One example relates to the simple fact that when transmission lines heat up, the metal becomes pliable and the lines sag, which can cause a short circuit if they come into contact with a tree or other grounding object. Wide area monitoring systems (WAMS) have many promising capabilities, one of which is line thermal monitoring. With this functionality, transmission operators could conceivably change the loading of transmission lines more freely by virtue of having a very clear understanding of how close a given line really is to its thermal limits.

The load on electricity supply systems has increased continuously over the past few years. There are many reasons for this:

- Increased cross-border power trading in Europe, for example, is placing new demands on the tie lines between control areas. For example, power transmission on tie lines in the European grid increased almost 6-fold from 1975 to 2008 .
- Increased input of wind power and the planned shutdown of existing power plants will extend the transmission distances between generation and consumers.
- Severe weather and storms can put important lines out of operation, for a short time exposing the remaining grid to increased load quickly.

This means that the power system is increasingly operated closer to its stability limit and new load flows arise that are unfamiliar to network control center operators.

This is where SIGUARD PDP (Phasor Data Processor) comes in.

This system for network monitoring using synchrophasors helps with fast appraisal of the current system situation. Power swings and transients are indicated without delay to help the control center personnel find the causes and take countermeasures [14].

2.8 System Automation

In recent years, considerable interest has been shown in applying digital computers for substation control and protection [15-21]. The development and application of new methods and computational techniques in the field of substation automation have, as their prime objective, the need to satisfy the increasingly demanding requirements of the power systems concerned. These requirements are dictated by such factors as the growing size and complexity of the power systems, the use of larger and more highly rated plant units and, above all, the need to ensure that the power system as a whole is operated and controlled in the most effective, secure and economic manner possible.

The last factor mentioned is given particular emphasis by the present trend towards the control of substations from digital computer centres. As a High Voltage (HV) or Extra High Voltage (EHV) substation increases in complexity, decisions must be taken quickly and safely. It is extremely important to achieve rapid restoration of supply and speedy return to normal operating conditions following a substation equipment fault or other substation abnormality.

Computational methods have been published [22] to model substation interlocking and sequence switching in high-voltage substations. These methods use dynamic programming [22] or a heuristic approach [21] to detect the optimal sequence of on-line switching operations. However, relatively little has been done in the area of automatic restoration and rearrangement of the substation following a substation abnormality and making maximum utilisation of equipment. One of the purposes of this project is to present interactive technique for substation automation by studying models and techniques that have been previously developed to model the substation configuration and detect the available restoration operations following a fault in a substation equipment. These techniques recognise the existing, at the time of fault, operational configuration of the substation by

inputting the source and load points and the operating states (closed or open) of the breakers and isolators.

2.9 Modelling the substation switching operations

Modelling refers to the process of generating a model as a conceptual representation of some phenomenon. Typically a model will refer only to some aspects of the phenomenon in question, and two models of the same phenomenon may be essentially different, that is in which the difference is more than just a simple renaming. This may be due to differing requirements of the model's end users or to conceptual or aesthetic differences by the modellers and decisions made during the modelling process. [23]

Scientific modelling is the process of generating abstract, conceptual, graphical and/or mathematical models. Science offers a growing collection of methods, techniques and theory about all kinds of specialized scientific modelling. Also a way to read elements easily which have been broken down to the simplest form. Modeling is an essential and inseparable part of all scientific activity, and many scientific disciplines have their own ideas about specific types of modelling. There is little general theory about scientific modelling, offered by the philosophy of science, systems theory, and new fields like knowledge visualization. A scientific model represents empirical objects, phenomena, and physical processes in a logical way. Attempts to formalize the principles of the empirical sciences, use an interpretation to model reality, in the same way logicians axiomatize the principles of logic. The aim of these attempts is to construct a formal system for which reality is the only interpretation. The world is an interpretation (or model) of these sciences, only insofar as these sciences are true. [23]

For the scientist, a model is also a way in which the human thought processes can be amplified [24]. Models that are rendered in software allow scientists to leverage computational power to simulate, visualize, manipulate and gain intuition about the entity, phenomenon or process being represented.

A model is a simplified representation used to explain the workings of a real world system or event. A physical model (most commonly referred to simply as a model, however in this sense it is distinguished from a *conceptual model*) is a smaller or larger physical copy of an object. The object being modelled may be small (for example, an atom) or large (for example, the Solar System). The geometry of the model and the object it represents are often similar in the sense that one is a rescaling of the other; in such cases the scale is an important characteristic. However, in many cases the similarity is only approximate or even

intentionally distorted. Sometimes the distortion is systematic with e.g. a fixed scale horizontally and a larger fixed scale vertically when modelling topography of a large area (as opposed to a model of a smaller mountain region, which may well use the same scale horizontally and vertically, and show the true slopes). Physical models allow visualization, from examining the model, of information about the thing the model represents. A model can be a physical object such as an architectural model of a building. Uses of an architectural model include visualization of internal relationships within the structure or external relationships of the structure to the environment.

Instrumented physical models are the most effective way of investigating fluid flows such as around hydraulic structures. These models are scaled in terms of both geometry and important forces, for example using Froude number or Reynolds number scaling. A physical model of something large is usually smaller, and of something very small is larger. A physical model of something that can move, like a vehicle or machine, may be completely static, or have parts that can be moved manually, or be powered. A physical model may show inner parts that are normally not visible. The purpose of a physical model on a smaller scale may be to have a better overview, for testing purposes, as hobby or toy. The purpose of a physical model on a larger scale may be to see the structure of things that are normally too small to see properly or to see at all, for example a model of an insect or of a molecule. A physical model of an animal shows the animal's physical composition without it walking or flying away, and without danger, and if the real animal is not available. A soft model of an animal is popular among children and some adults as cuddly toy. A model of a person may for example be a doll, a statue, and in fiction a robotic humanoid. A model is a 3D alternative for a 2D representation such as a drawing or photograph, or in the case of a globe, a 3D, undistorted alternative for a flat world map.

During the last decade considerable attention has been devoted by power utilities to the evaluation of the effectiveness of their transmission and distribution systems from a reliability viewpoint. One of the main concerns of the published computational methods [25-27] has been the development of accurate and consistent models to represent true component and system behaviour. Furthermore, several papers [28-30] have specifically considered techniques that are suitable for evaluating the reliability of power-system substations. These techniques consider the concepts of open and short circuits, their impact on the operation of circuit breakers and the consequential effect on the reliability of load

points. The only reason for concentrating on substations is that these systems are quite complicated in their own right and comprise switching arrangements that are generally more complex than the corresponding ones in power-system networks.

In real-time environments, however, substation configuration is dynamic. This is because breakers and isolators may operate at any time producing the following effects:

(a) incoming or outgoing circuits may or may not be disconnected

(b) substation busbar sections may or may not separate, possibly forming new nodes in the system.

Automation systems are evolving towards ubiquitous, diverse, broad, agile, autonomous and integrated large-scale real-time information systems [31]. Information handling has become a crucial issue, given the need for cost-effective integration of multiple application domains such as monitoring, supervision, control, protection, asset management, maintenance, condition monitoring, incident management, power quality monitoring, configuration management or security management. With the purpose of optimizing information handling, object orientation is being widely introduced at the platform level.

In their paper at the C I R E D 18th International Conference on Electricity Distribution” entitled “towards model-driven design of substation automation systems” [32] Rogério Paulo and Adriano Carvalho concluded that illustration of a modelling approach, applied to the design process, shows that the adoption of object oriented modelling and the model-driven design approach leads to both cost-reduced and quality-enhanced system development.

It is therefore evident that provisions must be made to automatically incorporate, in real time, the effects of breaker operation on system topology and decisions for switching actions must be taken quickly and safely to maintain the continuity and quality of supply to consumers.

Electrical power is removed (switched off) and restored (switched on) for various reasons including:

- Operational requirements, and
- Electrical safety

According to the Department of Primary Industries, in the New South Wales Government of the United Kingdom with the mining industry as an example, [33] procedures for the

removal and restoration of power are intended to provide information in the safe removal of power at the mine, such as:

- Removal of power at the completion of the work day (shut site generator down).
- Safe access to plant for mechanical maintenance / repair in accordance with the site isolation procedures, and
- Removal of electrical power source under electrical fault conditions, that is, the operation of electrical protection devices.

Similarly the procedures for the restoration of power are intended to provide information for the safe application of power to electrical circuits, following the removal of power, as a controlled process, such as:

- Starting process for the generator at the start of the work day (start up procedures)
- Procedure for removing isolation to re-power the plant following mechanical maintenance / repair, and
- Reset procedures to restore power after an electrical protection device has tripped.

There are increased risks to operators and maintenance personnel if the process of switching off and switching on is not carried out in a systematic and rigorous manner. Any process developed for the removal and restoration of power at the operation should form part of the Mine Safety Management Plan as a control for the safe use of electricity.

2.10 Removal of Power

There are three methods for the removal of power, Manual – Whole Current, Manual – Remote Switching, and Automatic:

1. Manual - Whole Current – this is where switch devices are physically operated to switch the power supply off (the phase conductors have a physical gap).
2. Manual - Remote Switching – this is where control switches (stop switches, emergency stop switches, conveyor lanyards) are operated to stop the plant. Note: The use of remote switching must not be relied on for isolation purposes when doing mechanical maintenance and repair work.
3. Automatic – this is where switching devices (generally, these are circuit breakers) are operated and tripped by electrical protection systems (overload, short circuit and earth fault protection).

In electrical engineering, a switch is an electrical component that can break an electrical circuit, interrupting the current or diverting it from one conductor to another.[34][35]

The most familiar form of switch is a manually operated electromechanical device with one or more sets of electrical contacts, which are connected to external circuits. Each set of

contacts can be in one of two states: either "closed" meaning the contacts are touching and electricity can flow between them, or "open", meaning the contacts are separated and the switch is non-conducting. The mechanism actuating the transition between these two states (open or closed) can be either a "toggle" (flip switch for continuous "on" or "off") or "momentary" (push-for "on" or push-for "off") type.

A switch may be directly manipulated by a human as a control signal to a system, such as a computer keyboard button, or to control power flow in a circuit, such as a light switch. Automatically operated switches can be used to control the motions of machines, for example, to indicate that a garage door has reached its full open position or that a machine tool is in a position to accept another workpiece. Switches may be operated by process variables such as pressure, temperature, flow, current, voltage, and force, acting as sensors in a process and used to automatically control a system. For example, a thermostat is a temperature-operated switch used to control a heating process. A switch that is operated by another electrical circuit is called a relay. Large switches may be remotely operated by a motor drive mechanism. Some switches are used to isolate electric power from a system, providing a visible point of isolation that can be pad-locked if necessary to prevent accidental operation of a machine during maintenance, or to prevent electric shock.



A high-voltage disconnect switch used in an electrical substation. Such switches are used mostly to isolate circuits, and usually cannot break load current. High-voltage switches are available for the highest transmission voltages, up to 1 million volts. This switch is gang-operated so that all three phases are interrupted at the same time

2.11 Simulation

Simulation is the imitation of some real thing, state of affairs, or process. The act of simulating something generally entails representing certain key characteristics or behaviours of a selected physical or abstract system.

Simulation is used in many contexts, including the modeling of natural systems or human systems in order to gain insight into their functioning. Other contexts include simulation of technology for performance optimization, safety engineering, testing, training and education. Simulation can be used to show the eventual real effects of alternative conditions and courses of action. Simulation is also used when the real system cannot be engaged. The real system may not be engaged because it may not be accessible, it may be dangerous or unacceptable to engage, or it may simply not exist.[36]

Key issues in simulation include acquisition of valid source information about the relevant selection of key characteristics and behaviours, the use of simplifying approximations and assumptions within the simulation, and fidelity and validity of the simulation outcomes.

A computer simulation (or "sim") is an attempt to model a real-life or hypothetical situation on a computer so that it can be studied to see how the system works. By changing variables, predictions may be made about the behaviour of the system[37]

Computer simulation has become a useful part of modeling many natural systems in physics, chemistry and biology[37], and human systems in economics and social science (the computational sociology) as well as in engineering to gain insight into the operation of those systems. A good example of the usefulness of using computers to simulate can be found in the field of network traffic simulation. In such simulations, the model behaviour will change each simulation according to the set of initial parameters assumed for the environment.

Traditionally, the formal modeling of systems has been via a mathematical model, which attempts to find analytical solutions enabling the prediction of the behaviour of the system from a set of parameters and initial conditions. Computer simulation is often used as an adjunct to, or substitution for, modeling systems for which simple closed form analytic solutions are not possible. There are many different types of computer simulation, the common feature they all share is the attempt to generate a sample of representative scenarios for a model in which a complete enumeration of all possible states would be prohibitive or impossible. Several software packages exist for running computer-based

simulation modeling (e.g. Monte Carlo simulation, stochastic modeling, multimethod modeling) that makes the modeling almost effortless.

Simulation and especially computer simulation is a basic tool since it enables engineers to understand how systems work without actually needing to see them. They can learn how they work in different circumstances and optimize their design with considerably less cost in terms of time and money than if they had to carry out tests on a physical system.

A system is a set of interacting or interdependent entities, real or abstract, forming an integrated whole. In general, a system is a construct or collection of different elements that together produce results not obtainable by the elements alone[38]

There is a wide range of commercial brands on the market offering products for electrical simulation. These are powerful tools, but require the engineer to have a perfect knowledge of the electrical field. Substation Automation System (SAS), established using multifunctional Intelligent Electronic Devices (IEDs) and advanced network communication technologies, could provide us with the effective substation monitoring, local and remote control, protection, primary equipment condition monitoring and many other functions.

The key objectives for designing substation automation architecture are interoperability between IEDs, satisfaction of communication performance, and extensibility of the architecture. For instance, the International Electro-technical Commission (IEC) 61850, the global communication standard for Substation Automation System, defines the communication between IEDs and not only solves the interoperation problem but also specifies other system requirements like message performance, information security in SAS network. According to the IEC 61850-5, the message transmission time requirements for SAS network must be ensured under any operating conditions and contingencies inside the substation [39]. Dynamic performance of the SAS network must be studied during the planning stage in order to catch network performance problem ahead of the deployment stage.

2.12 Benefits of improved efficiency through automation auditing.

The “business case” for energy efficiency is fairly straightforward: using less energy means paying less for energy. But a simple cost-benefit analysis might overlook some very important benefits that efficiency brings.

Within the context of the power system, it is important to recognize how interrelated energy efficiency is with grid reliability. In many areas of the US, transmission constraints have

reached the point where they not only cost consumers billions of dollars in congestion charges, they threaten the integrity of the power system itself. Over the past twenty years, the situation has continued to deteriorate to the point where now the question of installing a new line is nearly moot in some locations. By the time it was completed, demand would long since have outstripped the ability of the local grid to meet it, so a short-term solution must be implemented in the interim.

FACTS devices offer a good example of how efficiency and reliability improvements often go hand in hand. Unlike siting and building a new transmission line, FACTS devices can be implemented quickly (less than a year from purchase to completion in some cases). They immediately boost the transmission capacity of the given line while also providing voltage support and bolstering the local grid's ability to withstand disturbances.

CHAPTER THREE

3. METHODOLOGY

The principal goal of this research project was to analyze the cost-benefit of automating all the switching programs during outages and breakdowns within the Kenya Power as well as conducting an energy audit in one of the major transmission substations- Juja Rd 132/66Kv substation, to check whether power is transmitted and distributed most efficiently and economically.

3.1 Research Design and Method

The research design was divided into two areas of study namely the energy audit in one part and secondly, study of the switching operations with a view to reducing time taken during outage/or breakdown and therefore subsequent restoration of power.

The method used towards this end was (i) to conduct an energy audit using and following the general well established audit steps and (ii) doing a cost-benefit analysis of automating the switching operations thereafter. The study utilized both qualitative and quantitative methods. Qualitative methods included collection of standard commercial spares/ or fittings data from manufacturers' manuals, web sites and personal interaction with staff working in the selected substation. Quantitative methods included collection of recorded past switching data, system operation data and personal involvement in switching operations during system outages and breakdowns.

This particular bit involved a lot of travelling to visit and compare different substations in different geographical areas in the country. The visits included:

1. Juja Rd 132/66KV , Dandora 220/132KV and Embakasi 220/66KV substations all in Nairobi.
2. Kamburu 11/132KV, Kamburu 132/220KV substations in the Hydros or seven folks area along the Tana River
3. Rabai 220/132KV, New Bamburi 132/66KV and 132/33KV Galu substations all in Mombasa

3.1.1 Energy Audit Methodology

The big energy audit picture was done on three major Kenya Power transmission substations namely the 132/66KV Juja Rd, the 220/132KV Dandora and the 220/66KV

Embakasi substations all located within the capital city-Nairobi. However due to safety reasons, operational procedures, code of practice and project time limitation, the detailed energy audit study was narrowed down and carried in only one of the three, and thus Juja Rd 132/66KV substation was selected as a representative of the others.

3.1.2 Steps to goals and objectives of the audit

Qualitatively the audit research methodology consisted of the following steps:

i) Step 1- Interview with Key Facility Personnel

The Kenya Power is a limited company registered in the Nairobi Stock Exchange. Therefore this makes it a profit making facility/entity in its quest to transmit and distribute electrical power in the country. In order to get an insight of the whole transmission function, an initial meeting with the chief engineer, national control centre was conducted and permission granted to under take the energy audit study in the facility.

The meeting agenda focused on: audit objectives and scope of work, facility rules and regulations due to the high voltages involved- a live wire is a dead man/woman [40]. In addition to these administrative issues, the discussion during this meeting sought to establish the operating characteristics of the facility, energy system specifications, operating and maintenance procedures, preliminary areas of investigation and the survey operating constraints.

ii) Step 2- Facility Tour

After the initial meeting, a tour in each of the three substations was carried out (in different days) to observe the various switchgears first hand, and focusing on the major energy consuming systems and time taken to do and accomplish any particular switching operation, be it an outage or a breakdown. The architectural design and substation equipment layout, lighting and power monitoring in and out of the substations formed the basis of study.

iii) Step 3- Document Review

During the initial visit and subsequent kick-off meeting, available substations documentation were reviewed with the control engineers. This documentation included all available architectural and engineering diagrams, operation & maintenance procedures and logs of both incoming and out going power flows in the substation.

iv) Step 4- Facility Inspection

After studying and thorough reviewing of the construction and operating documentation, the major energy wasting processes in the substation chosen were further investigated. Where appropriate, field measurements were collected to substantiate operating parameters like temperature.

v) Step 5- Staff Interviews

Subsequent to the switchyard inspection, it was necessary to meet again with the operation staff to review preliminary findings and the recommendations being considered. This was in line with the audit objective of identifying hot spots that have high value impact to the customers in terms of temporary or major breakdowns and therefore uncalled for outages. Management input at this juncture was felt necessary to establish the foundation of a strong minimum electrical power interruption to customers. This in effect would improve the company's revenue collection by a constant non-interruptible supply.

vii) Step 6- Utility Analysis

The utility analysis was a detailed review of energy consumption from areas like substation yard flood lighting, all disconnecting switches, all conductor joints and other control equipment. The purchased or in-coming electrical energy as brought in by the transmission lines and taken out by distribution feeders was compared to evaluate the magnitude of energy loss in the substations by way of analysing the difference in power flow (in and out). It was prudent to do that especially with the advent of deregulation era where energy is, and can be purchased on contract from a number of third party marketers and therefore necessary to embrace efficiency to survive in the market. It is a world of high cost of energy purchase and it may be cost-effective to transmit it with minimum loss possible

viii) Step 7- Economic Analysis

Data collected during the audit was processed and analysed. Simulation with software was built to reproduce the field/or substation outage switching observations and developed as a base line against which to measure and quantify the energy savings potential. Calculation of the implementation cost in energy savings, time savings and simple payback periods were also evaluated.

ix) Step 8- Audit Findings and Recommendations

The results of findings and recommendations formed the final element of the audit project report. The report included a description of the substation installation and its operation, a discussion of major energy consuming areas, a description of recommended Energy Conservation Measures (ECMs) with their specific energy impact, implementation costs, benefits and payback. The report incorporated a summary of all the activities and effort performed throughout the project with specific conclusions and recommendations.

3.2 Study of Time Taken During Outage Switching Operations

After going round and visiting the major power transmission substations within the Kenya Power as indicated in section 3.1 above, the study of automation was narrowed down to the Juja Rd 132/66KV substation. Switching is one of the most important activities in power transmission and distribution systems. It arises whenever load transfer is needed, during planned outages and breakdowns to isolate, repair and restore a faulty system.

In order to gather enough information regarding this area of study, the method employed was reviewing of electrical power flow and utilization systems, examination of the system network line diagrams, inspection of the electrical plants, switchgears, instruments and tools used for works and collection of past data on switching procedures.

3.2.1 The power transmission network system in the Juja Rd substation

The system network was important studying in order to fully understand its layout for power flow examination. The incoming 132KV transmission power lines as well as the outgoing 66 KV feeders were checked and confirmed on line diagrams. The general layout of plant and equipment in the substation yard was also ascertained and proved. The actual equipment placement distances and areas were observed and noted

3.2.2 Plant, Switchgear, Instruments and tools inspection

For switching operations to move smoothly, there is need for use of sound and reliable plant, switchgear, instruments and tools. Inspection exercise was conducted on them to enhance accuracy, safety to health and equipment, create understanding and ensure confidence of the same during the study. The areas of inspection included

- i) 51- 132KV and 29- 66KV line isolators or disconnectors
- ii) Eight 132KV and Twenty six 66KV circuit breakers
- iii) 132KV Mesh/Ring Bus-Bar and 66KV Main and Reserve bus-bars

- iv) Seven 132/66KV step down power transformers
- v) One 66KV Main and Reserve bus-bar coupler
- vi) All the incoming and outgoing conductors, jointing clamps and the associated jumpers.
- vii) 46 Halogen Floodlights with High Pressure Sodium (HPS) Lamps
- viii) 521 Compact Fluorescent Lamps (CFLs) for Control rooms, Battery rooms, Washrooms, Staff quarters, Behind building blocks, Entrance gate, Corridors and Walkways.

3.3 Data collection

Empirical data collection is well achieved using quantitative data collection tools or instruments. These tools include questionnaires, tests, examinations, exercises, activity interviews, observations and instrumentation [41]. In this study the major tools used were:

- a) Survey of previous switching data to ascertain time taken between start of any switching process and the start of the work itself.
- b) Field tests during outages
- c) Self administered Observations during peak loads using an infra-red camera to monitor temperatures.
- d) Operational staff interviews

Empirical data collection procedure characterized the major part of data collection in this study. Data collected was either in secondary or primary data categories. Secondary data was collected through survey of historical switching records kept for purposes of monitoring and provision of numerical data on running of the substation. Primary data was collected using study tools (b) to (d). For purposes of this research, data of two particular past outages was noted, involving the 132KV bay and the 66KV bay as well. Each of the two was undertaken on different days and dates for purposes of system maintenance.

CHAPTER FOUR

4. FINDINGS, RESULTS AND DISCUSSION

The Kenya Power, not to be confused with the associated Kenya Electricity Generating Company (KenGen) is a limited liability Company which transmits, distributes and retails electricity to customers throughout Kenya. Kenya Power is a public company listed in the Nairobi Stock Exchange (NSE). The Company is a national electric utility company, managing electrical power transmission, distribution, electric metering, licensing, billing, emergency electricity service and customer relations. The company was recently in 2008 awarded the ISO 9001:2008 certificate for standardization, which ensures that the highest possible quality of service is provided at any given time. Kenya Power headquarters are at Stima Plaza, Kolobot Road in Parklands, Nairobi; it operates many offices throughout Kenya.

4.1 Energy Audit Findings

The following observations and findings were made during the energy audit:

- The major electrical loads of the substation include indoor and outside lighting;
- There are several local air conditioning systems, which some are switched on and off by the personnel when needed and others for batteries run throughout;
- Fluorescent lamps are used in most of the general areas of the control rooms. However, there are still over 45 incandescent lamps used in the substation;
- The substation is being installed with shunt reactors for power factor improvement on the 66KV bay.

Detailed areas of study included but not limited to the following observations and probable findings as was made during the energy audit:

There is no formal energy policy statement and energy manager in the whole company. The Chief Manager, Energy Transmission under whom the Juja Rd 132/66KV substation lies operation-wise together with the divisional technical staff address the energy issues, organizing regular maintenance of energy transmission equipment, replacing failed electrical plant equipment, providing for reliable operation of the transmission network, and planning future energy improvements.

No records to indicate any energy survey ever conducted at any of the company's substations or transmission lines by any auditor.

Therefore this audit is based strictly upon observations made at the time of the site visits where potential energy conservation and efficiency improvements, based on the physical operation of the facility at the time of the site visits is suggested .

4.1.0 Energy Management at the KPLC Transmission Substations

Subsequent to the series of meetings, facility tours and witnessing of quite a number of switching operations and procedures, the following findings were established and categorised as hereunder listed:

1. UTILITY INFRASTRUCTURE
2. ENERGY MANAGEMENT POLICY
3. ENERGY MONITORING SYSTEM
4. BENCHMARKING
5. MANAGEMENT OF CHANGE
6. TRAINING
7. ENERGY AUDIT INSTRUMENTS
8. SWITCHING TIME REDUCTION AND SIMULATION PROCEDURE

4.1.1 Utility Substation Infrastructure

The substation's sources of power are a number of six overhead 132KV transmission lines that enter and terminate on gantry (dead-end) structures as seen in appendix. The inlet lines are the Juja-Lessos lines 1 and 2, the Dandora-Juja lines 1 and 2, the Kindaruma-Juja line and the Juja-Rabai line. The lines are connected through disconnect switches with integral earth switches mounted on same structure, capable of visibly isolating the substation from the transmission lines and grounding when necessary. Electricity is routed from these switches across voltage transformers, through current transformers to circuit breakers. These breakers protect the seven power transformers that step voltage down to 66KV distribution levels. High voltage components are said to be located on the "high side" or "primary side" or 132KV bay of the substation. The low voltage sides of the transformers are connected to secondary breakers or transformer breakers.

If a transformer fault occurs, both the primary and secondary breakers will open to isolate the transformer from the rest of the system through the protection scheme. The secondary

breakers are connected to secondary buses that provide power to seven feeder breakers. These breakers are connected to two bus-bars dubbed “main and reserve” respectively. Medium voltage components are said to be located on the “low side” or “secondary side” of the substation.

The 66KV bay is approximately the source of half the load supplied to the City of Nairobi through the following 66KV feeders:

1. Ruaraka 1& 2 feeders towards Ruaraka in Nairobi North zone.
2. Parklands 1&2 feeders towards Westlands zone
3. Jevanjee 1&2 feeders towards the Central Business District
4. EMCO or Steel Billets feeder towards the Eastern side of the City and environs
5. Nairobi South 1, 2&3 feeders towards the Southern zone of the City.
6. Athi feeder towards AthiRiver township where there is a cluster of industries also.

The diversity of the feeder’s services offered to the City of Nairobi makes the Juja Rd substation one of the leading and most relied electrical power facility in Kenya.

The substation has been so arranged since its time of construction in the early 70s and so has no means of increasing reliability by having additional transmission lines, energized spare power transformers, motor-operated switches, apart from primary ring-bus protection and a secondary transfer bus which are not adequate to automate switching. Worse still is that both the Kindaruma and Rabai 132KV lines fly right over the Dandora-Juja interconnector and this is a serious threat should any cut and fall down. Such a situation will plunge the whole substation into darkness and the entire customer base will be affected. There is need for power loss reduction via full automation by way of changing to new efficient and reliable equipment.

4.1.2 Energy Monitoring System

Supervisory Control and Data Acquisition (SCADA) system has been utilized to play a vital role by providing the Kenya Power with valuable knowledge and capabilities that are key to a primary business function- delivering power in a reliable and safe manner. A quality SCADA solution is central to effective operation of a utility's most critical and costly distribution, transmission, and generation assets [42]

The Kenya Power management has set up and are even in the process of updating a comprehensive set of real-time or data logging monitoring SCADA system for all parameters required to complete the transmission efficiency to enable staff to identify

abnormal energy loss and areas of improvement. To this end, in the year 2010, the Kenya Power commissioned its 450 km Nairobi-Mombasa fibre optic line; implemented under a USD 32 million. In this item of auditing, Kenya Power has not fully utilized the SCADA system to automate its switching operations.

4.1.3 Benchmarking

Benchmarking both internally and externally are two powerful tools for energy efficiency performance assessment and logical evolution of avenues for improvement. Trend analysis of energy loss against cost of purchase and regular review of energy performance against the latest benchmarks is a tool used to monitor capacity utilization on energy transmission efficiency.

The European Investment Bank has facilitated the replacement of the old system which was installed in 1990, and which was no longer suitable for the fast growing electricity network in the country

4.1.4 Management of Change

It was established that Kenya Power is ISO certified- ISO 9001:2008 by Bureau Veritas certification body. The company has developed and instituted a system including use of proper written procedures to ensure that any system work procedure changes must take into consideration and include energy efficiency possibilities. Indeed at the level of transmission, it was established that there are at least two noted network outage management systems. These are ENERGY TRANSMISSION INCIDENT MANAGEMENT SYSTEM (ETIMS) and DISTRIBUTION AND TRANSMISSION MAINTENANCE MANAGEMENT SYSTEM (DTMMS). The ETIMS number appears in all transmission maintenance switching programs as seen in appendix 2.

These systems have provided the capabilities to efficiently identify and resolve outages and to generate and report valuable historical information. This is in line with today's increasing requirements of utilities to track and report outage incidences accurately to their consumers of supplied power. The ETIMS support accurate time stamping of outages and power restoration to customers on top of generating reports for management and regulatory reasons. The operations and maintenance works are performed in-house in the company by members of staff.

Internal ISO audits were confirmed taking place every year as evidenced in the very recent ISO audit schedule released in the month of April, 2011 and attached as appendix 1.

Kenya Power has in the last one year appointed a consortium of consultants to spearhead a planned re-branding and organizational culture change programme [38]. The consortium's mandate is to develop and roll out a strategy and implementation programme for the organizational culture change and corporate re-branding (Project dubbed Mwangaza).

Kenya Power Managing Director and CEO, Eng Joseph Njoroge has since indicated that the appointment of the consortium marks a major milestone in the history of the Company and signals the beginning of a new chapter that will see Kenya Power aggressively re-evaluate its existing corporate identity, prevailing corporate culture and vision, among key stakeholders [43].

4.1.5 Training

A key ingredient to success of any energy management programme is maintaining a high level of awareness among staff. This could be in form of both formal and informal training, newsletters, posters, publications and by incorporating energy management into existing training programmes [44]. Training provided to staff responsible for the operation and associated processes are effective and that such training adequately covers the retrieval, management and analysis of predefined parameters captured from the SCADA monitoring system. The training ensures that staff are kept up to date on changes to the work procedures pertaining to improved energy transmission efficiency. The figure 4.1 is a table of the staff trained in various system network courses in the last seven years as obtained from Human Resources and Administration record files.

Table 4.1 Trained personnel in different courses in the last two years.

Course No.	Course Name	No. of staff trained
1	Energy auditing	4
2	Energy management	8
3	Energy purchase and costing	20
5	Renewable energy technologies	3
6	Plant commissioning	50
7	Energy efficiency designs	8
8	Other pertinent courses	A big number

Training is expensive by nature. That was a commendable number of trained personnel and move towards the right direction. By the time of this audit, training on the functioning of the new installed SCADA system was in progress at the national control centre at Juja Road station. So, as far as training was concerned, the Company highly values that.

4.1.6 Energy Audit Instruments

For an energy audit to succeed, availability of portable, durable easy to operate and relatively inexpensive instruments is of utmost importance.

The following were the instruments used in making the audit project a success. Because of the expense in the cost of buying, all the instruments used were the property of Kenya Power.

1. Electrical power measuring instruments like voltmeters, ammeters, power factor meter, frequency meters and energy meters to collect data in appendix 10.
2. Contact thermometer for temperature measurement
3. Infra Red camera as a non-contact thermometer
4. Lux meter for illumination level measurement
5. Gas leak detectors for compressed circuit breaker gas detection

So at least the company greatly conforms generally to the requirements pertaining to identification and quantification of energy transmission measurements and they have adequate instruments for that work.

4.2 Notable Energy Saving Opportunities

During the audit, several no cost and low-cost short-term energy saving opportunities were identified, which if implemented will lead to substantial energy savings. This energy report comprises recommendations for implementation of these energy saving measures, supported with the corresponding savings calculations.

4.2.1 No cost measures:

- 1) The substation control room lights to the battery rooms, control panel rooms and corridors can be switched when and where it is necessary other than running on throughout as the case stands now.
- 2) The control rooms personnel should be encouraged to utilise the services of natural lighting by opening the windows wide open and stop using lights during day time.

4.2.2 Low cost measures:

For a few of the identified measures, the current situation and the proposed measure were described for each, including the financial impacts – if the measure was to be implemented.

4.2.3 Retrofit of the Substation Lighting System

Description

Several areas of the substation are currently illuminated by 60W tungsten filament and 500W quartz halogen incandescent lamps. These areas include the entrance gate, control rooms, washrooms, battery rooms, corridors and walkways, staff quarters and general area lighting behind building blocks. The halogen flood lights are used for security lighting at night. These lamps are being used during the night through out the year, but the usage time is different for particular areas. The light output of the 60W incandescent lamps is about 600 Lumens, while the light output of the 500W quartz halogen lamp is about 11,000 lumens. It is recommended to replace the 60W incandescent lamps with 11W compact fluorescent lamps (CFLs) with the same light output of about 600 Lumens and the 500W halogen floodlights with 100W high pressure sodium lamps with a similar light output. Furthermore, the CFLs and HPS lamps offer 10 times more service life than the incandescent lamps according to manufactures' data sheets.

This measure will result in the same level of illumination at lower energy consumption and cost, and much longer service life, further reducing maintenance costs. For the CFL lamps, the existing lamp fixture (batten/pendant lamp holders) can be re-used. Only the lamps need to be changed. To replace the halogen floodlights, complete HPS fixtures need to be installed. HPS lamps produce a yellowish light colour, but these are only being recommended for outdoor area lighting, where colour is not a major concern.

4.2.4 Financial impacts

Implementation of this measure will result in the following savings:

Energy Savings (kWh) = (No. of Lamps • Operating Hours • Power Difference) / 1,000

Demand Savings (kVA) = (No. of Lamps•Power Difference•12•Diversity Factor)/1,000

a) Security Lighting - Retrofit of Halogen Floodlights with HPS Lamps

All areas of the substations switch yards are currently illuminated by 500W quartz halogen incandescent lamps. The halogen flood lights are used for security lighting at night. These

lamps are being used during the night through out the year, but the usage time is about 12 hours daily. The light output of the 500W quartz halogen lamp is about 11,000 lumens.

The implementation of the measure will result in the following annual savings:

Estimated annual electrical energy savings – 68797.6 kWh/year.

Estimated monthly demand reduction – 17.02kVA

Total Annual Cost Savings = 1338832.29KSh/year

Estimated implementation cost – 506,000 KSh.

Payback period = 0.38 year.

Calculations of expected savings realization

Number of lamps to be replaced = 46.

Operating hours = 12 hours per day.

Replacement lamps: 100w HPS, with integral 30 watt ballast (130 watts total)

Annual energy savings: $46 \cdot 12\text{hrs/day} \cdot 365 \text{ days/yr} \cdot (500-130)\text{W}/1,000 = 68797.6$
kWh/year

Annual energy cost savings: $68797.6\text{kWh/yr} \cdot 18.57\text{KSh/kWh} = 1277560.29\text{KSh/yr}$ **[45]**

Demand reduction = $46 \cdot 370 / 1,000 = 17.02 \text{ kVA}$

Annual demand cost savings: $17.02 \text{ kVA} \cdot 300 \text{ KSh/kVA} \cdot 12 \text{ months} = 61272 \text{ KSh/yr}$

Total annual cost savings = 1277560.29+ 61272 = 1338832.29KSh/yr

Implementation cost:

Cost of procurement and installation of 46, 100 W HPS Flood Lights, wall or structure mounted assembly (fixture complete with ballast and control gear) at 10,000.00 KSh each:

Materials = $46 \times 100\text{W HPS Fixtures at } 10,000 \text{ KSh} = 460,000 \text{ KSh}$

Labour & Misc. (estimated 10% of materials) = 46,000 KSH

Total Implementation Cost = 506,000 KSh

The simple payback period = 506,000 / 1338832.29= 0.38 year.

b) General Area Lighting – entrance/gate, walkways, corridors and behind building blocks.

The implementation of the measure will result in the following annual savings:

Estimated annual electrical energy savings – 8,865 kWh/year.

Estimated demand reduction – 2.04 kVA

Total Annual Cost Savings – 171909.45 KSh/year

Estimated implementation cost - 85,250 KSh.

Payback period = 0.496 year.

Calculations of expected savings

Number of lamps to be replaced = 55

Operating hours = 12 hours per day, with an 80% assumed diversity factor.

Annual energy savings = $55 \cdot 80\% \cdot 12\text{hrs/day} \cdot 365 \text{ days/yr} \cdot (60-14)\text{W}/1,000 = 8,865$ kWh/year, *3W is added to the CFL lamp rating for the ballast power consumption)*

Annual energy cost savings = $8,865 \text{ kWh/yr} \cdot 18.57 \text{ KSh/kWh} = 164623.05\text{KSh/yr}$

Demand reduction = $55 \cdot 46 \text{ W} \cdot 80\% /1,000 = 2.04 \text{ kVA/month}$

Annual Demand cost savings = $2.04 \text{ kVA/year} \cdot 12 \cdot 300 \text{ KSh/kVA} = 7,286 \text{ KSh/yr}$

Total annual cost savings = $164,623.05 + 7,286.40 = 171909.45 \text{ KSh/yr}$

Implementation cost:

Cost of procurement and installation of 55 CFL lamps rated at 11W, using existing lighting fixtures:

Materials = $55 \cdot 1550 \text{ KSh} = 85,250 \text{ KSh}$

Internal resources can be used for replacing lamps. Therefore no labor cost is included.

Total Implementation Cost = 85,250 KSh

The simple payback period = $85,250/ 171909.45 = 0.496 \text{ year.}$

c) Staff Quarters.

The implementation of the measure will result in the following annual savings:

Estimated annual electrical energy savings – 24,177.60kWh/year

Estimated monthly demand reduction – 9.94 kVA.

Total Annual Cost Savings – 484,762.03 KSh/year

Estimated implementation cost – 558,000 KSh.

Payback period = 1.15 year.

Calculations of expected savings

Number of lamps to be replaced = 360.

Average operating hours = 4 hours per day.

Annual energy savings: $360 \cdot 4 \text{ hrs/day} \cdot 365 \text{ days/yr} \cdot (60 - 14)\text{W}/1,000 = 24,177.60\text{kWh/year}$, *3W is added to the CFL lamp rating for the ballast power consumption*)

Annual energy cost savings: $24177.60 \text{ kWh/yr} \cdot 18.57\text{KSh/kWh} = 448,978.03 \text{ KSh/yr}$

Monthly demand savings: $360 \cdot 46\text{W} \cdot 60\% /1,000 = 9.94 \text{ kVA/month}$

Annual demand cost savings: $9.94\text{kVA/year} \cdot 12 \cdot 300 \text{ KSh/kVA} = 35784 \text{ KSh/yr}$

Total annual cost savings = $448,978.03 + 35,784 = 484,762.03 \text{ KSh/yr}$

Implementation cost:

Cost of procurement and installation of 360 CFL lamps rated at 11W, using existing lighting fixtures:

Materials = 360 No. 11W CFL lamps at 1550 KSh = 558,000 KSh

Internal resources can be used for replacing lamps. Therefore no labour cost is included.

Total Implementation Cost = 558,000 KSh

The simple payback period = $558,000 / 484,762.030 = 1.15 \text{ year}$.

d) Control rooms, Battery rooms and Washrooms

The implementation of the measure will result in the following annual savings:

Estimated annual electrical energy savings – 21,356.9 kWh/year

Estimated monthly demand reduction – 2.93 kVA

Total Annual Cost Savings = 407145.63 KSh/yr

Estimated implementation cost – 164,300 KSh.

Payback period = 0.4year.

Calculations of expected savings

Energy Savings (kWh) = (No. of Lamps • Operating Hours • Power Difference) / 1,000

Demand Savings (kVA) = (No. of Lamps•Power Difference•12•Diversity Factor)/1,000

Number of lamps to be replaced = 106

Operating time = 12 hours per day.

Annual energy savings = $106 \cdot 12\text{hrs/day} \cdot 365 \text{ days/yr} \cdot (60-14) \text{ W}/1,000 = 21,356.9 \text{ kWh/year}$, *3W is added to the CFL lamp rating for the ballast power consumption*).

Annual energy cost savings = 21356.9 kWh/yr • 18.57 KSh/kWh = 396597.63KSh/yr

Monthly demand reduction = 106 • 46W • 60% • /1,000 = 2.93kVA/month

Annual demand cost savings = 2.93kVA/month • 12 • 300 KSh/kVA = 10,548 KSh/yr

Total annual cost savings = 396597.63 + 10,548 = 407145.63 KSh/yr

Implementation cost:

Cost of procurement and installation of 106 CFL lamps rated at 11W, using existing lighting fixtures:

Materials = 106 • 1550 KSh/lamp = 164,300 KSh.

Internal resources can be used for replacing lamps. Therefore no labor cost is included.

Total Implementation Cost = 164,300 KSh

The simple payback period = 164,300 KSh / 407145.63 KSh/yr = 0.4 year.

e) Reduction of outage switching time, hotspot correction and simulation of switching operations.

Apart from the energy audit i.e. checking whether there were areas of energy saving opportunities, the other major aim of this project research was to investigate whether automating and thus reducing the outage switching time would have had any considerable significant economic value to Kenya Power as a commercial entity.

To achieve this goal, attendance of several switching operations was done, witnessed and participated. Figure 4.1 is of the Juja Rd 132/66 and shows the substation layout.

Both in-coming and out-going feeders, transformers, conductors, bus-bars and all other auxiliary plant were visually inspected from within the substation, 20 metres from the entrance and exit gantries of the substation on foot. Doing so intended to identify advanced stages of probable causes of damage to cross-arms, hardware, and conductors.

The 132KV bay of the substation is connected in a closed ring/mesh circuit. All the incoming transmission lines terminate in this bay via line isolators with mechanical integral earth switches. On the 132KV bus, each line terminates in between two isolators and circuit breakers. Apart from the breakers which are automated, all the isolators are manually operated save for a few motorised ones which have faulty motors. If reversed and changed to motorised operation, then a big percentage of the objective of this project would be realised and achieved. Then we have the substation seven step-down power transformers connected to the 132KV bay through transformer isolators. Similarly, the 66KV bay has

quite a large number of manually operated no-load disconnect switches/isolators which compounds the problem of the whole substation outage switching.

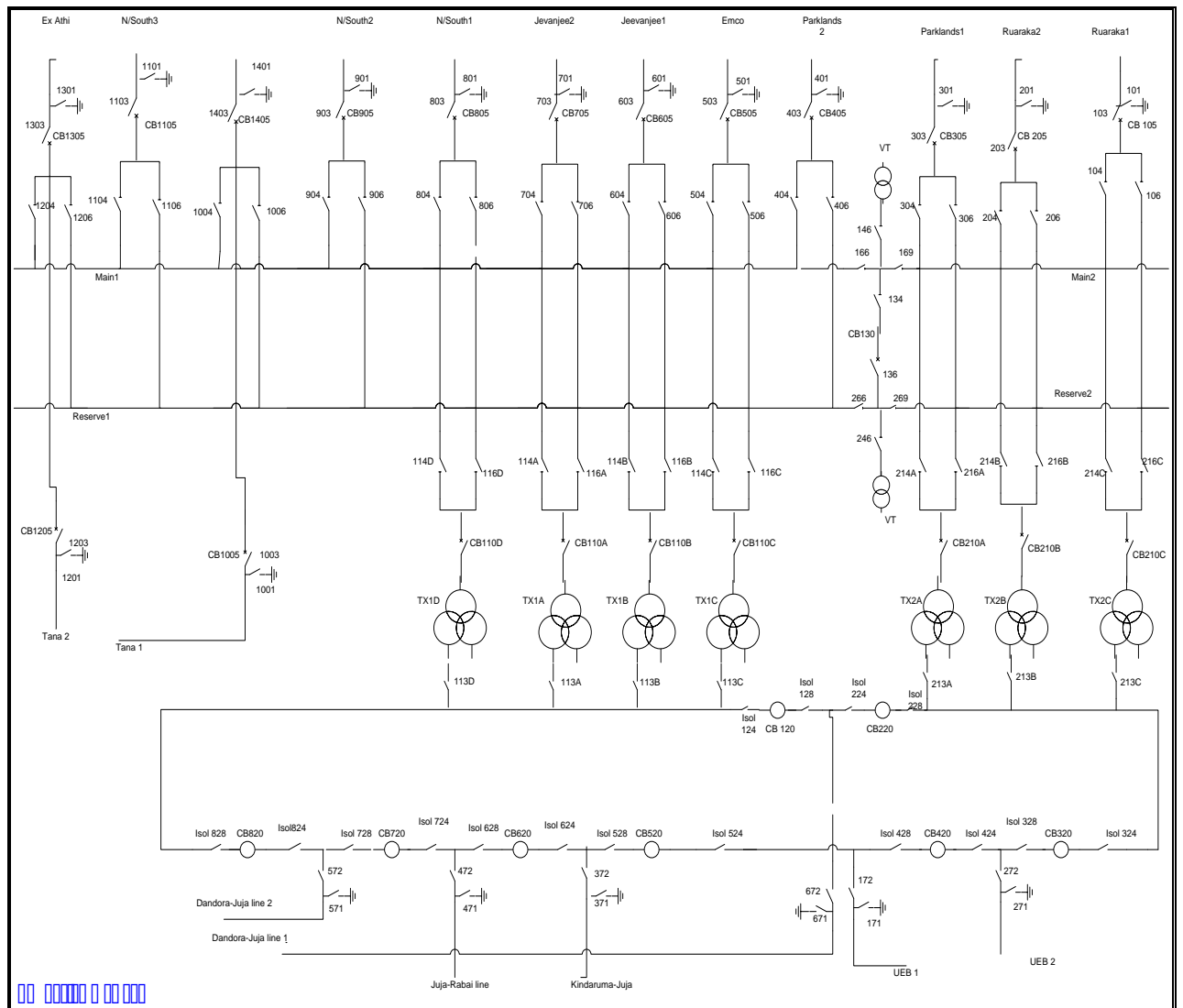


Figure 4.1 Juja Rd 132 to 66KV Substation

Financial impacts

There are two notable measures to take advantage of from the foregoing, namely:

- e)(a) Fitting of motors on the isolators to achieve remote control and operation and thus achieving automation.
- e)(b) Work toward reducing the many areas prone to hot spots - a source of great thermal energy loss..

e)(a) (i) Motorisation of isolators

Implementation of this measure will result in the following savings:

Energy Savings (kWh) = (No. of feeders involved in an outage • Difference in switching Operation Hours • Average Power in a feeder • No. of outages in a year) / 1,000

Assumptions

- 1) The total switching operation time is the sum of a minimum of two switching hours during start of outage and a minimum of two hours of power restoration.
- 2) The average number of feeders affected during outage is 2 and average feeder power is 20000kWh
- 3) Out of 12 months in a year, at least one outage takes place every month.

Calculations of expected savings

Number of motors to be fitted = 65.

Switching Operation hours after motorisation = 1 hour per day.

Energy Savings (kWh) = (No. of feeders involved in an outage • New switching Operation Hours • Average Power in a feeder • No. of outages in a year).

$$= 2 \times 1 \times 20000 \times 12 = 480,000$$

Annual energy cost savings: 480,000 kWh/yr • 18.57KSh/kWh = 8,913,600KSh/yr

Implementation cost:

Cost of procurement and installation of 65 motors isolator structure mounted assembly (fixture complete control gear) at 25,000.00 KSh each:

Cost of motors = 65 x kSh. 25000 = kSh. 1,625,000

Labour & Misc. (estimated 30% of materials) = 487,500 KSH

Total Implementation Cost = 2,112,500 KSh

The simple payback period = 2,112,500 / 8,913,600= 0.24 year.

e)(a)(ii) Control of thermal energy loss on the hot spots

Infrared Inspection results — knowing that nonferrous line hardware in good condition will operate cooler than the conductor [46]. Unreliable or loose connections tend to operate hotter and were identified by infrared inspection camera/equipment.

The following figure is a table of one of the infrared scanning report (Table 4.2) done on the 19th April, 2011 and used to undertake the outage of the 24th April, 2011 whose switching program is herein attached as appendix 2. From the switching program, the switching operation to full isolation and presentation of the system ready for repair work took slightly more than two hours. This is evidenced by the time of start of isolation and time of issuance of the safety document (electrical permit to work) by the day's supervisor in charge with the consent of the system control engineer. The document of the electrical permit to work is attached as appendix 3. Similarly, the restoration of supply after the repair works took almost the same duration of time. This is shown by the difference between the permit's clearance time and that of cancellation.

From the report, all the areas with temperature marked in red required immediate outage planning to avert a system reliability crisis.

Implementation of this measure will result in the following savings:

Energy Savings (kWh) = (Average No. of hot spots detected in one scan x No of scans per month x Average Power dissipated per hot spot x No. of months per year x cost of power/kWh x No. of hrs /day)

Calculations of expected savings

Average No. of hotspots per infrared scan = 10

Average power per hotspot = 3kWh

Average No. of scans per month = 10

Annual Energy Savings (kWh) = 10 x 10 x 3 x 12 x 18.57 x 24 = 1,604,448 KSH


Implementation cost: Approximate Cost of hotspot control per year = kSh. 1,200,000

Labour & Misc. (estimated 30% of hotspot control) = 360,000 KSH

Total Implementation Cost = 1,560,500 KSh

The simple payback period = 1,560,000 / 1,604,448 = 0.97 year.

Table No. 4.2 of the Infrared report of the 19th May, 2011

 <p>The Kenya Power & Lighting Co. Ltd</p>	ISO 9001:2000 QMS Infra Red Inspection Report Sheet LOCATION: Transmission Central Office		Doc. No. KPLC1/7/MS/R-02	Issue No. 1
	SUBJECT: Infra Red Inspection		Revision No. 0	Date of Issue 2006-03-
	WORK ORDER NO.		INSPECTED BY: Eri	
	4.1 SUBSTATION NAME: Juja Rd s/s		DATE OF INSPECTION:	
AREAS INSPECTED:66 KV Side 04/ 11				
Equipment No. & No.	Description of Hotspot Position	Temperature °C	Priority Level	Remarks
Isol 1206	Flex lug conn side of male contact Y φ	121 ⁰ c	High	Normal 26
Btw isol 506&	Short flex conn clamp to busbar B φ	101 ⁰ c		
Isol 404	Flex lug conn side of male contact Y φ	104 ⁰ c		
Isol 503	Flex lug conn bolt Y φ Side of male contact Flex lug side of male contact B φ	150 ⁰ c 89.5 ⁰ c		
CB505	Jumper conn btw CT & C B φ R φ	110 ⁰ c 77.7 ⁰ c		
CB 405	Dropper Y φ	65.5 ⁰ c		Needs to be changed
Isol216B	Male female contact Y φ Side of dropper	99 ⁰ c		
CB210B	Dropper conn.clamp upperside Y φ	66.9 ⁰ c		
Isol1003	Jumper conn clamp from wave trap to isol Y φ	99 ⁰ c		

Priority Level

1. High – Temperatures above 100 °C - Corrective action not to exceed 1 Week
2. Medium – Temperatures 50 °C to 100 °C - Corrective action not to exceed 2 Weeks
3. Low – Temperatures below 50 °C - Corrective action within a month.

4.3 Switching Automation Simulation

Computer simulation has become a useful part of modeling many natural systems in physics, chemistry and biology[47], and human systems in economics and social science (the computational sociology) as well as in engineering to gain insight into the operation of those systems.

In order to simulate the switching process in this project i.e. show the automation of the opening and closing of the circuit breakers and isolators, the Zilog Z-80 microcomputer based software was selected to demonstrate how signals could be generated to close and open a breaker or an isolator in circuit. Figure 4.2a is a circuit representation block diagram while figure 4.2b is the circuit diagram of the basic structure of a Zilog microprocessor based system.

The Zilog microcomputer contains the central processing unit (CPU), a pre-programmed memory containing the operating system software, scratchpad memory for storing temporary results, logic for communicating with a computer terminal, and three parallel input/output ports for hardware control applications [48].

An example program written, assembled, compiled and tried in the simulation software for a blinking system was as follows:

4.3.1 Test Program of a blinking output on the Z-80 microcomputer system flat-form.

```
                LD SP, 1000H
BACK            LD A,0FFH
                OUT (00),A
                CALL DELAY
                LD A,00H
                OUT (00),A
                CALL DELAY
                JP BACK
DELAY          PUSH AF
                LD DE,00FFH
LOOP           DEC DE
                LD A, E
                OR D
                JP NZ,LOOP
                POP AF
                RET
```

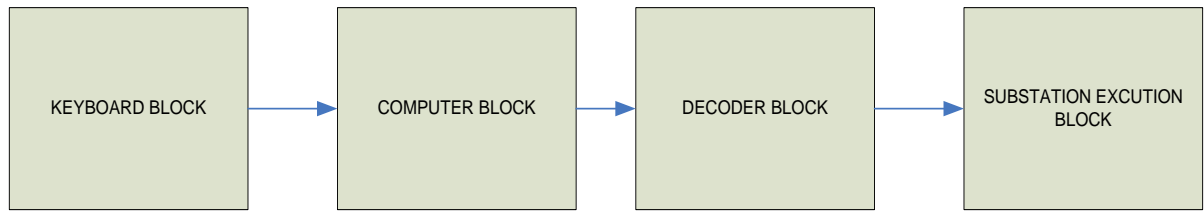


Figure 4.2a of the block diagram representation of the simulation process

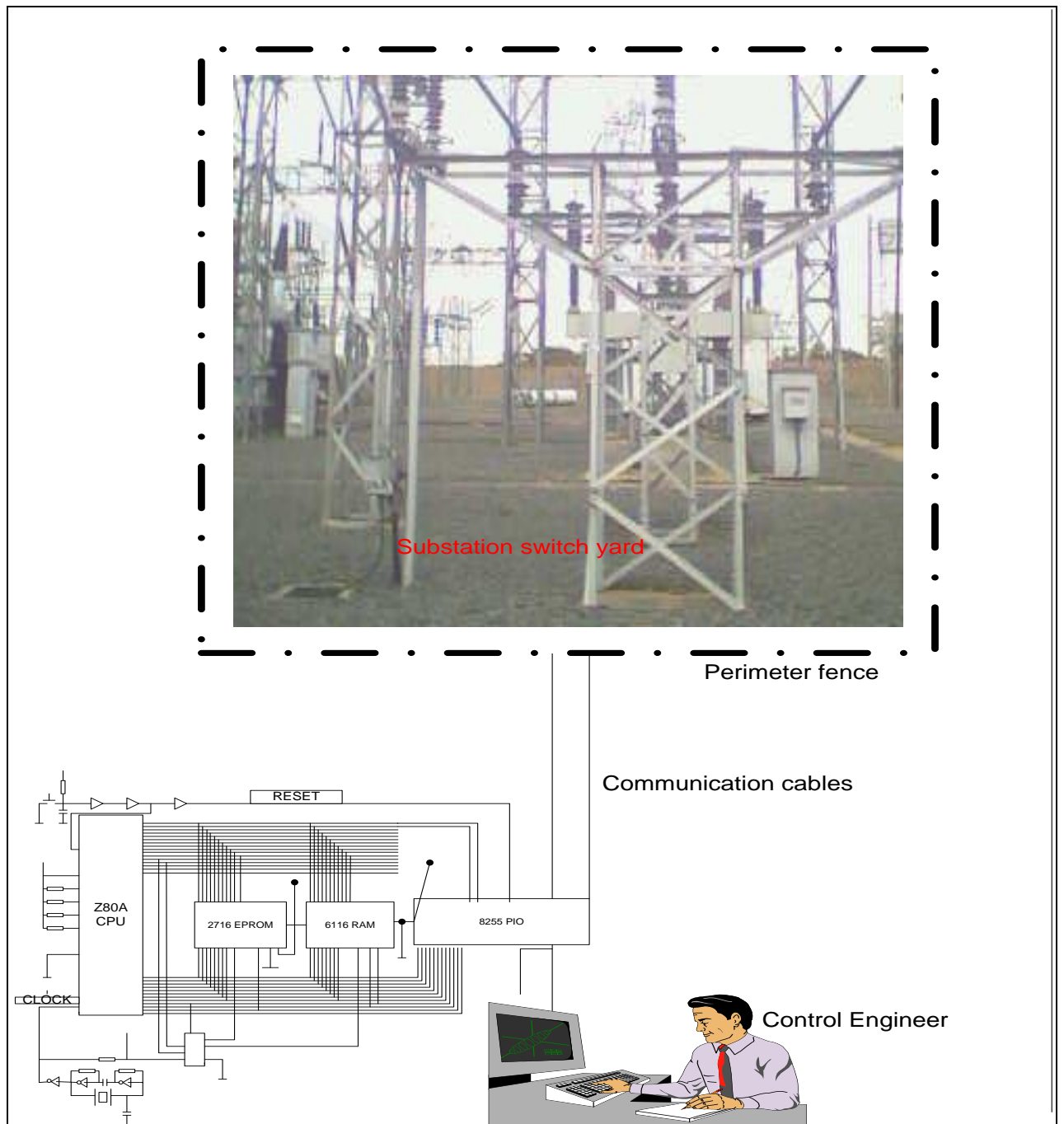


Figure 4.2b of the Zilog microprocessor based system used to simulate switching operations

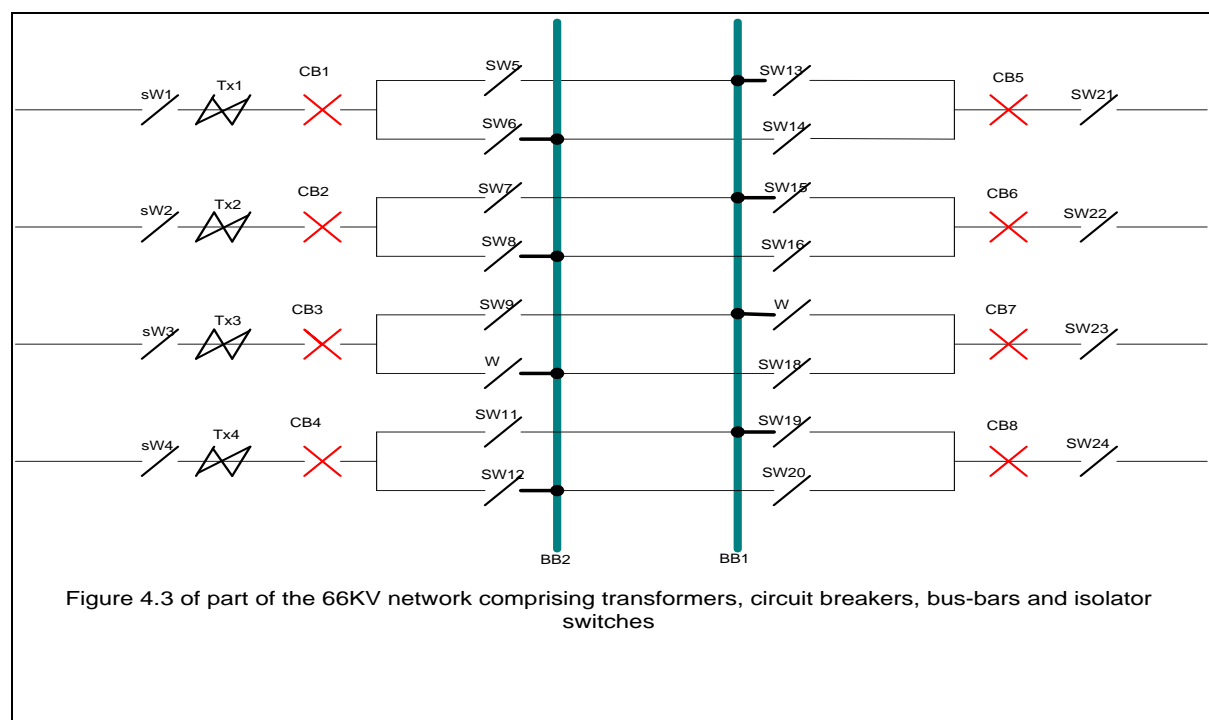
The Zilog microcomputer contains the central processing unit (CPU), a pre-programmed memory containing the operating system software, scratchpad memory for storing temporary results, logic for communicating with a computer terminal, and three parallel input/output ports for hardware control applications [48].

An example program written, assembled, compiled and tried in the simulation software for a blinking system was as follows:

4.3.2 How the Simulation process was realized.

A representative network drawn from part of the Juja Rd substation on the 66KV bay was here by used to demonstrate a real time network circuit. The various electrical plant equipments were then noted and accorded unique numbers to identify and distinguish them from one another. Figure 4.3 is the circuit used to show the process of simulation.

The network comprises of 4 power transformers, 8 circuit breakers, two bus-bars and 24 isolators or disconnect switches all interconnected to form the whole. For ease of management of all switching operations, the circuit breakers were numbered CB1, CB2 all through CB8. The transformers were numbered Tx1 through Tx4, the bus-bars BB1 and BB2. Finally the isolators were assigned numbers S1 through S24. Table 4.3 indicates each unit and its corresponding Hexadecimal code number pressed on the key board to give an out put display number in binary form.



With this kind of information, the might of microprocessors was invoked to input signals from a keyboard to control the corresponding output signals to operate the addressed component of the circuit. This was possible by writing down the Z-80 control program to operate the microcomputer simulation software. By so doing, the operations time of opening and closing individual units was tremendously reduced right from the comfort of the system control engineer's desk. Section 4.3.3 is the program written and used to run the simulation process.

Table 4.3 of both the Hex and Obj codes of the units number assignment

Unit identifier	Keyboard Hex-code input	Output display Object- code/add
Tx 1	01H	00000001
Tx 2	02H	00000010
Tx 3	03H	00000011
Tx 4	04H	00000100
CB1	05H	00000101
CB2	06H	00000110
CB3	07H	00000111
CB4	08H	00001000
CB5	09H	00001001
CB6	0AH	00001010
CB7	0BH	00001011
CB8	0CH	00001100
BB1	0DH	00001101
BB2	0EH	00001110
SW1	0FH	00001111
SW2	10H	00010000
SW3	11H	00010001
SW4	12H	00010010
SW5	13H	00010011
SW6	14H	00010100
SW7	15H	00010101
SW8	16H	00010110
SW9	17H	00010111
SW10	18H	00011000
SW11	19H	00011001
SW12	1AH	00011010
SW13	1BH	00011011
SW14	1CH	00011100
SW15	1DH	00011101
SW16	1EH	00011110
SW17	1FH	00011111
SW18	20H	00100000
SW19	21H	00100001
SW20	22H	00100010
SW21	23H	00100011
SW22	24H	00100100
SW23	25H	00100101
SW24	26H	00100110

4.3.3 Zilog Z-80 Microprocessor Final Project Program

```
        PROG EQU 0000H
        STACK EQU 1000H
        WORD EQU 82H
        PORTA EQU 00H
        PORTB EQU 01H
        PORTC EQU 02H
        PORT4 EQU 03H
        ORG PROG
        LD SP,STACK
        LD A,WORD
        OUT (PORT4),A
NEXT    IN A,(01H)
        CALL DELAY
        OUT (00),A
        CALL DELAY
        JP NEXT
DELAY   PUSH AF
        LD BC,000FH
LOOP    DEC BC
        LD A,C
        OR B
        JP NZ, LOOP
        POP AF
        RET
```

When run in the assembler, it automatically generated the machine code necessary for running the simulation as can be seen in the simulation screen shots of figure 4.4 (a and b). A graphic user interface keyboard facilitates the pressing of component address code as the operator wishes.

4.3.4 Simulation Results

Appendix4 contains the drawn circuit network of the entire Juja Rd substation switchyard and the figure 4.4 shows a screen shot of the computer simulation results on running any written and compiled program.

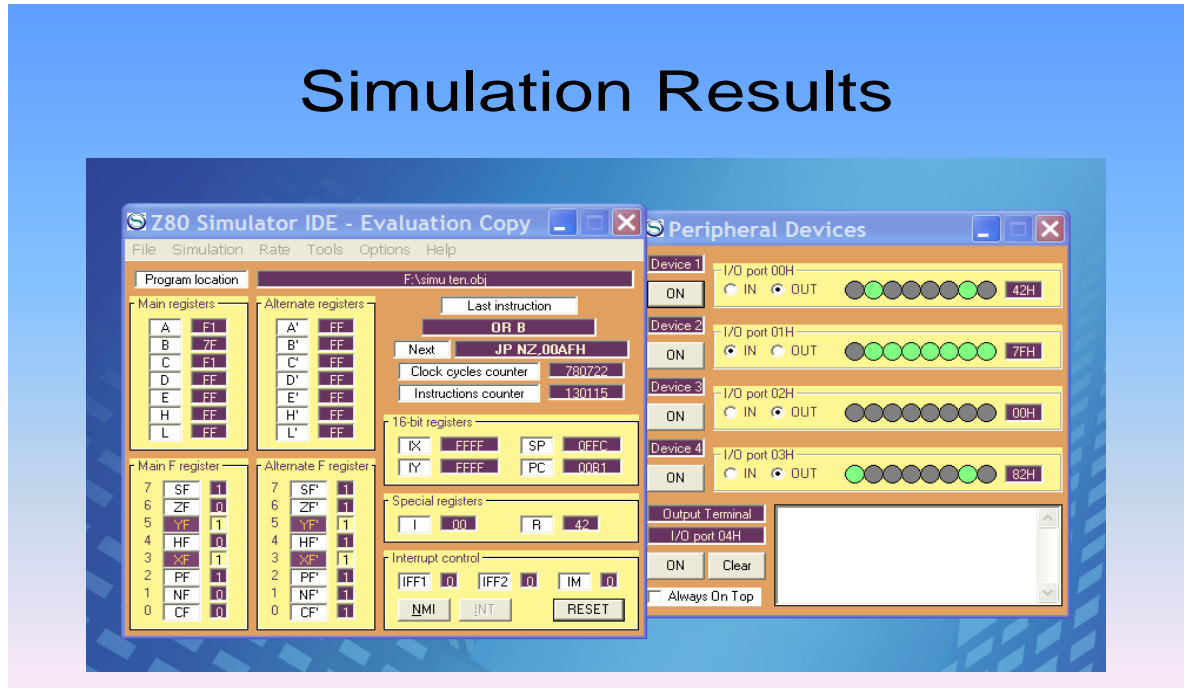


Fig.4.4a of the screen shots of the simulation first stage.

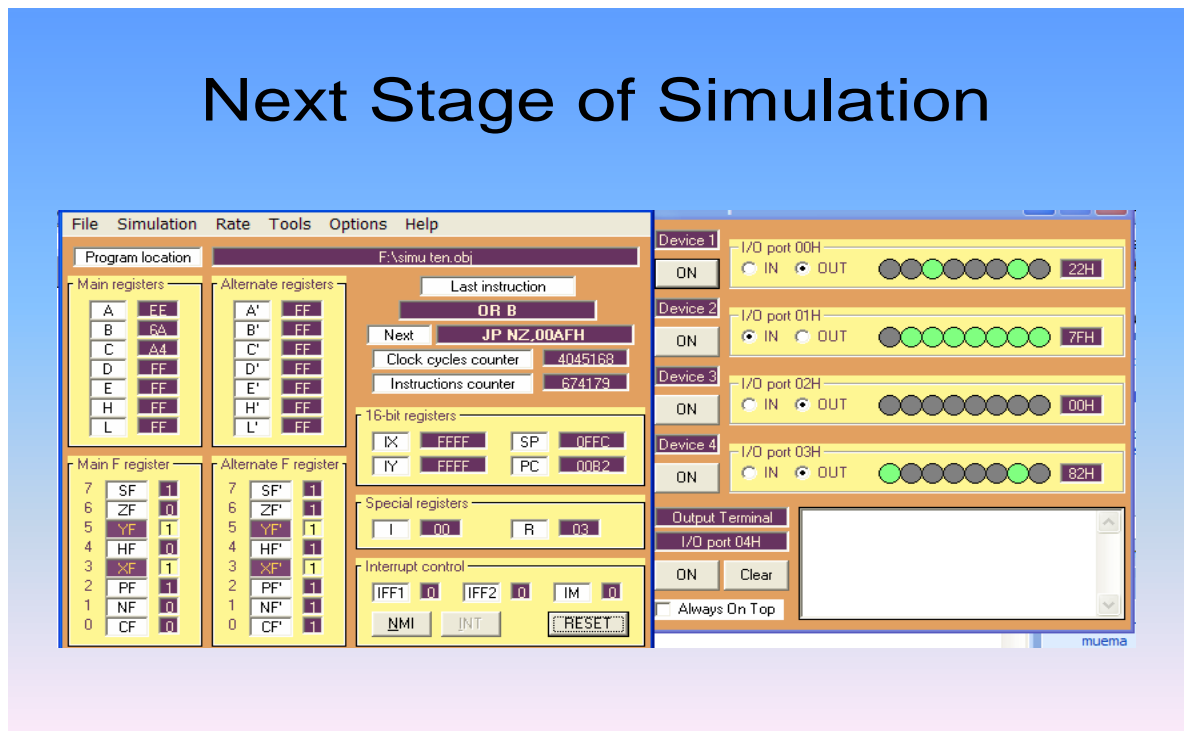


Figure 4.4b of the computer screen shot simulation results for the next stage.

Practically in real time, switching the circuit of figure 4.3 as at the Kenya Power Juja Road substation takes at least 2 hours to isolate a circuit for maintenance. However, after simulation, the same process would take less than 10 minutes. In real time operation considering signal transmission delays, the process of isolation can take at most 1 hour. This by itself is the beauty of automation because it reduces the switching time tremendously.

Considering the circuit diagram of figure 4.3 say a fault did occur along bus-bar1. Then the switching program would involve the following isolation points to completely present it for maintenance: Switches SW5, SW7, SW9, SW11, SW13, SW15, SW17 and SW19.

The switching program would then be as follows:

- 1) Trip CB1 and open switches SW5 and SW13 and lock off with non standard padlock to take approximately 15 minutes to cover distance involved.
- 2) Close back CB1.
- 3) Trip CB2 and open switches SW7 and SW15 and lock off with non standard padlock to take approximately 15 minutes to cover distance involved.
- 4) Close back CB2 .
- 5) Trip CB3 and open switches SW9 and SW17 and lock off with non standard padlock . Similarly it takes approximately 15 minutes.
- 6) Close back CB3.
- 7) Trip CB4 and open switches SW11 and SW19 and lock off with non standard padlock. Another 15 minutes gone.
- 8) Close back CB4.
- 9) Test whether dead/not charged.
- 10) If not charged, apply a set of overhead circuit main earth at the point of work.
- 11) Sanction for electrical permit to work according to regulations.

Practically this process in real time would take more than one hour because the units are spread over a distance from each other and would therefore require the operator to walk and cover quite a distance to manually open the isolators. However, with the application of the software program, it was demonstrated that it would definitely take less than 3 minutes from the comfort of the control engineer's desk when all the switchgear involved are fully

automated. The successful demonstration of the working simulation results marked the end of this project.

In cost terms, this two hours before and after maintenance can be quantified as follows:

- 1) Two plus two gives a total of four (4) hours in every outage.
- 2) Assuming an average of five (5) outages in a month, in a year will have 60 in number.
- 3) Assuming the average power evacuation by each feeder as 2 megawatt giving a total of 22MW for the eleven feeders as listed in section 4.1.1
- 4) The 4 hours per outage by 60 outages translates to 240 hours in a year or 22MW by 60 outages totalling to 14400MW in a year saved and sold towards the revenue base.
- 5) In revenue terms $14400\text{MW} \times 1000 \times 18.57\text{Ksh/KWh}$ gives Ksh.267408000. So basically a total of Kenya shillings **267 millions** will be saved in a year by the mere fact of automating and switching from the control engineer's desk. If the cost to implement this was assumed to be 7 millions using the new SCADA system currently under installation, then the total savings would amount to **Kenya shillings 260 millions** in a year.

CHAPTER FIVE

5.0 RECOMMENDATIONS

1. All substations in Kenya Power occupy large areas of land to accommodate the design requirements of the given facility. However, each time power flows through a substation to step down the voltage, more energy is lost as the power flows through the transformers, switches and other equipment. The efficiency of the lower-voltage lines coming out of the substation is also markedly lower than their high-voltage counterparts. If power can be transmitted at higher voltage to a substation that is closer to where the energy will be consumed, significant efficiency improvements are possible - a feature with Gas Insulated substations.

This is what is recommended for Kenya Power in the long run to improve on Transmission and Distribution efficiency and reduce losses.

2. With the advent of a new type of High Voltage Direct Current, invented by ABB and dubbed HVDC Light [45], the benefits of DC transmission and distribution are now being realized on much shorter distances. This can be highly recommended in Kenya Power substation feeders to reduce distribution feeder losses and therefore strike a near balance between power input and that of output.

3. It is highly recommended exploration of the use of superconducting materials for conductors within substations to curb the notable losses through infra-red hotspots. Superconducting materials at or near liquid nitrogen temperatures have the ability to conduct electricity with near-zero resistance and carry three to five times the power of conventional cables. The losses in the High Temperature Superconductor cables are also significantly lower than the losses in conventional lines. A major vendor [49] of superconducting conductors claims that the HTS cable losses are only half a percent (0.5%) of the transmitted power compared to 5-8% for traditional power cables. Superconducting materials can also be used to replace the copper windings of transformers to reduce losses by as much as 70% compared to current designs in the power transformers within Kenya Power.

4. It is recommended to replace the 500W halogen floodlights with 100W high pressure sodium lamps with a similar light output. Furthermore, HPS lamps offer 10 times more

service life than the incandescent lamps. This measure will result in the same level of illumination at lower energy consumption and cost, and much longer service life, further reducing maintenance costs. To replace the halogen floodlights, complete HPS fixtures need to be installed. HPS lamps produce a yellowish light colour, but these are only being recommended for outdoor area lighting, where colour is not a major concern. However the Company management should be aware of the colour rendition from these fixtures before deciding whether to implement recommendation.

5. Other notable paths to improved efficiency would be

- Voltage optimization through the reactive power compensation being undertaken
- Asset replacement schedule optimization to phase out old inefficient plant and equipments
- Distribution loss reduction via distribution automation
- Load management (e.g., smart metering or price-sensitive load control)

CHAPTER SIX

6.0 CONCLUSION

Power system reliability is the field of engineering devoted to assessing the adequacy and security of power systems. Adequacy is defined as the ability to meet the aggregate electrical demand and energy requirements of customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements.

It was evident that if provisions were made to automatically incorporate, in real time, the effects of breaker operation on system topology and decisions for switching actions made quickly and safely, then little cost would be used to maintain the continuity and quality of supply to consumers. The function of a power system is to supply consumers with electric energy economically, at any time and location, observing reliability and quality standards. The practical economic impossibility to store significant amounts of electric energy implies that a balance between generation and load, including network losses, must be maintained at all points in time.

Today's fast moving and economy-driven business environment has dictated that companies, both private and public, cannot be competitive without closely examining traditional design practices and taking full advantage of the tools available to help them overcome limitations. They must make conscious efforts to make paradigm shifts and welcome new ideas, technologies, and practices. The computer is the major tool of the corporate world, and this project did come up with a tool that would allow the transmission line industry Kenya Power to make a major move within the re-engineering effort.

The interactive computational software model developed would be able to switch all the alternative switching points which are available following the occurrence of a substation abnormality, making maximum utilisation of substation equipment.

This energy audit project was therefore used to identify cost effective ways to improve the reliability and efficiency of transmission substations in Kenya Power.

7. PROJECT BUDGET

The following 7.1 was the initial projected budget for the project expenditure. The total project cost was estimated at about ninety to hundred thousand Kenya shillings.

Table 7.1 of projected budget

No.	Items	Cost(kshs)	Remarks
1	Transport expenses	10,000	
2	Stationery	10,000	
3	Tools	5,500	
4	Instruments	15,000	
5	Photocopying	5,000	
6	Printing	7,500	
7	Project typing and binding	8,000	
8	Equipment hiring	15,000	
9	Contingencies	10,000	
10	Total	86,000	

However, due to availability of tools and equipment within the Kenya Power, the actual project cost scaled down to about KShs. 43,000 as indicated in table 7.2.

7.1 PROJECT COST

Table 7.2 the actual cost of doing the project.

ITEM	COST IN KSHS.	REMARKS
Transport expenses	12,850.00	For movement
Stationary	5,000.00	
Photocopying	5,000.00	
Tools and Equipment	1,200.00	
Instruments	750.00	
Project typing	3,000.00	
Printing and binding	10,000.00	
Contingencies	5,000.00	
Total	42,800.00	

8. APPENDICES

APPENDIX 1:- May, 2011 Kenya Power internal ISO audits schedule

This appendix contains a mail addressed to all company employees in preparation of the scheduled annual audits.

From: Catherine Ndungu

Sent: 19 April, 2011 15:51

To: Everyone in KPLC

Subject: IQA Audit Schedule - May 2011 final

Attached please find the schedule for the May 2011 Internal Quality Audits (IQAs), summary of the QMS requirements and a copy of the ISO 9001:2008 standard

The audits will be conducted on the dates indicated below for the different regions

9 th - 13 th May 2011	Central Office & Nairobi Region
16 th - 20 th May 2011	Coast Region
23 rd - 27 th May 2011	West Region
6 th - 10 th June 2011	Mt. Kenya Region

DIV	DEPART		AUDIT NO	AUDITORS/TEAM
MD & CEO'S OFFICE	TOP MANAGEMENT	MD, CM - Fin, CM - E/T, Dist, CM-PR&PM, CM – T, CM – HR & A, CM – & T, CM - CS, CM – C Communications, Comp Secretary	IQA/1/1/11	Henry Gichuru Joyce Ochien
	Quality Management System	Management Represent	IQA/2/1/11	
	Safety, Health & Environment	Head of Department & S	IQA/3/1/11	
	Corporate Communication	Head of section & Staff	IQA/4/1/11	
	Security	Head of Department & S	IQA/5/1/11	
	Internal Audit	Head of Department	IQA/6/1/11	Kimtai Bett Erick Wekesa
	General Audit	Head of section & Staff	IQA/7/1/11	
	Financial Audit	Head of section & Staff	IQA/8/1/11	
	Supplies Audit	Head of section & Staff	IQA/9/1/11	
	Investigation	Head of section & Staff	IQA/10/1/11	
	Information System Audit	Head of section & Staff	IQA/11/1/11	
	Technical Audit	Head of section & Staff	IQA/12/1/11	
COMPANY SECRETARY	Insurance	Heads of Section & Sta	IQA/13/1/11	
	Legal Office	Heads of Section & Sta	IQA/14/1/11	
	Record Management	Heads of Section & Sta	IQA/15/1/11	
	Property Office	Heads of Section & Sta	IQA/16/1/11	
	Shares Office	Heads of Section & Sta	IQA/17/1/11	
ENERGY TRANSMISSION	Energy Purchase & System Control	Head of Department	IQA/18/1/11	Geoffrey Mul Elizabeth Wany

	System control	Heads of Section & Sta	IQA/19/1/11	
	Energy purchase	Heads of Section & Sta	IQA/20/1/11	
	Technical Services	Head of Department	IQA/21/1/11	
	Electrical Plant Workshop	Heads of Section & Sta	IQA/22/1/11	
	Electrical Plant Projects	Heads of Section & Sta	IQA/23/1/11	
	Protection	Heads of Section & Sta	IQA/24/1/11	
	Transmission	Head of Department	IQA/25/1/11	
	Transmission & Network Maintenance	Heads of Section & Sta	IQA/26/1/11	
	Aviation Services	Heads of Section & Sta	IQA/27/1/11	
DISTRIBUTION	Operations & Maintenance	Head of Department	IQA/28/1/11	Wanyoike Mwaur Dalton Langat/4 *
	Design & Construction	Head of Department	IQA/29/1/11	
	Way leaves	Head of section & Staff	IQA/30/1/11	
	Drawing Office	Head of section & Staff	IQA/31/1/11	
	Survey	Head of section & staff	IQA/32/1/11	
	Central Design	Head of section & staff	IQA/33/1/11	
	Construction	Head of section & staff	IQA/34/1/11	
	Business Development	Head of section & staff	IQA/35/1/11	

APPENDIX 2:-Switching programme used to undertake the outage of the 24th April, 2011 at Juja Rd substation by the Kenya Power staff

ETIMS 2789

Outage of Reserve BB1 at Juja Rd. S/s for Hotspot Correction on Sunday 2011-04-24 - 0800-1600 hrs

- NRCC to transfer Athi load to Embakasi.
- In charge of work – Festus Muema.

Isolation – to be done even if Athi is not yet transeferred to Embakasi

1. Confirm BC 130 closed.
2. Close isols. 206 & 304 to make double parallel.
3. Close isol. 504, open isol. 506 L/O
4. Close isol. 1004, open isol. 1006 L/O
5. Close isol. 1104, open isol. 1106 L/O
6. Close isol. 1204, open isol. 1206 L/O
7. L/O in open position isols. 406,116C,116B,606,116A,116D,706,806,116R & 906
8. Open isol.266 live condition, no load to discharge Reserve BB1.
9. Test POW, prove dead, apply CMEs appropriately.
10. Sanction issue of EPTW.

Hotspot Correction on Isolator 1206 - to be done if Athi loads ex Juja have been transferred to Embakasi

Isolation

1. Confirm with NRCC that all Athi loads is ex Embakasi.
2. At Juja, open CB 1305, open isol.1303 L/O.
3. At Thika , transfer TR2 load to Line1 thus:
 - a. At Thika, close BS, open Incomer 2 OCB.
 - b. At Juja, open CB 1205.
 - c. At Thika, close isol. W212, open isol. 2W3 L/O.
 - d. At Thika, close Incomer 2 OCB, open BS.
4. At Juja, with CB 1205 open, open isol.1203 & 1204 L/O.
5. Test POW, prove dead, apply 2 sets of O/H CMEs either side.
6. Sanction issue of EPTW.

Restoration

Assumption - Isol.1206 also isolated and repaired

1. Clear/ Cancel EPTW ,recover all CMEs
2. Close isol. 266 to charge Reserve BB1.
3. Close isol. 1106, open isol. 1104
4. Close isol. 1006, open isol. 1004
5. Close isol. 506, open isol. 504
6. Confirm BC 130 closed, open isols. 206 & 304 to break double parallel.
7. At Juja, with CBs 1205 & 1305 open, close isols. 1206 & 1303.
8. At Juja, close CB 1305.
9. At Thika, close BS, open Incomer 2 OCB.
10. With CB 1205 open, close isol.2W3, open isol. W212
11. At Juja, close CB 1205.
12. At Thika, close Incomer 2 OCB, open BS. Confirm all okay at Thika.
13. NRCC to normalize Athi load.

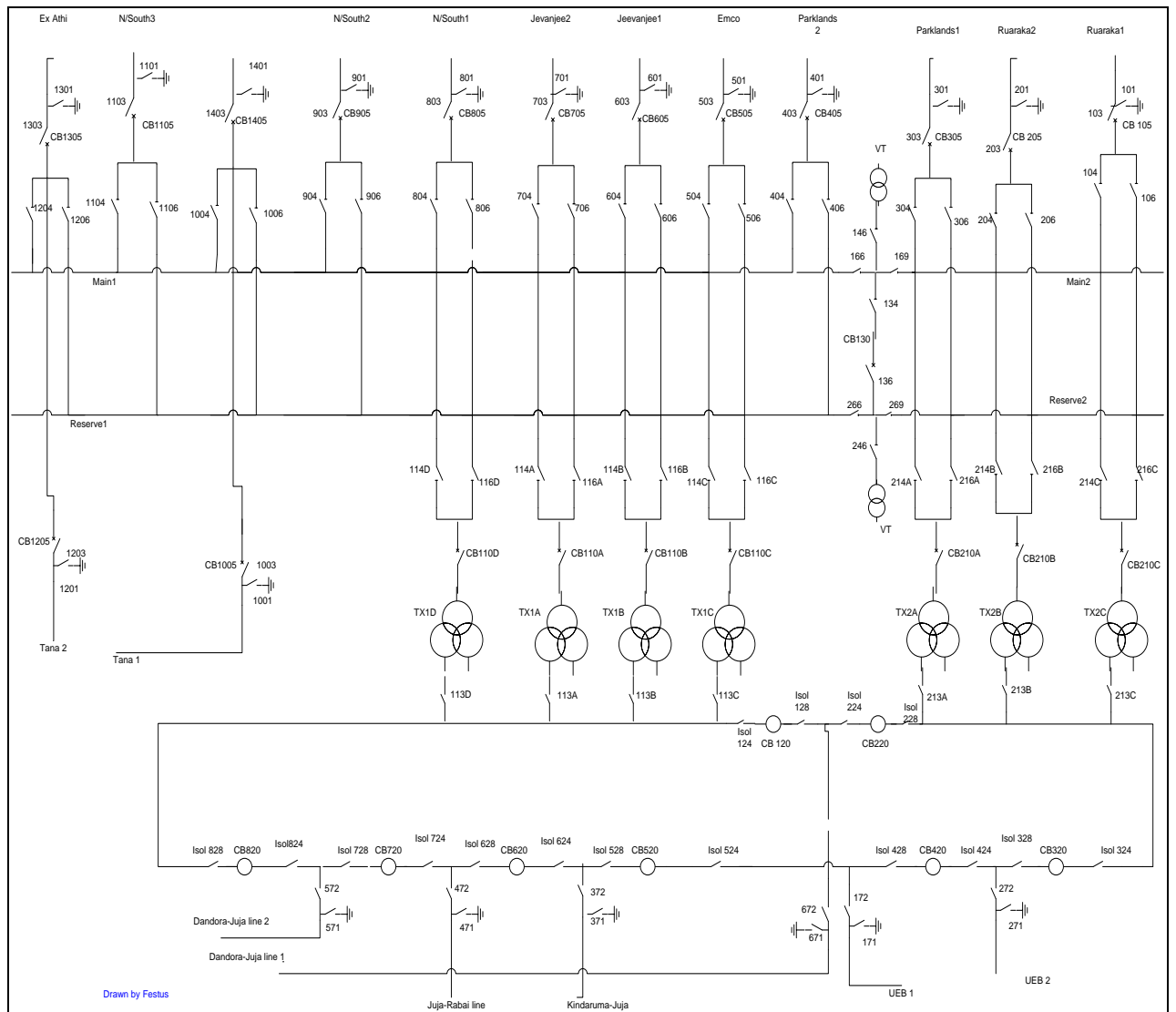
Prepared by: Cyril Bett -system control engineer on 2011-04-23

Checked by: Charles Maloba- Senior system control engineer

APPENDIX3

The scanned copy of the document of the **Electrical Permit to Work** on the 24th April, 2011 attached as appendix3

APPENDIX 4 Overall network circuit diagram for Juja Rd substation



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