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Energy audit of the Nigeria's International Airports: case of the Murtala Muhammed International Airport Lagos, Nigeria

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Abstract
Energy Audit is a means of capturing, measuring and analyzing energy consumption of a facility with the aim of achieving high energy efficiency. The American Society of Heating, Refrigerating and Air- Conditioning Engineers (ASHRAE) provides the guideline for the audit of facility in order to improve energy efficiency and reduce energy cost. This study was therefore designed to investigate the potential for energy cost reductionof the Murtala Muhammed International Airport, Lagos, Nigeria through auditing its power distribution network and energy consumption pattern.The Level One ASHRAE audit methodology was used in the study to analyze the energy consumption patterns and power distribution network of the Airport. A walk-through audit was carried out and data for the entire distribution network was collected, collated on Microsoft Excel, visualized on Geographic Information System Software (ArCGIS) and modelled using an Electrical Power Analysis Systems Software (ETAP). The power distribution network consists of; two 33kV primary distribution lines as supply feeders, two 8MV 33/11kV power transformers, eleven 11kV feeders and 106 distribution transformers and over 100 load centers. The analysis of the monthly electricity bill of the Airport revealed a daily peak load of 12.9MW at noon and a peak energy utilization of 548567.3W at 5pm, an average of 6,000,000 units of grid electricity, an average monthly grid energy cost of N230,000,000 and an off grid (diesel engine) electricity cost of N100,000,000 at the local airport. Load flow Analysis of the network on ETAP resulted in 38 overloaded bus bars and 3 overloaded transformers. Undersized network components that limits the capacity of the grid network and invariably increase energy cost were identified. The result indicates that an Annual energy cost saving achieved was N400,000,000 at the local wing when the power distribution network was retrofitted and optimized with network improvement components.This study established an inefficient power distribution network topology in the distribution networkof the airport and energy cost reduction; hence retrofitting is recommended.

Keywords: Energy Efficiency, Energy Cost Reduction, Utility bill analysis, Power distribution network

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I. Introduction

Energy is a critical factor for the economic development of any Nation. Emerging economies, such as Nigeria, have growing energy consumption and investments. As a result, a highly efficient energy value chain will be critical to improving productivity and expanding investment prospects.Energy availability and accessibility are well-known requirements for any country to achieve industrialization [1].Energy resources and commodities simulate economic advancement by improving productivity, income, and employment [1].For industrial operations, in many instances, the cost of energy far outweighs the cost of other production resources such as maintenance, operations, human resources and depreciation. The growing demand for the exploitation of limited energy resources coupled with the unstable cost of fossil fuel and the attendant environmental impacts of continuous exploitation to the climates has birthed the need for energy efficient systems.Energy efficiency is the use of a minimum amount of energy while maintaining a desired level of economic activity or service. In other words, energy efficiency is the amount of useful output achieved per unit of energy input. Improving energy efficiency means either achieving more from the same input or achieving the same output with less input [2]. Excessive and inefficient energy consumption increases the cost of goods and services especially in energy intensive industries.There is an untapped and significant potential for improved energy savings and energy efficiency in the different sectors of the Nigerian economy. There is therefore a need to identify the processes that degrade the quality of energy and energy system through a detailed analysis of the whole energy value chain of any facility with the aim of minimization energy waste and improving the overall efficiency of the energy system [3].The poor state of on-grid power in Nigeria has entrenched and informal and unregulated distributed and decentralized power system in the nation. Inadequate grid generation plants, radial transmission lines and poor distribution networks has made the supply of on-grid power highly unreliable. Consequently, many production companies are self-sufficient relying on captive generation to meet their energy requirement. This has invariably increased the average energy cost of production across the country to up to 40% of production cost [4]. Captive Generation by industries and limited knowledge on the efficient energy management has also indirectly enabled inefficient energy systems in Nigeria. Many Industries, in the sizing of their power plant, typically consider the different cost of the various available option, their inherent fuel cost, maintenance cost, replacement cost in comparison to the proposed overall cost of operations. The indirect cost of plant inefficiency is usually not quantified and therefore not considered. For example, most industries purchase plants whose installed capacity is usually far greater than their average load. This means that the power plant will operate with a low plant load factor (PLF), thereby expending more energy for a unit of production. The Plant load factor is a measure of the average output of a power plant compared to the maximum output it could produce. The Higher load factor usually means more output and lower production cost per unit, this means that as PLF approaches 100% the efficiency of the thermal plant increases [5]. Furthermore, on higher load, all the connected auxiliaries also run at close to full load, which results in utilization of the connected auxiliaries at higher efficiency[6].The Inadequate metering of customers and estimation of electricity bills in Nigeria has further entrenched an attitude of inefficiency in energy utilization across the country. An unmetered customer has little or no incentive to commit to energy efficient appliances and/or adapt to efficient energy consumption patterns. The lack of adequate electricity meters is a major contributing factor to the high commercial and collection losses being experience by power sector across the nation, and a major stumbling block to achieving energy efficiency as a nation.Metering is an important tool for measurement and a basic building block for building efficient energy systems. Effective energy metering and monitoring provides the necessary information to improve energy performance [7]. After metering, Energy Audit is the next step towards energy efficiency. Energy Audit is a means of capturing, measuring and analyzing energy consumption of a facility with the aim of achieving high energy efficiency. According to Energy Conservation Act, 2001, of the Republic of India, Energy Audit is defined as "verification, monitoring, and analysis of energy use, including submission of technical report containing recommendations for improving energy efficiency with a cost benefit analysis and action to reduce energy consumption" [8] by the Republic of India's Energy Conservation Act, 2001.An energy audit enquires deeper into a facility's energy usage in order to uncover energy-saving opportunities.

An audit can discover facility-specific energy conservation opportunities (ECOs) that can cut energy, natural gas, and water use, resulting in a reduction in total operational costs.

An Energy Audit entails a thorough examination of

- a facility energy Consumption patterns
- the cost of energy from different sources
- a recommendation program for changes in operating practices and/or retrofitting of energy consuming equipment that will effectively lower the facility's energy costs.

An energy audit of a high-energy (Industrial) consumer is a useful tool for establishing a sustainable and comprehensive energy management program for a facility.

The audit serves to identify all energy streams in a facility while quantifying energy usage according to discrete functions [9]. Energy audits provide information on how energy and fuels are utilized, as well as assisting in the identification of potential energy and fuel savings regions of waste and, as a result, opportunities for improvement. Furthermore, the audit exercise report serves as a reference for successful energy management, energy forecasting, and energy planning.

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Airports

An airport is a location where planes can take off and land.It is a complex system of runways and buildings used for aircraft operations.

It is typically utilized for commercial air transportation and often includes storage and maintenance facilities.A landing place, an aerially accessible open space, a runway for planes to take off, and utility buildings such as control towers, hangers, and terminals make up an airport in its most basic form [10].Air transportation is a crucial enabler of economic development and growth.According to estimates, the global airline industry moved 3.78 billion passengers and 52.7 million tons of cargo in 2017, and a study found that more than $18.6 billion in commodities transit by air each day and this amounted to one-third of all global trade [11].

Aviation plays a unique role in linking businesses to markets, bringing families and friends together, bridging the gap in the business world, and assisting people in exploring the world.Air travel facilitates integration into the global economy and provides critical national, regional, and international connectivity.It contributes to the growth of trade, tourism, and job opportunities [12].It plays a vital role in transporting fresh produce from agricultural communities in developing economies to markets in the industrialized world. At the international level, a country's economic development is largely determined by the frequency, magnitude, and nature of its interactions with other economies, which means that airports, as major gateways into these countries, must play an important role in any nation's growth and development. At the local level, airports contribute significantly to economic growth by permitting the fastest possible flow of products and people, including service providers, between different locations [13].Lighting, heating, ventilation, air conditioning, and transportation systems all consume a significant amount of energy at airport terminals; It is reported that Airport buildings consume 40% of all electrical energy consumed in the United States.Some airports have cut costs by focusing on energy efficiency, which takes into account both energy supply and consumption.When energy inputs are lowered for a certain level of service, or services are added or upgraded for a given quantity of energy inputs, energy efficiency improves.Energy efficiency is the least expensive, most environmentally friendly, most immediately deployable, least visible, least understood, and most neglected approach to deliver energy services.

II. Literature Review

The 1970’s oil embargo by the Organization of Arab Petroleum Exporting Countries and ensuing energy crisis proved to be a pivotal point in major industrial countries around the world. It revealed a global weakness in the energy business, as major industrial nations suffered significant petroleum shortages (both real and perceived) and unreliable energy supplies, which, when combined with other variables, ushered in a time of high inflation in the global market.The 'embargo' and other political concerns combined to create a critical opportunity for developing and updating national energy policies, including energy efficiency measures [14].

Energy Audits were born out of the formation of national energy master plans by numerous countries as a way to measure energy consumption while finding energy saving options.An energy audit is a systematic approach to problem solving and decision making. The primary objectives are to qualify and quantify a facilities energy system, to optimize energy utilization through performance improvement and to measure the impacts (financial and otherwise) of the optimization program. Energy audits are a powerful tool for uncovering operational and equipment improvements that will save energy, reduce energy costs and lead to higher performance.

2.2 Levels for energy audit

The American Society of Heating, Refrigerating and Air- Conditioning Engineers (ASHRAE) define three progressive levels of audits: [15]

- ASHRAE Level 1 – Walk-Through Analysis/Preliminary Audit
- ASHRAE Level 2 – Energy Survey and Analysis
- ASHRAE Level 3 – Detailed Analysis of Capital Intensive Modifications

ASHRAE Level 1 – Walk-Through Analysis/Preliminary Audit

The Level 1 audit alternatively is called a “simple audit”, “screening audit” or “walk-through audit” and is the foundation for building energy utilization optimization. It involves the following

- Interviews with operating personnel at the facility
- Preliminary review of the facility’s consumption patterns and other operating data,
- Brief walk-through of the building.

The ASHRAE Level-1 audit is geared towards understanding the general building configuration, describing the type and nature of energy systems and the easy and fast identification of the potential for energy utilization optimization. The expected result of this audit is a high-level energy utilization analysis for the facility and a short report detailing the findings, which may include identifying a variety of recognizable efficiency opportunities. Usually this report does not provide in depth recommendations, except for very visible projects or operational faults [16].The ASHRAE Level-1 audit requires the lowest level of information about the building and its systems, and the least commitment of time by the building personnel. It is intended to help the energy team understand where the building performs relative to its peers; establish a baseline for measuring improvements; deciding whether further evaluation is warranted; and if so, where and how to focus that effort [16].

ASHRAE Level 2 – Energy Survey and Analysis

The Level-2 audit builds on the foundation of the results on level one the Level-1 audit but also includes more detailed energy calculations and financial analysis of proposed energy efficiency measure. It evaluates the building energy systems (Building envelop, Lighting, Plug Loads, Compressed Air, Process Uses, Heating, Ventilation, Air Conditioning (HVAC)) in detail to define a variety of potential energy-efficiency improvements. The Level-2 assessment may include an evaluation of conditions that may affect energy performance and occupants comfort, this includes but not limited to lighting, air quality, temperature, ventilation and humidity. The process also includes detailed discussions with the building management team and occupants to explore potential problem areas, evaluation of utility bills (24 to 36 months) and clear discussion of financial and non-financial objectives of the program. The Level-2 audit should result in a clear report that describes a variety of Energy Efficiency Measures (EEMs) including no- and low-cost measures, modifications to system controls and building automation, operational changes, and potential capital upgrades [16] this type of audit identifies all energy conservation measures appropriate for a facility given its operating parameters. A detailed financial analysis is performed for each measure based on implementation cost estimates, site-specific operating cost savings and the customer's investment criteria[17].Many of the EEMs revealed during the ASHRAE Level-2 audit can be implemented quickly with immediate financial incentives for the facility. For other EEMs involving complex interaction among building systems and potentially huge financial investments, it may be necessary to dig deeper into the building operation. This is where the
ASHRAE Level-3 audit becomes useful.

ASHRAE Level 3 – Detailed Analysis of CapitalIntensive Modifications

This level of engineering analysis focuses on the potentially capitalintensive projects identified in the Level 2 analysis and involves more detailed field data gathering as well as more rigorous engineering analysis to give insights into the benefits, costs and performance expectations [17].Energy Efficiency measures that require significant investments of capital, personnel, and other limited resources is the reason for "investment-grade" Level-3 ASHRAE audit.This audit is alternatively called comprehensive audit, detailed audit, or technical analysis audit. It develops its scope from the outcome of the Level 2 audit by providing a dynamic model of energy use characteristics of both the existing facility and all energy conservation measures identified. The Level-3 uses "computer simulation", to model the way the brick-and-mortar building would respond to changes in the energy systems. The model is calibrated using actual utility data to provide a realistic baseline against which to estimate saving for proposed measures. Comprehensive attention is given to understanding not only the operating characteristics of all energy consuming systems and process but also the situations that cause load profile variations on both a daily and yearly basis. Depending on the EEMs, the ASHRAE Level-3 audit can involve much more detailed data collection over the course of weeks or months. Data loggers might be placed temporarily to monitor the operation of pumps and motors, temperatures of affected spaces, lighting levels, switching behavior, and other factors. Existing utility data is supplemented with sub-metering of major energy consuming systems and monitoring system operating characteristics [17]

Table 1: Types of Audit as defined by ASHRAE

Level	Type of Audit Brief Description
Level 1	Brief on-site assessment of facilities energy systems Savings and cost analysis of low-cost/no-cost Energy Conservation Measures (ECMs) Identification of potential capital improvements meriting further consideration
Level 2	More detailed building survey of systems and operations Breakdown of energy source and use Identification of EEMs for each energy system Savings and cost analysis of all ECMs Prioritize EEMs requiring more thorough data collection and analysis (Level 3)
Level 3	Attention to prioritized capital-intensive projects identified during the Level 2 audit More detailed field analysis More rigorous engineering analysis Cost and savings calculations with a high level of accuracy Whole building computer simulation calibrated with field date

Accurate modeling of EEMs and power/energy response

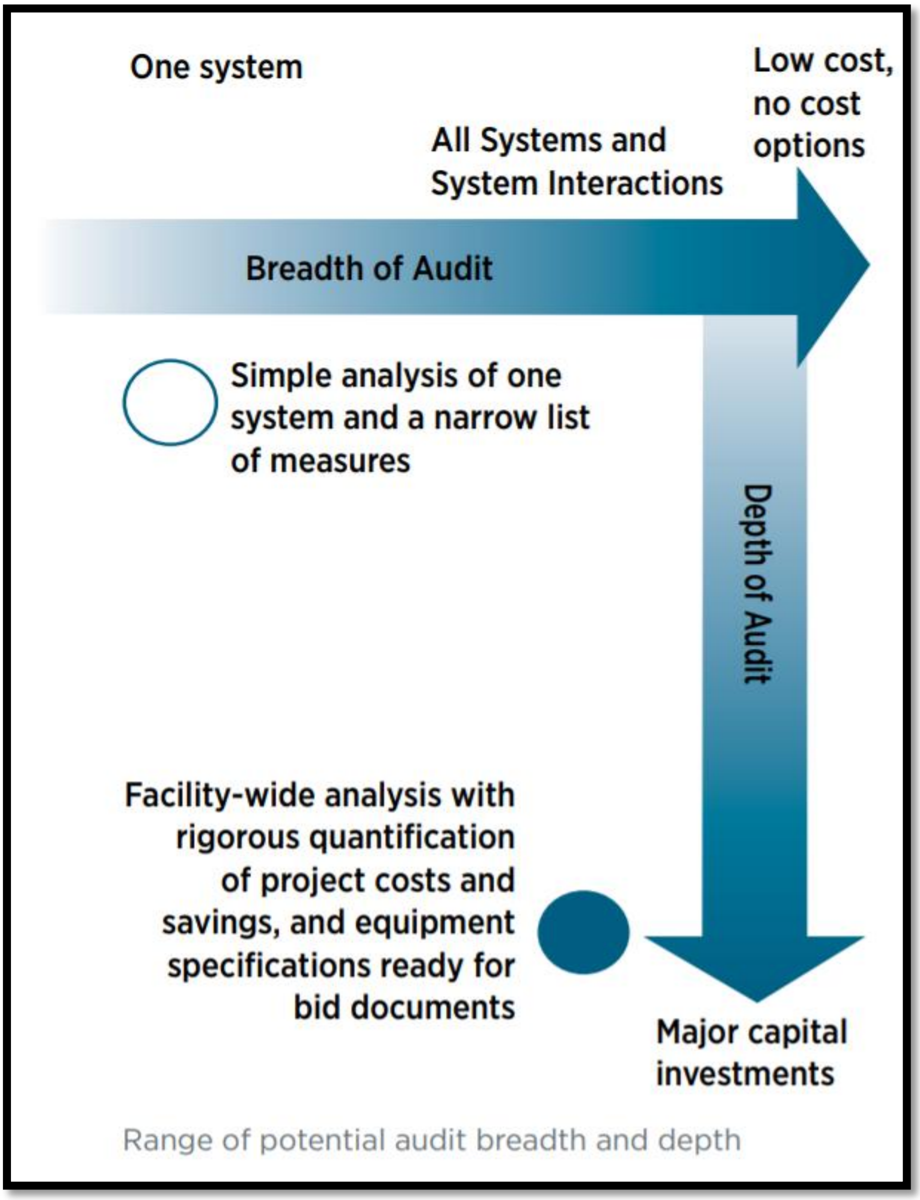
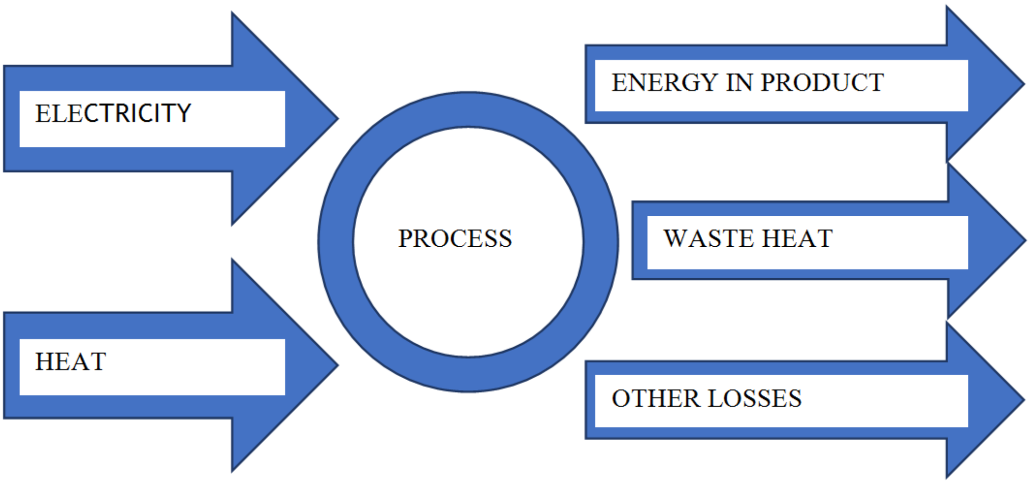


Figure 1: ASHRAE Level of energy audit

Oyedepo et al carried out a walk through energy audit of selected industries (food processing, ceramic distillation and bottling industries) in the Southwestern Nigeria. The study identified the major sources of energy, determined levels and patterns of consumption of the energy sources, discovered the areas of energy wastage and recommended measures for energy efficiency. The audit revealed that a negligible quantum of energy was received from the national grid ranging between 0.04 – 1.78%; while the major bulk of the energy was self-generated; gas and diesel generators. Further analysis unveiled the major energy utilization equipment; electric motors accounting for about 40 – 77% of the total energy consumption and thermal equipment (Boilers and heaters) aggregating 65% of the total energy used. It was proposed that an estimated 10-30% reduction in energy utilization can be achieved as little or no cost by adopting energy efficient utilization pattern [18].The preliminary energy audit on eight large industrial building of a car manufacturing holding in Italy enabled Matteo et al to build a specific factory energy model which is used to quantify and study the impact of energy conservation activities on the primary energy utilization site. They study further demonstrated that improvement of the building envelopes and optimization of the performances of the existing HVAC systems like thermal insulation of walls and roof-tops, the replacement of old boilers and the use of heat recovery units in the can reduce gas consumption by up to 15% and produce an economic saving of about € 100,000 per year. The payback time of the proposed thermal retrofitting is evaluated to be less than 6 years [19] .There is a potential of up to 20% energy saving if smart and sustainable energy conservation strategy is implemented to tackle the several barriers to high energy efficiency. Frenser et al postulated that a huge amount of cost effective energy efficiency measures remains unimplemented because of financial limitations, lack of adequate information and limited technical skills on energy audits. This auditing outlook was experimented in 280 companies across Europe (Austria, Bulgaria, Cyprus, Italy, Romania, Slovakia and Span). The resultant effect of the energy efficiency measures implemented was a saving of 6500 toe per year of primary energy and a greenhouse gas emission reduction of 13,500 tonnes per year [20]. Olayinka et al discovered in the energy cost analysis of cement production using the wet and dry processed in Nigeria that it is less expensive to produce cement through a gas powered plan that through the national grid. The comparative analysis of electrical energy from the national grid and the gas turbine on the average cost per ton resulted in a difference of approximately N169.26/ton and N214.13/ton between the national grid and gas turbine plant, in favour of the gas turbine for the wet and dry processes. Furthermore, the average energy cost of production revealed that the wet process is approximately 40% more expensive in cement production that the dry process [21].Eugene Airport Administrative Building Airport was audited with the ASHRAE Level One Energy Audit Methodology. A walk through audit executed and energy consumption calculated per square meter of the different floor of the administrative building. Energy waste procedures were corrected they include inefficient lighting fixtures, poor control of HVAC system and improper control of aviation equipment. The result of preliminary analysis revealed an approximate potential savings of 20% cost with the application of no cost and low cost measures to energy utilization pattern [22]



III. Methodology

Introduction

The primary purpose of performing network analysis is to determine the utilization patterns of energy at the Lagos airport. This forms a foundation for strategies to improve energy efficiency. This chapter gives an overview of the survey at the Lagos Airport. It presents the methodology used in this study and distribution network analysis; which is broken down into the findings of total energy use, energy distribution across department and unit sections and finally tries to reconcile the energy use with the purchased in the energy diagram. The technique describes the historical performance of the existing system and utilizes the historical performance to model the system on a software. The network indices are evaluated using a load flow analysis.The energy survey described in this study is based on preliminary audit type and to achieve the set objectives the “top-down” approach was used. First the power distribution network topology was created, as it was previously unavailable. A thorough study of the distribution network was carried out to understand the ring power distribution network installed at the airport. The Topology of the distribution network gives the connectivity among its numerous assets such as feeders, distribution transformers, power transformers, switches ad circuits. This information of the underlying network topology is useful for efficient management of outages in distribution networks.Secondly, A GIS Map of all the transformers (distribution and power) were tagged on Geographical map. This is the first step in creating a complete Automated Power Distribution System. It was however difficult to create a GIS Map of all the associated feeders as the repository of this information were unwilling and or unavailable to provide the route length at the time of this survey.Thirdly, an analysis of the already existing data like invoices and electrical bills was carried out. The bills from May 2017 to May 2018 was considered the total energy, maximum demand, base demand and average demand was used for the analysis in the report.The total installed power and distribution capacity of the airport was aggregated. The total installed capacity was determined through a manual tracing of all the power distribution infrastructure installed at the airport. The energy flow of each feeder and all the associated distribution assets and switchgears was analyzed. The aggregated installed distribution capacity was then used to determine the installed distribution capacity per feeder and project on the base, average and peak load, because the installed 11kV feeders were not equipped with load measurement tools. The status of the associated switchgears was also recorded. Finally, the network was modelled on an advanced distribution management system for proper load flow studies.The information for this analysis was obtained through interviews with the Head of Engineering MMA, Power Plant Lead Engineer, Power distribution Engineer, Injection Substation Operators. Other information was obtained from considering energy bills from Ikeja Electric, outdated power flow diagrams, energy meter reading and informal discussion with associated engineering personnel. Other Complimentary sources were the internet and other reference materials.For the study the iterative process in the figure below was adopted for the graphical representation on AutoCAD, Data Analysis on Microsoft Excel and ETAP

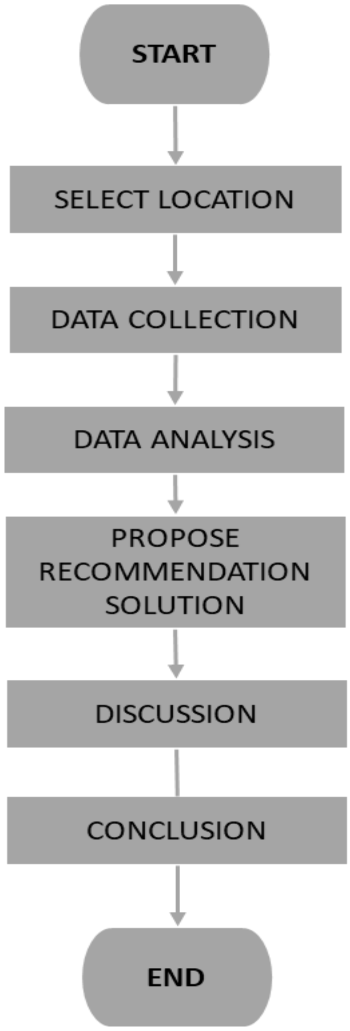


Figure 2: Project Methodology

3.3Network assessment, Metrics and indices

The result of a quantitative research will provide numbers that will enable us gather insights into the power distribution network and the consumptions pattern of the Lagos airport. A quantitative research will allow the classification of these numbers into various features and will allow the construction of a statistical models, table and figures to explain the direction of the analyzed data.

3.3.1 Distribution Network Topology Model

Electrical networks are composed of stages of generation, transmission/distribution and utilization of electricity, these networks allow evacuation of load from generation to load points. The interconnection of this network is usually defined as the grid and the configuration, in Nigeria in typically manual and intuitive (only stored in the heads of the network designers and not in a document). Distribution Network Topology is the arrangement of nodes and feeders in a network and their relationship with each other. The core purpose of a network data model is to provide and accurate representation of a network as a set of lines and nodes. The topology model allows for end to end visualization of the distribution network with its different unique elements and symbols. It aids the understanding the distribution network and its network characteristics. It is a critical design data for network analysis, modelling and design. A network topology model is typically created with a Computer Aided Design Tool. The choice of the power system distribution topology is very important against the backdrop of critical-load outages.

There are five major power system distribution topologies.

Secondary-Selective "Main-Tie-Main' Arrangement
In this arrangement there are two busses, each one supplies power to approximately 50% of the Load, however, the bus is sized to carry the entire load. The figure depicts that each transformer, and its secondary switch gears (circuit breakers, current transformers and the secondary bus) is sized to carry the entire load of the circuit. This system is redundant, should a transformer fail the entire load can be evacuated through the second transformer and associated switchgears.

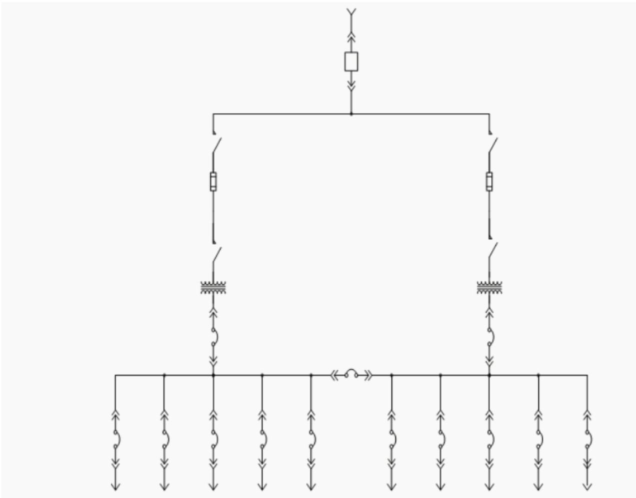


Figure 3: Main-Tie-Main Arrangement. Source: Electrical Engineering portal

Main-Tie-Main Topology.
This arrangement simply has two secondary busses connected al the time. In the Main-Tie-Main Topology, at standard conditions, one power source carries the entire load and the other is strictly a fail-safe.

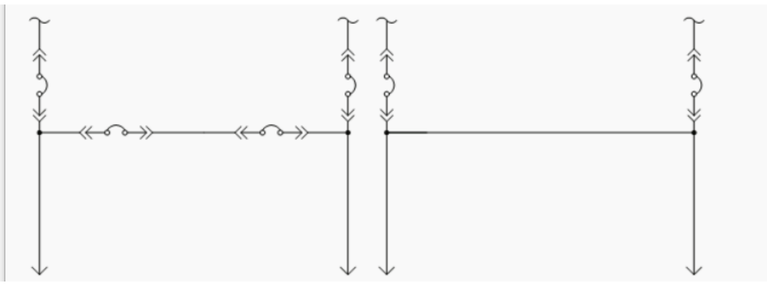


Figure 4: Main-Tie-Main Topology. Source: Electrical Engineering Portal

Ring Bus Arrangement
The ring bus arrangement allows the flexibility of supplying multiple loads using multiple busses. It is a closed loop arrangement with all the circuit breakers in closed position

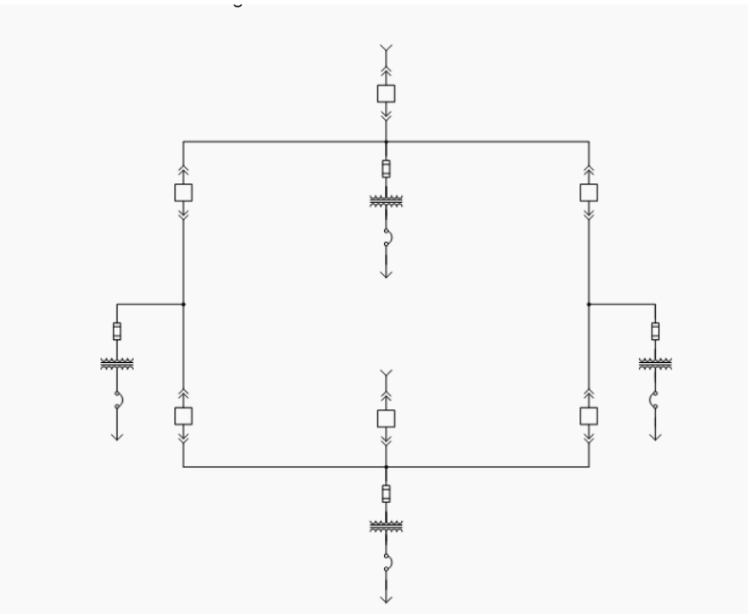


Figure 5:Ring Bus Arrangement. Source:Electrical Engineering Portal

Primary Loop Arrangement: This arrangement, even though ultimately supplied by once sources gives the flexibility to supply all loads from either side of the loop.

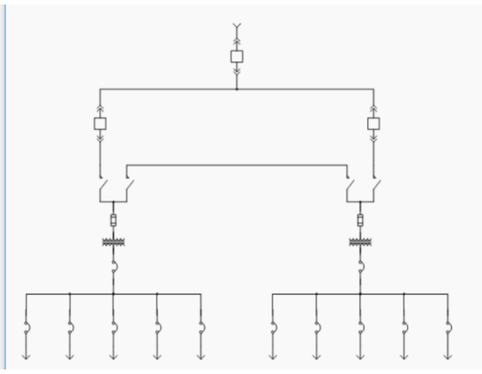


Figure 6: Primary Loop Arrangement. Source: Electrical Engineering Portal

Composite Primary Loop/Secondary Selective Arrangement.

The combination of different topologies offers extremely flexible with increased reliability and allow for multiple failure contingency.

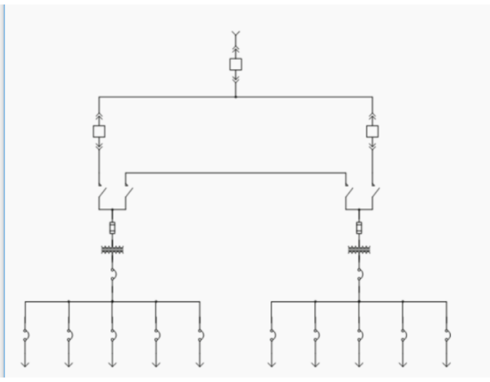


Figure 7: Composite Primary Loop. Source: Electrical Engineering Portal

3.3.2 Energy consumption patterns; Utility bill analysis

For the study on the overall energy consumption pattern, the electricity bill of the Lagos Airport for the past thirty-six months was collected, Collated and Analyzed using Microsoft Excel. The total electricity bill was also analyzed vis-à-vis the electricity tariff and the average number of hours of grid power availability to the grid. This analysis can help identify if there are available saving on the supply or demand side of their energy costs. The supply side saving will be a reduction of the of the cost of energy, while the demand side will be a reduction of the cost associated with energy usage

Factors to be considered:

- Minimum Service Charge
- Energy Charge
- Demand or maximum level of service charge
- Power factor penalties
- Adjustment e.g taxes
- Fuel cost adjustment
- Utility Energy Bill Analysis.

There are four major methods of utility bill analysis.
Type #1. This takes electric and natural gas utility data and performs a high-level analysis that can be easily understood. The essence of this type of utility analysis is for easy data representation.
Type #2 This combine the electric and natural gas utility data with selected survey data and performs and analysis to depict the energy cost and potential energy saving.
Type #3: This type of analysis established baseline date, proposed energy efficient measure, implements those measure and produces an analysis of the "after" in view of the energy conservation retrofits. It uses the billing review to quantify the saving from the energy conservation measures implemented.

Network Modeling

A power distribution system can be viewed as a network of its components connected together either in series, parallel, ring or a combination of any of these. The network analysis tools used in this design models the distribution networks with network apparatus such as transformers, distribution lines and composite load. This model forms the basis for elementary analysis such as load flow and short circuit calculations and also enables the investigation of effects of voltage regulation, load break and helps determine the optimal location and capacities of substations and optimal feeder route paths which would provide electric power to a given set of load demand notes at the barest minimum cost, with acceptable levels of efficiency and reliability while fulfilling all the required technical constraints.Load flow analysis is the most critical approach to investigating problems in the power system planning and operations. Based on the specific generating state and distribution structure, load flow analysis solves the steady operation state with node voltages and branch power flow in the power system. Load flow analysis can provide a balanced steady operations state of the power system, without considering system transient processes.

IV. Results and Discussions

This chapter presents detailed power system and energy consumption analysis of the case study, the Lagos airport. The data collected from the airport was used to determine the distribution network performance and the overall reliability of the FAAN distribution network

1 Network data collected

The distribution network for this study is made up of two 33kV feeders, two 15MVA power transformers, seven unique 11kV feeders, three (level two) 11kV feeder and six (level three) 11kV feeders and 106 distribution transformers. This diagram depicts an unbalanced load distribution on the 11kV feeders in which feeder nine is grossly overloaded and connected with three (level two) 11kV feeders and six (level three) 11kV feeders. The aggregated distribution transformer capacity on feeder nine is at 31.2MVA, 6 times its actual wheeling capacity. The actual loading capacity of the distribution transformers is at 15MVA which is still three times its actual wheeling capacity.

33kV FEEDERS	ASSET OWNER	STATUS
AIPORT ISOLO	IKEJA ELECTRIC	OPERATIONAL
AIRPORT EJIGBO	IKEJA ELECTRIC	OPERATIONAL

POWER HOUSE 33KV PANEL - ABB	
RATED VOLTAGE	33KVAC
RATED CURRENT	1250A
RMS	31.5KA

POWER HOUSE INCOMER	
CT	400/1A
VT	33KVAC/110V
BREAKER RATED VOLTAGE	36KV
BREAKER CURRENT	1250A

TRANSFORMER	**ASSET OWNER**	**STATUS**
2X 8MVA	FAAN	OPERATIONAL
3 X 15MVA	FAAN	NEW BUT NOT IN CIRCUIT

11kV FEEDERS	**ASSET OWNER**	**STATUS**
11 x 11kV FEEDERS	FAAN	OPERATIONAL

11KV PANEL	
RATED VOLTAGE	11KVAC
RATED CURRENT	2000A
RMS	29KA
INCOMER	
CT	200-400/5/5A
VT	11KVAC/110V
BREAKER RATED VOLTAGE	12KV
BREAKER CURRENT	630A

DISTRIBUTION TRANSFORMER	**ASSET OWNER**	**STATUS**
106DISTRIBUTION TRANSFORMERS	FAAN AND ASSOCIATED PRIVATE COMPANIES	90% OPERATIONAL

MAIN PANEL	**TOTAL DT CAPACITY**	**SUB PANEL**	**SUB PANEL**	**COMBINED DT CAPACITY**
FEEDER 9	31.2MVA	K25		10225
		K26		2400
			QUARTERS	1600
			WATER PUMP	2930
			ARIK	2000
			WHITE HOUSE	1300
			GAT	2000
			HEADQUARTERS	2500
		K27 (MM2)		6250
K13	8.4MVA			8415
K20/K19	3.7MVA			3715
K18	6MVA			6000
K17	11.6MVA			11630
K16	6MVA			6000
k12	0.9MVA			885
TOTAL	**67.9MVA**			

Network design layout

The design philosophy of the airport was Main-Tie-Main Configuration (as seen in fig 8 and fig 9) at the primary distribution voltage (33kV) and a ring/mesh network at the secondary voltageThe benefits of the Main-Tie-Main system configuration is reliability of the entire system. The tie breaker is normally open and the system acts as two independent circuit supplied by two independent sources. However, because of network limitations, this network has been rearranged for operational reasons; the tie breaker on the source side is now normally closed while the Airport-Ejigbo 33kV feeder has become the primary source and Airport-Isolo 33kV the backup source. The secondary distribution voltage, 11kV was also designed as a ring network, but due to poor maintenance all the ring main units installed for the purpose of the mesh network has failed and there has been no repair or maintenance.Further analysis into the panel voltage and current rating revealed that the instrument transformers (Current Transformer) installed at the secondary voltage (11kV incomer) panels isunderrated as an incomer panel and as such panel cannot deliver maximum power to the bus. This limitation has given rise to massive load shedding within the airport.

$P = \sqrt{3} IV \cos \emptyset$ Equation 1: Power Equation

Maximum current that can be delivered the 11kV Incomer Panel of the 8MVA.

$$I = \frac{8000}{1.732 \ x \ 11 \ x \ 0.8}$$

$$I = 524.88A$$

Rating of the current transformer installed at the 11kV incomer panel at the Airport Power House, 400/5A. The current mismatch has created a bottle neck in the distribution network and limits the amount of current that can be evacuated from the source to the load as shown in fig

Recommendation One: A replacement of the two 11kV incomer Current transformers.

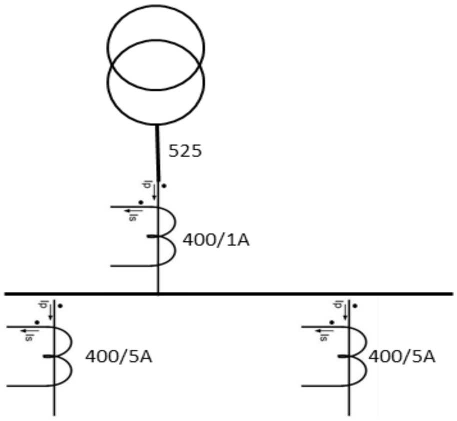


Figure 8: Current Transformer Arrangement in the Power House

Additional analysis into the panel arrangement revealed unveiled a much steeper bottle neck, the overloading of one 11kV panel by over 300% causing massive load shedding at critical infrastructure at the downstream despite availability at the upstream. The combined distribution transformer capacity on this feeder is over 31.2MVA and at 70% utilization, 22MVA. This has created suppressed load of over 17MVA from the Staff Quarters, MM1 and MM2 load centers of the airport.

Table 2: Feeder 9 and associated downstream distribution assets

MAIN PANEL	TOTAL DT CAPACITY	SUB PANEL	SUB PANEL	COMBINED DT CAPACITY
FEEDER 9	31.2MVA	K25		10225
		K26		2400
			QUARTERS	1600
			WATER PUMP	2930
			ARIK	2000
			WHITE HOUSE	1300

			GAT	2000
			HEADQUARTERS	2500
		K27 (MM2)		6250

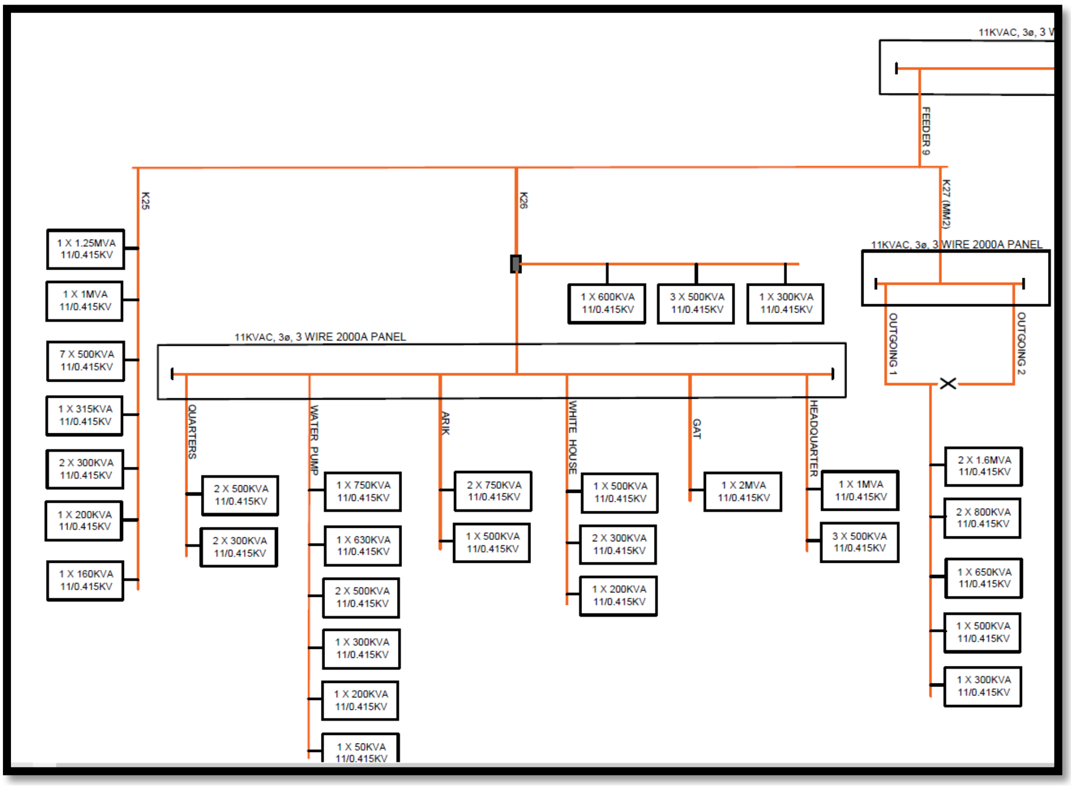


Figure 9: Block Diagram of Feeder 9

The resultant effect is utilization of diesel generators by the other critical load centers and the increase in energy cost for these load centers. Particular attention will be pay to the increase in the energy cost of MMA2. The second domestic terminal of the biggest airport in Nigeria which seats on over 10,000sqm of land and is a commercial hub for travelers. All the load in this location is suppressed as a result of the design error at the upstream. This design and installation error of lumping a huge amount of load together into one switchgear has huge cost and environmental Implications.

MMA2 currently runs on four diesel generators as shown in the figure and table below.

MMA 2 GENERATORS	
CAPACITY	2 X 2.2MWA AND 2 X 1.65MVA
VOLTAGE	415V

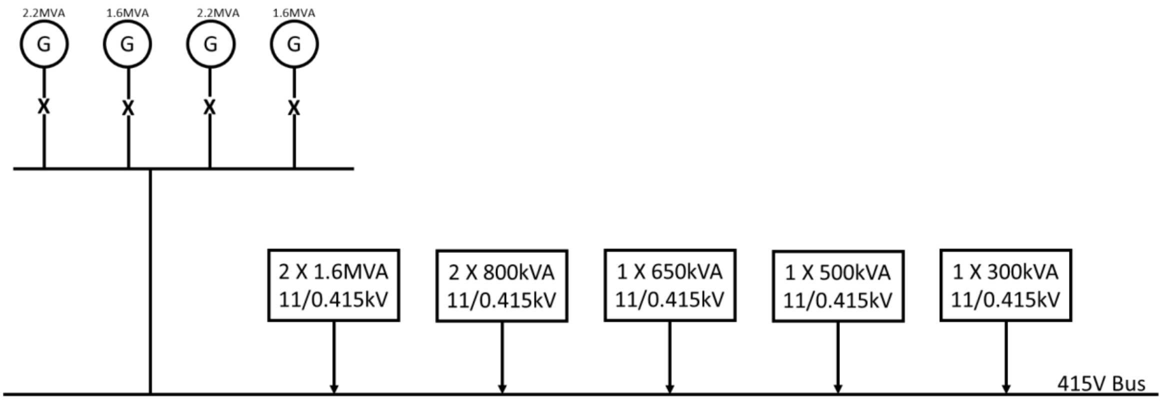


Figure 9: MM2 Network topology

Table 3: Cost of owning and operating diesel generator at full load over a 10-year period. Adjusted

Output	**Operational Hours**	**Initial Cost**	**Annual Energy Cost**	**NPV over 10 years at 20 % Discount**	**Annual Energy Cost**	**NPV over 10 years at 20 % Discount**	**Combined power rate per kW**
(kW)	Hrs	US$	US$	US$	Million Naira	Million Naira	Naira/kw hr
2000	0	100000	2012267	5077233	724	1827.8039	41.35
2000	4	100000	2224941	9328004	801	3358.0814	45.72
2000	6	100000	2331279	9773821	839	3518.5756	47.9
2000	8	100000	2437616	10219637	878	3679.0693	50.09
2000	10	100000	2543953	10665453	916	3839.5631	52.27
2000	12	100000	2650291	11111270	954	4000.0572	54.46
2000	18	100000	2969303	12448718	1069	4481.5385	61.01
2000	24	100000	3288315	13786167	1184	4963.0201	67.57

Table 5, gives the approximate cost of diesel generators per kw hour. The current running schedule of MM2 is 24hr for one 1.6MVA and 2.2MVA which is a total of 3.8MVA at a utilization factor of 70%

- Number of Units (per day) = KVA Capacity x Power Factor x Utilization Factor x 24
- Number of units (per day) = 3800 x 0.8 x 0.7 x 24 =51072 kwh per day
- Cost of Energy per day (Naira/kwh) = 51072 * 67.57 = N3,450,936.04
- Number of units (per month) = Number of Units (per day) x 30 days
- Number of units (per month) = 51072 x 30 = 1,532,160 kwh per month
- Cost of Energy per month (Naira/kwh) = 1532160 x 67.57 = 103, 528, 051.2
- Cost of Energy for one diesel generator per year = 1,259,591,289.60

	Number of Units	**Cost per kwh**	**Cost per kwh**
		Diesel (67.57N/kWh)	**Grid (38.38N/kWh)**
Day	51072	3,450,935.04	1,960,143.36
Month	1532160	103,528,051.20	58,804,300.80
Year	18641280	1,259,591,289.60	715,452,326.40

Total cost of running two diesel generators per year = 2,519,182,579.20

Network rearrangement at the power house

In order to remove the bottle neck of the panel arrangement at the power house, two major changes are required

Upgrade of the Incomer 11kV Panel Current Transformer (CT)

Instrument transformer is a general term for voltage transformers and current transformers that are used with electrical instruments. The main purpose of instrument transformers is to extend the measurement range for electrical quantities (voltage, current, power, power factor) on large-current and high-voltage circuits. They serve to convert currents and voltages to levels that are suitable for measurement, and to insulate the instrument, etc. from high-voltage circuitry. The installed current transformer at the incomer panel of the 11kV circuitry is underrated for the load demand of this circuit.

Figure 10: High Voltage Current Transformer

Cost of a New 11kV Current Transformer: N200,000

New 11kV Cable from the power house to the panel at MM2.

For effective grid supply to the approximate 3.5MW of the MM2, the installation of a new 11kV underground cable from the Power house to the load distribution center of MM2 is a critical requirement. This cable will run through a route length of approximately 4km from the FAAN Power House to the MMA Load distribution Center as seen in fig 13.

Figure 11: High Voltage Cable

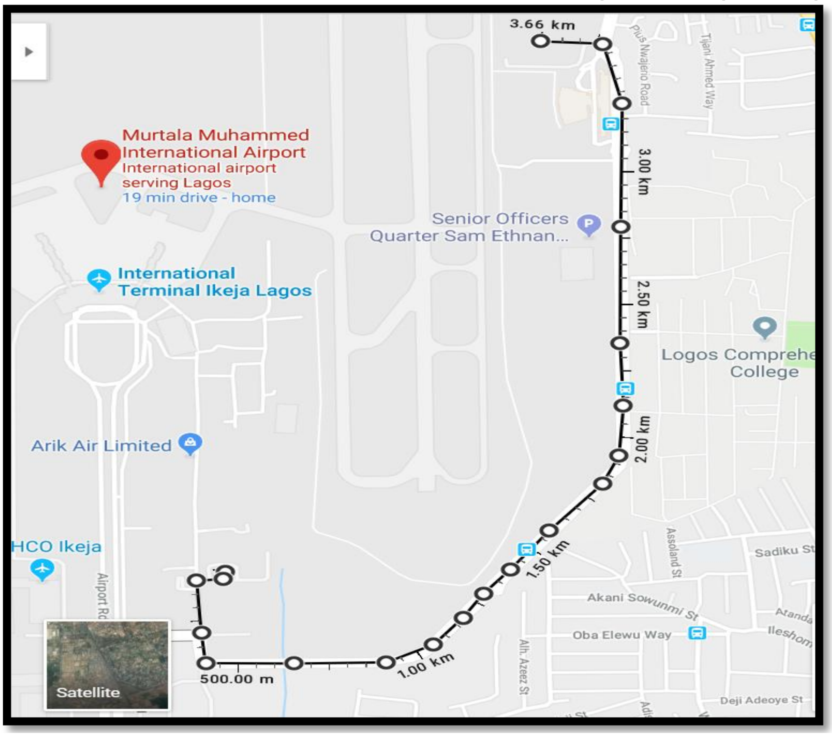


Figure 12: Proposed route length of new 11kV Feeder

Total cost of Retrofitting the Network

Description	Unit	Qty	Amount	Total
Current Transformer	No	3	600,000	1,800,000.00
150mm2 x 3C 11KV XLPE Cable	Mtrs	4000	20,000	80,000,000.00
Cable Installation Cost	No	4000	1000	4,000,000.00
Panel Rearrangement Cost	Lot	1	200000	200,000.00
Protection Scheme Design	Lot	1	200000	200,000.00
Contingency	Lot	1	12690000	12,690,000.00
Total				**97,290,000.00**

3.2.1 Model Block Diagram of the Airport

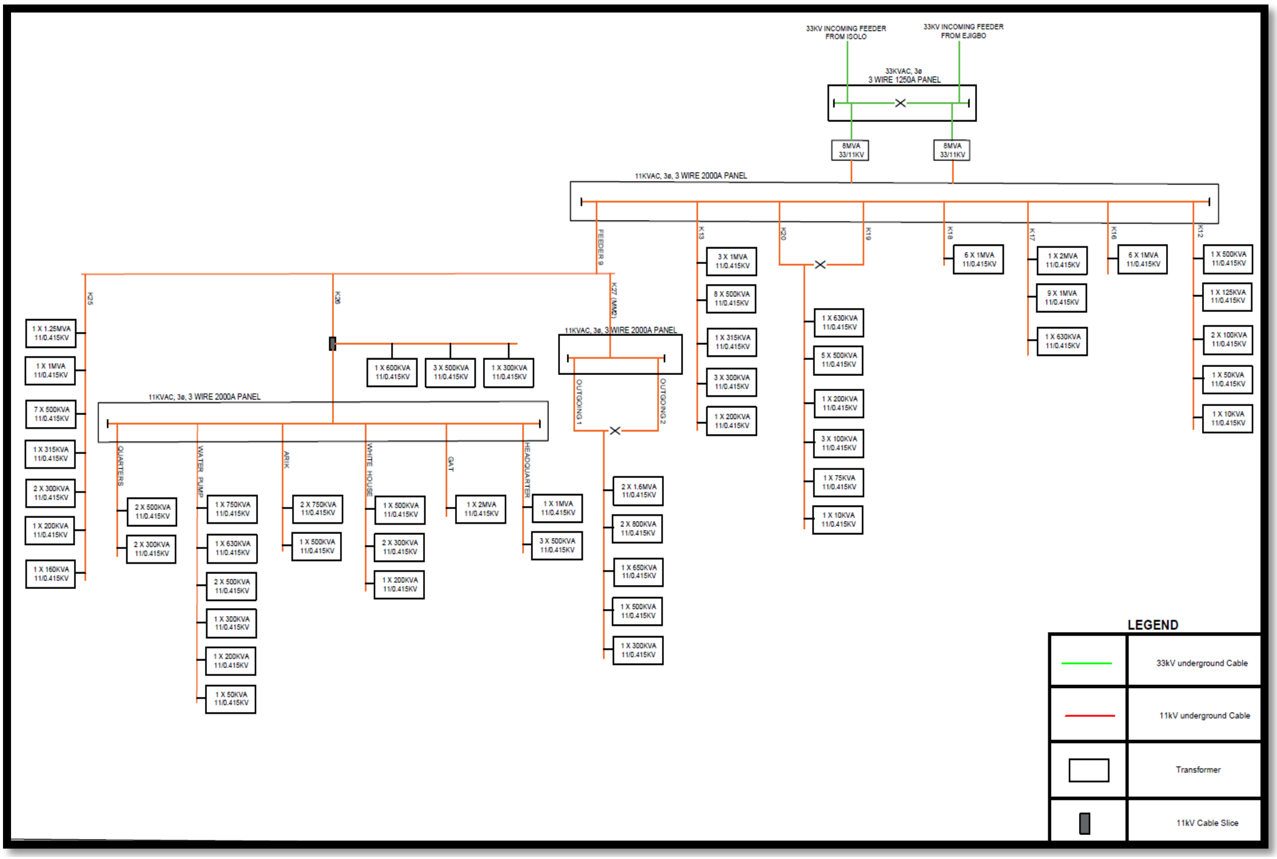


Figure 13: Block Diagram of the Lagos Airport Network

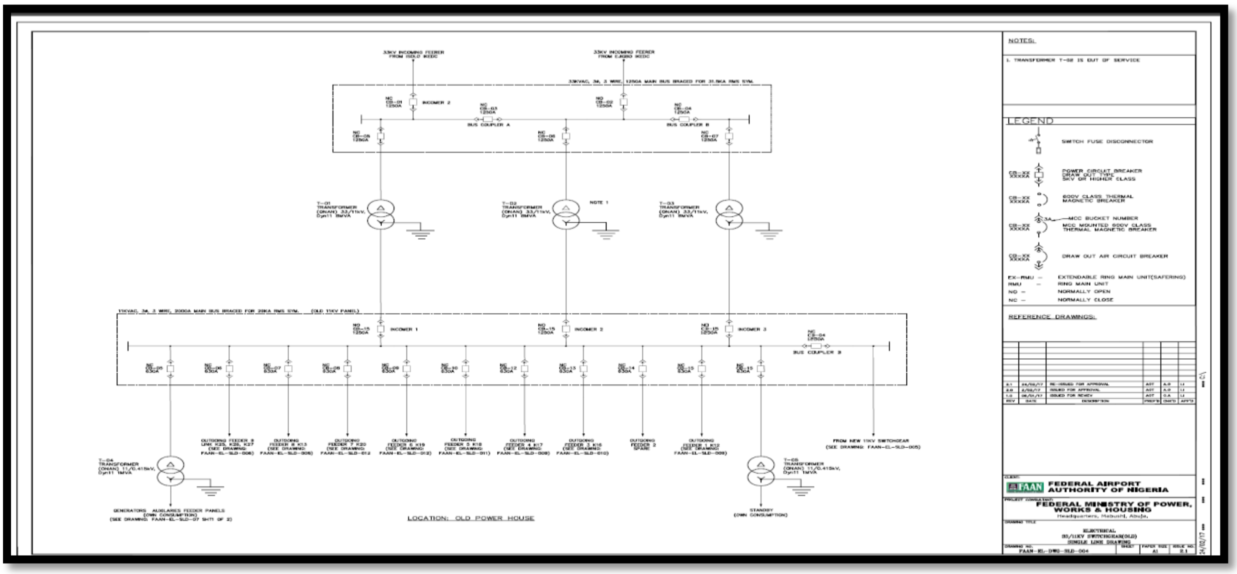


Figure 14: Network Diagram of the power source

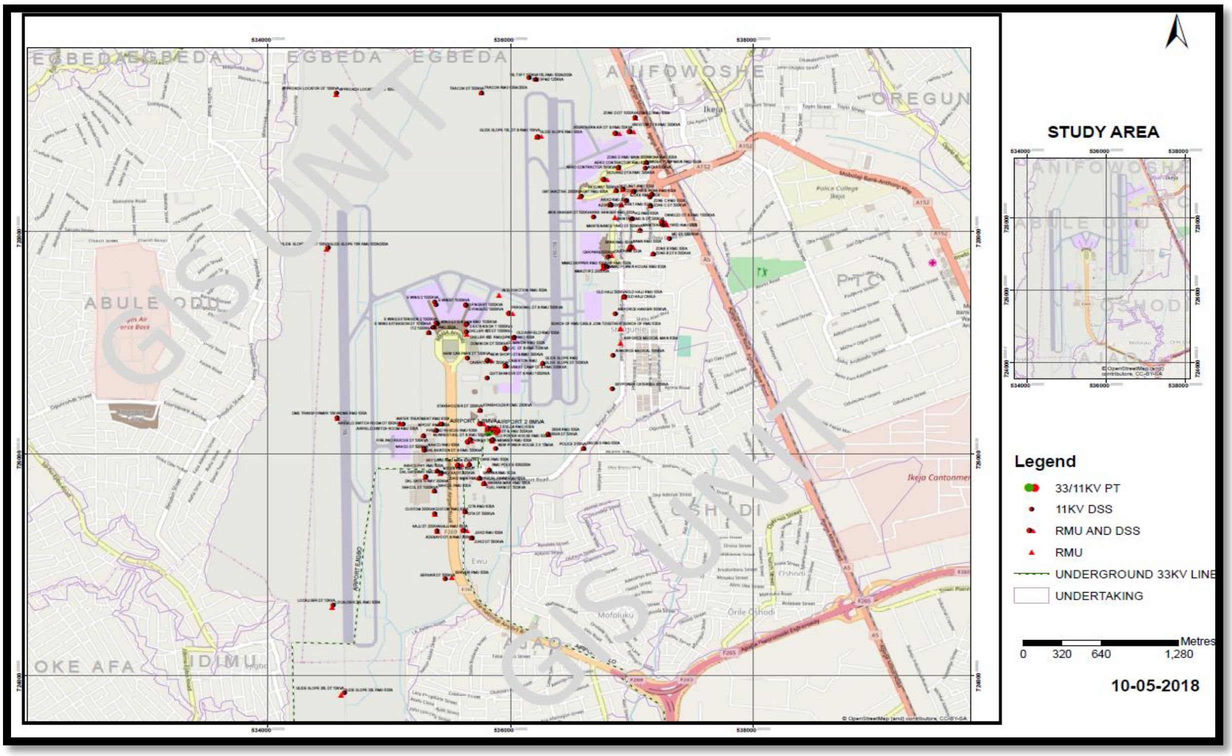


Figure 15: GIS mapping of the distribution asset of the Lagos Airport

ENERGY CONSUMPTION PATTERNS

Currently the Lagos Airport is one of the highest on-grid power utilization centers. Figures 17 and 18 shows the daily load curve while figure 19 show the utility bill analysis curve

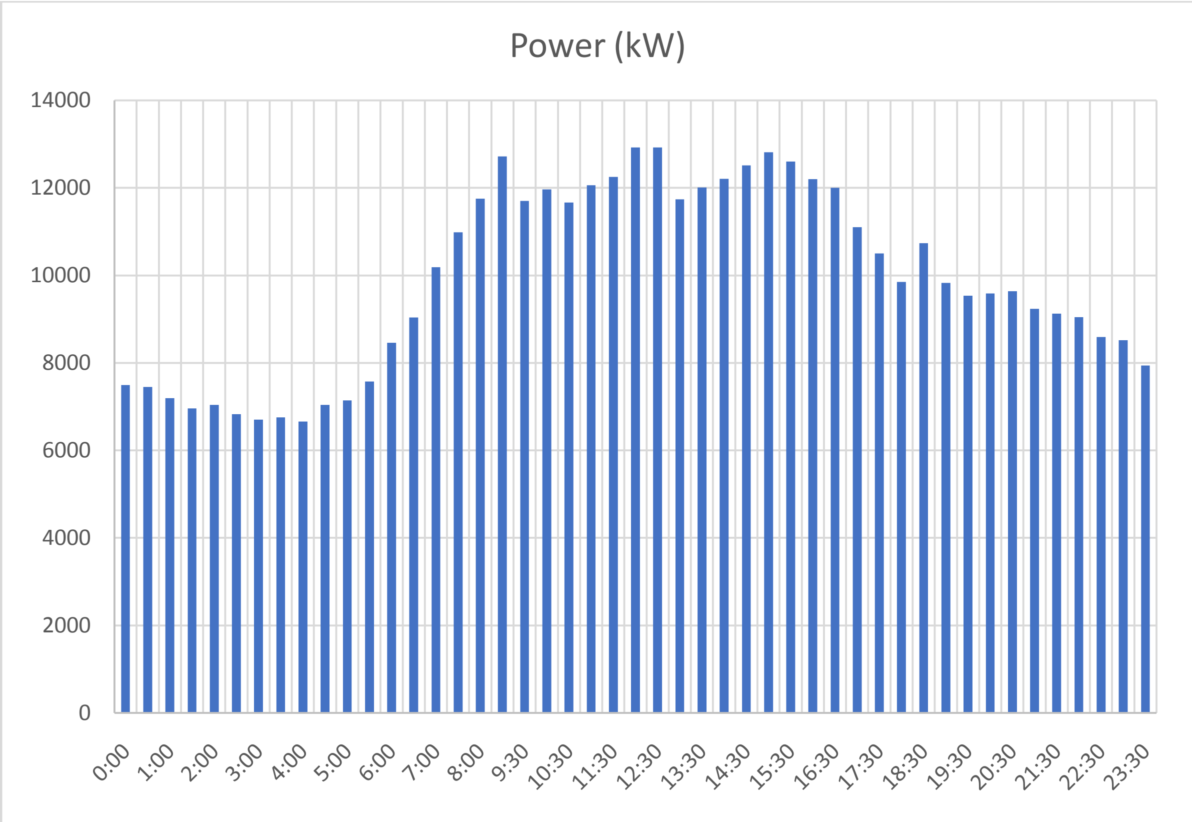


Figure 16: 24-hr Load Curve: Power

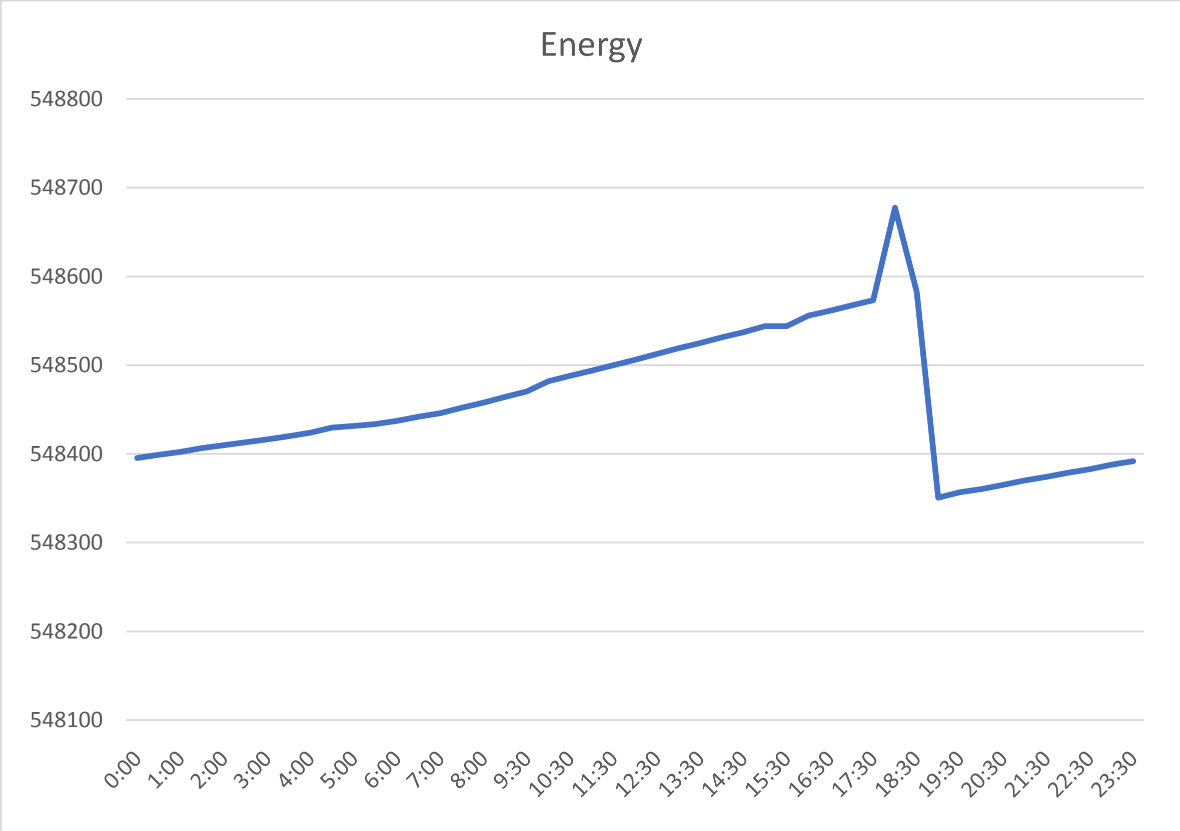


Figure 17: 24hr Load Curve: Energy

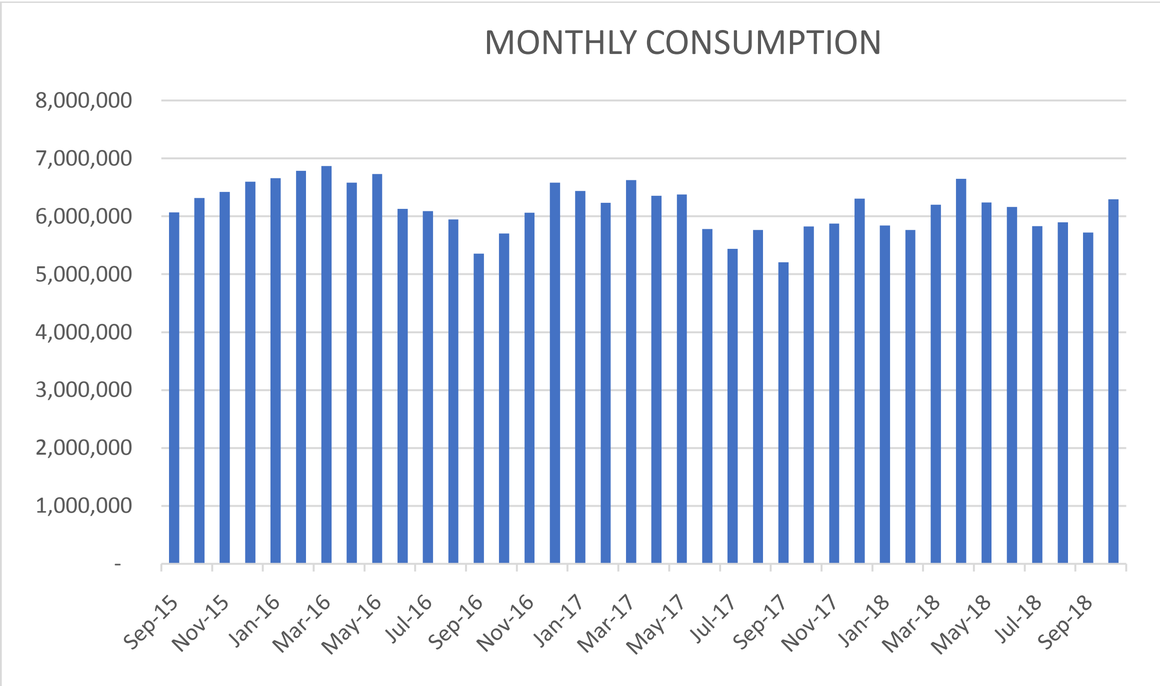
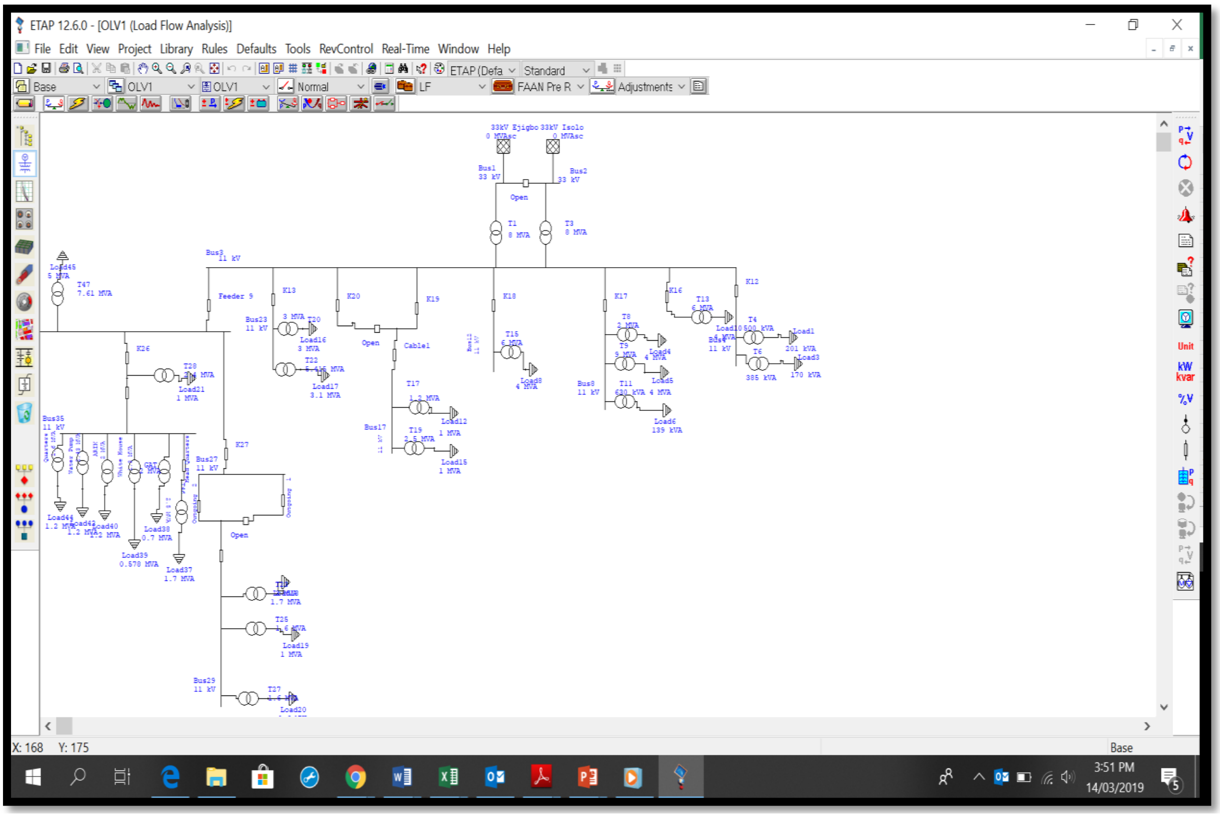


Figure 18: Utility Bill Analysis: 36 months

Network Modelling and analysis

The distribution network of the airport is presented in a modelling software – ETAP. This is for systemized optimization and reliability. The software allows for visualization of the network with Computer Aided Design and stimulation of normal and abnormal conditions. The results of this simulation provides insights into the reaction of the system in ideal and abnormal conditions.



Bus Loading Summary Report

Bus			Directly Connected Load								Total Bus Load		
			Constant kVA		Constant Z		Constant I		Generic			Percent	
ID	kV	Rated Amp											
		MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar	MVA	% PF	Amp	Loading
Bus1	33.000	0	0	0	0	0	0	0	0	17.352	72.5	303.6	
Bus2	33.000	0	0	0	0	0	0	0	0	17.352	72.5	303.6	
Bus3	11.000	-0.000	-0.000	0	0	0	0	0	0	31.020	79.9	1821.5	
Bus4	11.000	-0.000	0.000	0	0	0	0	0	0	0.290	1.2	17.0	
Bus6	0.415	-0.000	0.000	0.001	0.154	0	0	0	0	0.154	0.9	244.9	
Bus7	0.415	0.000	0.000	0.001	0.130	0	0	0	0	0.130	0.9	206.7	
Bus8	11.000	0.000	-0.000	0	0	0	0	0	0	6.136	77.4	361.5	
Bus9	0.415	-0.000	-0.000	2.098	1.683	0	0	0	0	2.689	78.0	4562.8	
Bus10	0.415	0.000	-0.000	2.508	1.750	0	0	0	0	3.058	82.0	4865.7	
Bus11	0.415	-0.000	-0.000	0.094	0.053	0	0	0	0	0.108	87.0	170.8	

Bus12	11.000	0.000	0.000	0	0	0	0	0	0	3.092	76.0	181.8	
Bus13	0.415	0.000	0.000	2.339	1.876	0	0	0	0	2.999	78.0	4818.1	
Bus16	11.000	0.000	0.000	0	0	0	0	0	0	0.000	0.0	0.0	
Bus17	11.000	-0.000	-0.000	0	0	0	0	0	0	1.553	84.3	91.3	
Bus18	11.000	-0.000	0.000	0	0	0	0	0	0	1.555	84.3	91.3	
Bus19	0.415	0.000	0.000	0.612	0.427	0	0	0	0	0.746	82.0	1201.6	
Bus20	0.415	-0.000	0.000	0.691	0.354	0	0	0	0	0.777	89.0	1226.2	
Bus21	11.000	0.000	0.000	0	0	0	0	0	0	3.096	80.0	182.1	
Bus22	0.415	-0.000	-0.000	2.467	1.722	0	0	0	0	3.008	82.0	4826.0	
Bus23	11.000	0.000	-0.000	0	0	0	0	0	0	4.714	80.4	277.1	
Bus24	0.415	0.000	0.000	1.895	1.174	0	0	0	0	2.229	85.0	3597.7	
Bus25	0.415	-0.000	0.000	1.878	1.409	0	0	0	0	2.348	80.0	3753.1	
Bus26	11.000	-0.000	0.000	0	0	0	0	0	0	12.120	82.2	718.8	
Bus27	11.000	-0.000	-0.000	0	0	0	0	0	0	2.525	83.7	149.9	
Bus28	11.000	-0.000	0.000	0	0	0	0	0	0	2.524	83.7	149.9	
Bus29	11.000	-0.000	0.000	0	0	0	0	0	0	2.522	83.7	149.9	
Bus30	0.415	-0.000	0.000	1.096	0.651	0	0	0	0	1.275	86.0	2048.1	
Bus31	0.415	-0.000	0.000	0.633	0.392	0	0	0	0	0.744	85.0	1200.2	
Bus32	0.415	-0.000	0.000	0.372	0.260	0	0	0	0	0.454	82.0	726.2	
Bus33	11.000	-0.000	0.000	0	0	0	0	0	0	5.773	81.0	342.9	
Bus35	11.000	0.000	0.000	0	0	0	0	0	0	5.006	81.9	297.6	
Bus36	0.415	-0.000	0.000	0.566	0.499	0	0	0	0	0.754	75.0	1208.3	
Bus69	11.000	0.000	0.000	0	0	0	0	0	0	1.286	82.3	76.5	
Bus70	0.415	-0.000	0.000	1.050	0.678	0	0	0	0	1.250	84.0	2028.0	
Bus71	0.415	-0.000	0.000	0.458	0.271	0	0	0	0	0.532	86.0	849.0	
Bus72	0.415	-0.000	0.000	0.375	0.223	0	0	0	0	0.436	86.0	698.6	

Bus			Directly Connected Load								Total Bus Load			
			Constant kVA		Constant Z		Constant I		Generic				Percent	
ID	kV	Rated Amp												
		MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar	MVA	% PF	Amp	Loading	
Bus73	0.415	-0.000	0.000	0.732	0.511	0	0	0	0	0.892	82.0	1439.6		
Bus74	0.415	-0.000	0.000	0.738	0.515	0	0	0	0	0.900	82.0	1445.6		
Bus75	0.415	-0.000	-0.000	0.723	0.505	0	0	0	0	0.882	82.0	1431.2		
Bus76	0.415	-0.000	0.000	3.158	1.957	0	0	0	0	3.716	85.0	5996.4		

* Indicates operating load of a bus exceeds the bus critical limit (100.0% of the Continuous Ampere rating).

# Indicates operating load of a bus exceeds the bus marginal limit (95.0% of the Continuous Ampere rating).

Branch Loading Summary Report		
		Transformer
CKT / Branch	Cable & Reactor	

	ID	Type	Ampacity (Amp)	Loading Amp	%	Capability (MVA)	Loading (input) MVA	Loading (input) %	Loading (output) MVA	Loading (output) %	
	ARIK	Transformer				2.000		0.914	45.7	0.892	44.6
	GAT	Transformer				2.000		0.539	26.9	0.532	26.6
	Quarters	Transformer				2.000		0.908	45.4	0.882	44.1
*	T1	Transformer				8.000		17.352	216.9	15.510	193.9
*	T3	Transformer				8.000		17.352	216.9	15.510	193.9
	T4	Transformer				0.500		0.157	31.5	0.154	30.8
	T6	Transformer				0.385		0.133	34.5	0.130	33.7
*	T8	Transformer				0.500		2.922	584.4	2.689	537.8
	T9	Transformer				9.000		3.116	34.6	3.058	34.0
	T11	Transformer				0.630		0.109	17.4	0.108	17.2
	T13	Transformer				9.000		3.096	34.4	3.008	33.4
	T15	Transformer				6.000		3.092	51.5	2.999	50.0
	T17	Transformer				6.000		0.771	12.8	0.746	12.4
	T19	Transformer				6.000		0.787	13.1	0.777	12.9
	T20	Transformer				3.000		2.309	77.0	2.229	74.3
	T22	Transformer				3.000		2.409	80.3	2.348	78.3
	T23	Transformer				3.000		1.300	43.3	1.275	42.5
	T25	Transformer				1.600		0.762	47.6	0.744	46.5
	T27	Transformer				1.600		0.461	28.8	0.454	28.4
	T28	Transformer				2.400		0.768	32.0	0.754	31.4
	T46	Transformer				2.500		1.286	51.5	1.250	50.0
	T47	Transformer				7.610		3.814	50.1	3.716	48.8
	Water Pump	Transformer				2.000		0.917	45.9	0.900	45.0
	White House	Transformer				2.000		0.443	22.2	0.436	21.8
	* Indicates a branch with operating load exceeding the branch capability.										

Branch Losses Summary Report

CKT / Branch ID	From-To Bus Flow MW	From-To Bus Flow Mvar	To-From Bus Flow MW	To-From Bus Flow Mvar	Losses kW	Losses kvar	% Bus Voltage From	% Bus Voltage To	Vd % Drop in Vmag	
T1		12.580		11.952		-12.395		-9.324		184.7
T3		12.580		11.952		-12.395		-9.324		184.7
Feeder 9		10.077		6.951		-9.968		-6.895		109.0
K12		0.004		0.290		-0.004		-0.290		0.0
K13		3.797		2.804		-3.792		-2.801		5.0
K16		2.482		1.859		-2.477		-1.857		4.2
K17		4.767		3.895		-4.749		-3.886		18.0

K18		2.352		2.012		-2.349		-2.011		2.9
K19		1.312		0.836		-1.311		-0.835		0.7
K20		0.000		0.000		0.000		0.000	89.4	89.4
T4		0.002		0.157		-0.001		-0.154		0.6
T6		0.002		0.133		-0.001		-0.130		0.6
T8		2.141		1.989		-2.098		-1.683		43.1
T9		2.514		1.842		-2.508		-1.750		5.9
T11		0.095		0.055		-0.094		-0.053		0.3
T15		2.349		2.011		-2.339		-1.876		10.5
Cable1		-1.310		-0.834		1.311		0.835		1.5
T17		0.617		0.462		-0.612		-0.427		5.0
T19		0.693		0.372		-0.691		-0.354		1.7
T13		2.477		1.857		-2.467		-1.722		10.5
T20		1.907		1.302		-1.895		-1.174		12.0
T22		1.885		1.499		-1.878		-1.409		7.0
K26		4.682		3.391		-4.675		-3.388		7.0
K27		2.116		1.382		-2.114		-1.381		1.9
T47		3.170		2.122		-3.158		-1.957		11.6
Outgoing 2		2.114		1.381		-2.113		-1.380		1.5
Line1		2.113		1.380		-2.110		-1.380		2.4
T23		1.100		0.692		-1.096		-0.651		3.9
T25		0.636		0.419		-0.633		-0.392		3.7
T27		0.374		0.270		-0.372		-0.260		1.4
Line2		4.107		2.871		-4.101		-2.871		6.2
T28		0.567		0.517		-0.566		-0.499		1.7
Head Quarters		1.059		0.731		-1.059		-0.731		0.6
ARIK		0.736		0.541		-0.732		-0.511		4.3
GAT		0.459		0.282		-0.458		-0.271		1.5
CKT / Branch	**From-To Bus Flow**		**To-From Bus Flow**		**Losses**		**% Bus Voltage**		Vd	
								% Drop		
ID	MW	Mvar	MW	Mvar	kW	kvar	From	To	in Vmag	
Quarters		0.728		0.542		-0.723		-0.505		5.3
Water Pump		0.741		0.540		-0.738		-0.515		3.6
White House		0.377		0.234		-0.375		-0.223		1.6
T46		1.059		0.731		-1.050		-0.678		8.7
					674.8		6708.7			

Critical Report

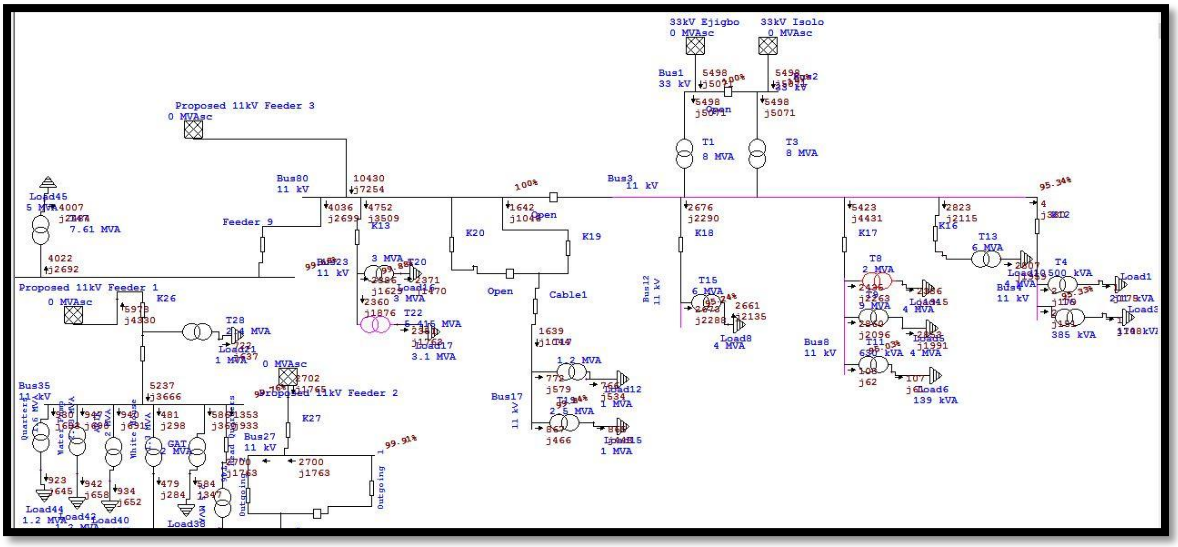
Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Bus10	Bus	Under Voltage		0.415	kV		0.363
Bus11	Bus	Under Voltage		0.415	kV		0.367
Bus12	Bus	Under Voltage		11.000	kV		9.822
Bus13	Bus	Under Voltage		0.415	kV		0.359
Bus16	Bus	Under Voltage		11.000	kV		9.832
Bus17	Bus	Under Voltage		11.000	kV		9.817
Bus18	Bus	Under Voltage		11.000	kV		9.827
Bus19	Bus	Under Voltage		0.415	kV		0.358
Bus20	Bus	Under Voltage		0.415	kV		0.366
Bus21	Bus	Under Voltage		11.000	kV		9.817
Bus22	Bus	Under Voltage		0.415	kV		0.360
Bus23	Bus	Under Voltage		11.000	kV		9.821
Bus24	Bus	Under Voltage		0.415	kV		0.358
Bus25	Bus	Under Voltage		0.415	kV		0.361
Bus26	Bus	Under Voltage		11.000	kV		9.735

Critical Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Bus27	Bus	Under Voltage		11.000	kV		9.726
Bus28	Bus	Under Voltage		11.000	kV		9.720
Bus29	Bus	Under Voltage		11.000	kV		9.712
Bus3	Bus	Under Voltage		11.000	kV		9.832
Bus30	Bus	Under Voltage		0.415	kV		0.359
Bus31	Bus	Under Voltage		0.415	kV		0.358
Bus32	Bus	Under Voltage		0.415	kV		0.361
Bus33	Bus	Under Voltage		11.000	kV		9.722
Bus35	Bus	Under Voltage		11.000	kV		9.712
Bus36	Bus	Under Voltage		0.415	kV		0.360
Bus4	Bus	Under Voltage		11.000	kV		9.832
Bus6	Bus	Under Voltage		0.415	kV		0.363
Bus69	Bus	Under Voltage		11.000	kV		9.707
Bus7	Bus	Under Voltage		0.415	kV		0.363
Bus70	Bus	Under Voltage		0.415	kV		0.356
Bus71	Bus	Under Voltage		0.415	kV		0.362
Bus72	Bus	Under Voltage		0.415	kV		0.361
Bus73	Bus	Under Voltage		0.415	kV		0.358
Bus74	Bus	Under Voltage		0.415	kV		0.359

Bus75	Bus	Under Voltage	0.415	kV	0.356
Bus76	Bus	Under Voltage	0.415	kV	0.358
Bus8	Bus	Under Voltage	11.000	kV	9.801
Bus9	Bus	Under Voltage	0.415	kV	0.340
T1	Transformer	Overload	8.000	MVA	15.510
T3	Transformer	Overload	8.000	MVA	15.510
T8	Transformer	Overload	0.500	MVA	2.689

After



		ETAP			
Project:				Page:	1
Location:		12.6.0H		Date:	03-14-2019
Contract:				SN:	
Engineer:			Study Case: LF		
Filename:	FAAN Model			Config.:	Normal

Bus Loading Summary Report

Bus				Directly Connected Load								Total Bus Load			
				Constant kVA		Constant Z		Constant I		Generic			Percent		
ID		kV	Rated Amp												
			MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar	MVA	% PF	Amp	Loading	

Bus1	33.000	0	0	0	0	0	0	0	0	7.480	73.5	130.9	
Bus2	33.000	0	0	0	0	0	0	0	0	7.480	73.5	130.9	
Bus3	11.000	-0.000	-0.000	0	0	0	0	0	0	14.263	76.6	785.2	
Bus4	11.000	0.000	-0.000	0	0	0	0	0	0	0.330	1.2	18.2	
Bus6	0.415	0.000	0.000	0.001	0.175	0	0	0	0	0.175	0.9	261.2	
Bus7	0.415	0.000	0.000	0.001	0.148	0	0	0	0	0.148	0.9	220.5	
Bus8	11.000	0.000	-0.000	0	0	0	0	0	0	6.981	77.4	385.6	
Bus9	0.415	0.000	0.000	2.386	1.915	0	0	0	0	3.059	78.0	4866.8	
Bus10	0.415	0.000	0.000	2.853	1.991	0	0	0	0	3.479	82.0	5189.9	
Bus11	0.415	0.000	0.000	0.107	0.061	0	0	0	0	0.123	87.0	182.2	
Bus12	11.000	0.000	-0.000	0	0	0	0	0	0	3.518	76.0	193.9	
Bus13	0.415	0.000	0.000	2.661	2.135	0	0	0	0	3.411	78.0	5139.1	
Bus16	11.000	0	0	0	0	0	0	0	0	0	0.0	0.0	
Bus17	11.000	0.000	-0.000	0	0	0	0	0	0	1.944	84.3	102.2	
Bus18	11.000	-0.000	0.000	0	0	0	0	0	0	1.946	84.3	102.2	
Bus19	0.415	0.000	0.000	0.766	0.534	0	0	0	0	0.934	82.0	1344.3	
Bus20	0.415	0	0	0.865	0.443	0	0	0	0	0.972	89.0	1371.8	
Bus21	11.000	0.000	-0.000	0	0	0	0	0	0	3.522	80.0	194.2	
Bus22	0.415	0.000	0.000	2.807	1.959	0	0	0	0	3.423	82.0	5147.6	
Bus23	11.000	-0.000	0.000	0	0	0	0	0	0	5.900	80.4	310.1	
Bus24	0.415	0.000	-0.000	2.371	1.470	0	0	0	0	2.790	85.0	4024.9	
Bus25	0.415	0.000	-0.000	2.351	1.763	0	0	0	0	2.938	80.0	4198.8	
Bus26	11.000	-0.000	-0.000	0	0	0	0	0	0	4.840	83.1	254.8	
Bus27	11.000	0	0	0	0	0	0	0	0	3.225	83.7	169.4	
Bus28	11.000	-0.000	0.000	0	0	0	0	0	0	3.222	83.7	169.4	
Bus29	11.000	0.000	-0.000	0	0	0	0	0	0	3.220	83.7	169.4	
Bus30	0.415	0.000	-0.000	1.400	0.831	0	0	0	0	1.628	86.0	2314.4	
Bus31	0.415	0	0	0.808	0.501	0	0	0	0	0.950	85.0	1356.2	
Bus32	0.415	0	0	0.476	0.332	0	0	0	0	0.580	82.0	820.6	
Bus33	11.000	0.000	0.000	0	0	0	0	0	0	7.372	81.0	387.4	
Bus35	11.000	0.000	0.000	0	0	0	0	0	0	6.392	81.9	336.3	
Bus36	0.415	0	0	0.722	0.637	0	0	0	0	0.963	75.0	1365.3	
Bus69	11.000	-0.000	-0.000	0	0	0	0	0	0	1.643	82.3	86.5	
Bus70	0.415	-0.000	0.000	1.341	0.866	0	0	0	0	1.596	84.0	2291.6	
Bus71	0.415	-0.000	-0.000	0.584	0.347	0	0	0	0	0.679	86.0	959.4	
Bus72	0.415	0	0	0.479	0.284	0	0	0	0	0.557	86.0	789.4	

			Directly Connected Load							**Total Bus Load**			
Bus			Constant kVA		Constant Z		Constant I		Generic			Percent	
ID	kV	Rated Amp											
		MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar	MVA	% PF	Amp	Loading
Bus73	0.415	-0.000	-0.000	0.934	0.652	0	0	0	0	1.139	82.0	1626.8	

Bus74	0.415	-0.000	0.000	0.942	0.658	0	0	0	0	1.149	82.0	1633.6	
Bus75	0.415	0	0	0.923	0.645	0	0	0	0	1.126	82.0	1617.2	
Bus76	0.415	0.000	0.000	4.007	2.484	0	0	0	0	4.715	85.0	6754.5	
Bus77	11.000	0	0	0	0	0	0	0	0	7.381	81.0	387.4	
Bus78	11.000	0	0	0	0	0	0	0	0	3.227	83.7	169.4	
Bus80	11.000	0	0	0	0	0	0	0	0	12.704	82.1	666.8	

Branch Loading Summary Report

	CKT / Branch		Cable & Reactor			Transformer				
			Ampacity (Amp)	Loading Amp		Capability (MVA)	Loading (input)		Loading (output)	
	ID	Type			%		MVA	%	MVA	%
	ARIK	Transformer				2.000	1.167	58.3	1.139	57.0
	GAT	Transformer				2.000	0.688	34.4	0.679	34.0
	Quarters	Transformer				2.000	1.160	58.0	1.126	56.3
	T1	Transformer				8.000	7.480	93.5	7.131	89.1
	T3	Transformer				8.000	7.480	93.5	7.131	89.1
	T4	Transformer				0.500	0.179	35.8	0.175	35.1
	T6	Transformer				0.385	0.151	39.2	0.148	38.4
*	T8	Transformer				0.500	3.325	664.9	3.059	611.9
	T9	Transformer				9.000	3.545	39.4	3.479	38.7
	T11	Transformer				0.630	0.124	19.8	0.123	19.6
	T13	Transformer				9.000	3.522	39.1	3.423	38.0
	T15	Transformer				6.000	3.518	58.6	3.411	56.9
	T17	Transformer				6.000	0.965	16.1	0.934	15.6
	T19	Transformer				6.000	0.984	16.4	0.972	16.2
	T20	Transformer				3.000	2.890	96.3	2.790	93.0
	T22	Transformer				3.000	3.015	100.5	2.938	97.9
	T23	Transformer				3.000	1.660	55.3	1.628	54.3
	T25	Transformer				1.600	0.973	60.8	0.950	59.4
	T27	Transformer				1.600	0.588	36.8	0.580	36.2
	T28	Transformer				2.400	0.980	40.8	0.963	40.1
	T46	Transformer				2.500	1.643	65.7	1.596	63.8
	T47	Transformer				7.610	4.840	63.6	4.715	62.0
	Water Pump	Transformer				2.000	1.171	58.6	1.149	57.4
	White House	Transformer				2.000	0.566	28.3	0.557	27.9

* Indicates a branch with operating load exceeding the branch capability.

Branch Losses Summary Report

	CKT / Branch	**From-To Bus Flow**		**To-From Bus Flow**		**Losses**		**% Bus Voltage**		Vd	
									% Drop		
	ID	MW	Mvar	MW	Mvar	kW	kvar	From	To	in Vmag	
	T1		5.498		5.071		-5.464		-4.583		34.3
	T3		5.498		5.071		-5.464		-4.583		34.3
	K12		0.004		0.330		-0.004		-0.330		0.1
	K16		2.823		2.115		-2.819		-2.113		4.8
	K17		5.423		4.431		-5.403		-4.421		20.5
	K18		2.676		2.290		-2.673		-2.288		3.3
	T4		0.002		0.179		-0.001		-0.175		0.7
	T6		0.002		0.151		-0.001		-0.148		0.7
	T8		2.435		2.263		-2.386		-1.915		49.1
	T9		2.860		2.096		-2.853		-1.991		6.7
	T11		0.108		0.062		-0.107		-0.061		0.4
	T15		2.673		2.288		-2.661		-2.135		11.9
	K20		0.000		0.000		0.000		0.000	100.0	100.0
	Cable1		-1.639		-1.044		1.641		1.045		1.9
	T17		0.772		0.579		-0.766		-0.534		6.2
	T19		0.867		0.466		-0.865		-0.443		2.1
	K19		-1.641		-1.045		1.642		1.046		0.9
	T13		2.819		2.113		-2.807		-1.959		11.9
	K13		-4.746		-3.506		4.752		3.509		6.3
	T20		2.386		1.629		-2.371		-1.470		15.0
	T22		2.360		1.876		-2.351		-1.763		8.8
	Feeder 9		-4.022		-2.692		4.036		2.699		13.7
	T47		4.022		2.692		-4.007		-2.484		14.7
	K27		-2.700		-1.763		2.702		1.765		2.5
	Outgoing 2		2.700		1.763		-2.698		-1.762		1.9
	Line1		2.698		1.762		-2.695		-1.762		3.1
	T23		1.405		0.884		-1.400		-0.831		4.9
	T25		0.813		0.534		-0.808		-0.501		4.8
	T27		0.477		0.344		-0.476		-0.332		1.7
	K26		-5.969		-4.326		5.978		4.330		8.9
	Line2		5.244		3.666		-5.237		-3.666		8.0
	T28		0.725		0.660		-0.722		-0.637		2.2
	Head Quarters		1.353		0.933		-1.352		-0.933		0.7
	ARIK		0.940		0.691		-0.934		-0.652		5.5
	GAT		0.586		0.360		-0.584		-0.347		1.9

CKT / Branch	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage	
								% Drop
ID	MW	Mvar	MW	Mvar	kW	kvar	From	To
Quarters		0.930		0.693		-0.923		-0.645
Water Pump		0.947		0.690		-0.942		-0.658
White House		0.481		0.298		-0.479		-0.284
T46		1.352		0.933		-1.341		-0.866

Critical Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Bus10	Bus	Under Voltage	0.415	kV	0.387		
Bus11	Bus	Under Voltage	0.415	kV	0.391		
Bus13	Bus	Under Voltage	0.415	kV	0.383		
Bus22	Bus	Under Voltage	0.415	kV	0.384		
Bus6	Bus	Under Voltage	0.415	kV	0.388		
Bus7	Bus	Under Voltage	0.415	kV	0.387		
Bus9	Bus	Under Voltage	0.415	kV	0.363		
T8	Transformer	Overload	0.500	MVA	3.059		

Marginal Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Bus12	Bus	Under Voltage	11.000	kV	10.477		
Bus19	Bus	Under Voltage	0.415	kV	0.401		
Bus21	Bus	Under Voltage	11.000	kV	10.472		

Marginal Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Bus24	Bus	Under Voltage	0.415	kV	0.400		
Bus25	Bus	Under Voltage	0.415	kV	0.404		
Bus3	Bus	Under Voltage	11.000	kV	10.488		
Bus30	Bus	Under Voltage	0.415	kV	0.406		
Bus31	Bus	Under Voltage	0.415	kV	0.405		
Bus4	Bus	Under Voltage	11.000	kV	10.487		
Bus70	Bus	Under Voltage	0.415	kV	0.402		
Bus73	Bus	Under Voltage	0.415	kV	0.404		
Bus74	Bus	Under Voltage	0.415	kV	0.406		

Bus75	Bus	Under Voltage	0.415	kV	0.402
Bus76	Bus	Under Voltage	0.415	kV	0.403
Bus8	Bus	Under Voltage	11.000	kV	10.454
T22	Transformer	Overload	3.000	MVA	2.938

V. Conclusion

In this study, it has been established that the distribution network topology of the case study is highly inefficient with limitations that prevent the maximal evaluation of on grid energy thereby increasing the energy cost through the utilization of off-grid diesel powered generators. It was also established that the instrument transformers of the secondary distribution lines are wrongly sized, creating a bottle neck and limiting the low on energy from source to load and one of the 11kV feeders is grossly overloaded to the tune of 300%. This implies that there will be availability of grid supply. The modeled network in the study revealed over 41 network assets that currently operate at under voltages. Network limitation at the airport identified in the study. Opportunities for energy cost reduction were also identified in the study coupled with the solutions for network optimization and energy cost reduction

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