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Monetary and ecological cost-benefit analysis of onshore power supply : a case study of the port of Mombasa

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MONETARY AND ECOLOGICAL COST-BENEFIT ANALYSIS OF ONSHORE POWER SUPPLY

A Case Study of the Port of Mombasa

By

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DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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ABSTRACT

Title of Dissertation: **Cost- Benefits Analysis of Onshore Power Supply, Port Stay Fuel Costs and Associated Ecological Costs - A Case Study of the Port of Mombasa**.

Degree **MSc**

The shipping industry has of late been faced with “Tidal Waves” of environmental regulations and strict compliance requirements. These regulations extend not only to vessels while at sea, but also while staying in ports. Ships burn diesel to run their auxiliary engines to produce power for hotelling, loading and unloading activities while onshore. Shore power avails itself as a potential substitute and a way to partially mitigate the strict and costly regulation requirements.

A breakthrough in International standards on OPS, the lack of which has been a draw back in OPS implementation, was realized in July 2012 with the launching of IEC/ISO/IEEE 80005-1. Other challenges have been different frequency levels of vessel power systems and a large variance in power requirements by vessels, ranging from less than 1MW in some bulk carriers to 12MW in large cruise vessels.

The viability of OPS implementation is not a case of “one size fits all”. Project appraisal should be done on a case by case basis taking into consideration individual port operation characteristics.

This research analyses all the vessel visits to the port of Mombasa in the year 2012, draws up their profiles of power and other vessel properties, comes up with a relationship between these properties and hotelling power demand and then empirically calculates the overall fuel quantity consumed by these vessels while in port, total cost of these bunkers and the externality costs. Additionally, an OPS system capable of supplying the total vessel visits with OPS is designed and quotations for its costs obtained. A likely power bill had the vessels used OPS, is calculated using the current prevailing power rates in Kenya. A project appraisal is then undertaken taking into consideration all the above costs and recommendations based on the outcome of the appraisal are made to Kenya Ports Authority.

Keywords: Onshore Power Supply-OPS, externalities, regulations, hotelling, empirical, viability, appraisal, Port of Mombasa

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LIST OF ABBREVIATIONS

AE	Auxiliary Engine
AGW	Average Grade of Waiting
AMP	Alternative Maritime Power
ARB	Air Resources Board
AST	Average Service Time
BOQ	Bill of Quantities
BOR	Berth Occupancy Ratio
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
DWT	Deadweight
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Indicator
ERC	Energy Regulatory Commission
FCC	Fuel Cost Charge
FERFA	Foreign Exchange Rate Fluctuations Adjustment
FEU	Forty Foot Equivalent Units
FLA	Full Load Amperes
GHG	Green House Gas
GRT	Gross Registered Tonnage
HV	High Voltage
HVSC	High Voltage Shore Connection
IA	Inflation Adjustment
ICAO	International Civil Aviation Organization
IEC	International Electro-technical Commission
IEEE	The Institute of Electrical and Electronics Engineers
IGBT	Insulated Gate Bipolar Transistor
IMO	International Maritime Organization
IRR	Internal Rate of Return

ISO	International Organization for Standardization
KENGEN	Kenya Electricity Generating Company
KOT	Kipevu Oil Terminal
KPA	Kenya Ports Authority
KV	Kilovolts
LNG	Liquefied Natural Gas
LOA	Length Overall
LPG	Liquefied Petroleum Gas
LPI	Logistics Performance Index
LV	Low Voltage
MARPOL	International Convention for the Prevention of Pollution from Ships
MCC	Marginal Control Cost
ME	Main Engine
MEPC	Marine Environment Protection Committee
MPA	Maritime Port Authority of Singapore
MPDP	Mombasa Port Development Project
MW	Megawatts
NMVOC	Non-Methane volatile organic compounds
NNEI	No Net Emission Increase programme
NO_x	Nitrogen oxides
NPV	Net Present Value
NRT	Net Registered Tonnage
OECD	Organization for Economic Co-operation and Development
OPS	Onshore Power Supply
PDCA	Plan, Do, Check, Act
PM_{10}	Particulate matter/material with aerodynamic diameter 10 micrometers
REP	Rural Electrification Program
Ro-Ro	Roll on Roll Off
SCAQMD	South Coast Air Quality Management District
SCC	Social Cost of Carbon

SEEMP	Ship Energy Efficiency Management Plan
SF_6	Sulphur Hexafluoride Gas
SFOC	Specific Fuel Oil Capacity
SLD	Single Line Diagram
SO_x	Sulphur Oxides
SOT	Shimanzi Oil Terminal
SPO	Shore Power Outlets
STS	Ship to Shore Gantry Cranes
TEU	Twenty Foot Equivalent Units
UNCTAD	United Nations Conference on Trade and Development
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollars
VAT	Value Added Tax
XLPE	Cross-Linked Polyethylene
YOB	Year of Build

1.0 INTRODUCTION

1.1 Background

“Without International shipping, half the world would freeze and the other half would starve” (Mitropoulos, 2005). In the year 2011, International ports worldwide handled around 80% of global trade by volume and over 70% by value all of which was carried by sea (Hoffman et al, 2012. p. XVIII). These shares are even higher in the case of most developing countries. It is undoubtedly a fact that shipping plays a pivotal role in underpinning international trade. Thanks to shipping, the transaction cost in international trade has been greatly reduced and has thus acted as a cost-effective way to transport raw materials, semi-finished components, finished goods, fuel and foodstuffs over any great distances. As a matter of fact, globalization both drives and is driven by low cost of transport.

These great benefits have, however, not come along freely. “Shipping is estimated to have emitted 1,046 million tonnes of CO_2 in 2007, which corresponds to 3.3% of the global emissions during 2007. International shipping is estimated to have emitted 870 million tonnes, or about 2.7% of the global emissions of CO_2 in 2007” (IMO, 2009, p.7).

If left uncontrolled, with the current growth trend in shipping and in the absence of policy, the same study forecasts that ship associated emissions may grow by up to 250% in comparison with the 2007 figures by the year 2050. By comparison, the sulfur content of standard marine fuel is 2,700 times higher than that of conventional diesel for cars.

According to the report, exhaust gases are the primary source of emissions from ships. Ship exhaust gases include CO_2, NO_x SO_2, CH_4, CO[1] and PM_{10} among many others in minute quantities. CO_2 leads to positive "radiative forcing" and long-lasting global warming. It is the most significant GHG emitted by ships, both in terms of quantity and of global warming potential, with the contribution of the other GHG emissions from ships being comparatively less.

These gases not only affect the environment, but have serious impacts on human health. Ambient Particulate Matter (PM) concentrations have been associated with a wide range of health impacts including asthma, heart attacks, and hospital admissions. According to epidemiological studies, PM emissions contribute to approximately 60,000 deaths annually worldwide, with impacts concentrated in coastal regions on major trade routes (Kuna-Dibbert, Krzyzanowski & Schneider, 2005).

Inhalation of NO_x may cause or worsen respiratory ailments such as bronchitis and emphysema and aggravate existing heart diseases. This pollutant can deeply penetrate into sensitive lung tissue and damage it, causing premature deaths in extreme cases.

Current scientific evidence links exposure to SO_2 with an array of adverse respiratory effects including bronchoconstriction and increased asthma symptoms.

CO can have significant cardiovascular effects on those who suffer from heart disease. The central nervous system can also be affected. Breathing high levels of CO can result in blurred vision, a reduced ability to work or learn, and reduced manual dexterity.

The Port and the City have always co-existed with many ports having developed in very close proximity to urban areas and many urban areas being developed due to the existence of a thriving port entity. The question of which, between the port and the city, came first has always been a paradox. Consequently, in harbor cities, ship emissions are often a dominant source of urban pollution affecting the health of people living and working in these areas. Pollutant emissions from shipping have continued to rise, while

[1] Consider List of Abbreviation for the full names of abbreviations

emissions from land-based sources have gradually come down due to dedicated efforts to achieve green production.

To this end, "The non-shipping world is looking critically at the marine industry's contribution to greenhouse gas (GHG) emissions and asking how they can be reduced" (Lloyds Register, 2012, p.24).

In 1992, an international treaty, the United Nations Framework Convention on Climate Change (UNFCCC) was formed between countries, to cooperatively consider mitigating action against average global temperature increases.

To fast track the environmental protectionism measures agreed, the countries launched negotiations to strengthen the global response to climate change in 1995, and, two years later, adopted the Kyoto Protocol. "The Kyoto Protocol legally binds developed countries to emission reduction targets. The Protocol's first commitment period started in 2008 and ended in 2012. The second commitment period began on 1 January 2013 and will end in 2020" (http://unfccc.int/essential_background). The member states pledged to pursue the reduction of emissions of GHGs not controlled by the Montreal protocol from aviation and bunker fuels through cooperation with IMO and ICAO and to ensure that their aggregate anthropogenic carbon dioxide equivalent emissions of GHG gases do not exceed their assigned amounts (Nakazawa, 2012, p 5).

IMO on the other hand, being the United Nations' specialized agency concerned with maritime affairs, through IMO: Resolution A.963 (23), in December 2003, pledged to establish a GHG emission baseline together with development of a methodology to describe GHG Emission Index. In addition, a review of its policies and practices was envisaged to be in line with the threat of global warming. To date, many technical and operational measures together with market based solutions are being pursued by IMO with a target of achieving a reduction of emission rate of 25% below the current emission levels.

As a hot topic on the IMO Agenda, any measure aimed at reducing emissions will greatly benefit the ship owners, operators and shipping industry in general.

The means through which GHGs can be reduced has been a complex discussion and there are different views on how it can be done. Onshore Power Supply presents itself as a potential part of the necessary solutions for achieving a sustainable reduction in air pollution and especially CO_2 emissions from vessels while in port (http://www.ops.wpci.nl/ops-installed/). This concept has received a lot of support and has been implemented in several third and fourth generation ports around the world. This paper will seek to establish whether the same is applicable in first and second generation ports and more specifically at the Port of Mombasa.

1.2 Research Objectives

The research will seek to fulfill the following key objectives-:

1. Carry out a quantitative analysis of power demand levels for the different vessels that visited the Port of Mombasa in the year 2012 and establish a relationship between these vessels' dimension properties and their hotelling needs.
2. Quantitatively explore the total fuel consumed by these vessels during their stay at the port, and from this figure, establish the fuel costs involved and the cost of ecological externalities by their operation while at the berths.
3. Carry out an investment appraisal of an onshore power supply as an alternative energy supply to these vessels taking into consideration the opportunity costs of ecological pollution, power bill and fuel costs.

1.3 Research Questions

In achieving the above objectives, this research paper shall strive to answer the following questions-:

What are the profiles of the different vessels that visited the port of Mombasa in the year 2012 and is there any relationship between these vessels' dimensions and their hotelling power demands?

What is the total cost of running auxiliary engines combined with the cost of internalization of the Social Cost of Carbon (SCC) during the port dwell time for all the vessels that visited the port of Mombasa in this same year?

Can the above costs be economically offset, albeit partially, by implementing an onshore power supply system taking into account the power bill, cost of fuel and cost of externalities?

1.4 Kenya Ports Authority (KPA)

The port of Mombasa is the gateway to East and Central Africa and is one of the busiest ports along the East African coastline. The port is located at coordinates 4°04′S and 39°41′E at the Southern part of the country of Kenya.

Figure 1.1 Container Terminal at the Port of Mombasa

Source: Author

Figure 1.2: Kenya Ports Authority Headquarters in Mombasa City

Source: Author

Currently, the port has 19 berths; eight of which are container berths, two oil jetties and nine conventional cargo berths. The port's major markets are Western Europe, Asia, Far East, the Americas and the rest of Africa. The port receives regular feeder services between Mombasa and Dar-es-salaam, Durban, Mogadishu, Djibouti, Salalah and Dubai.

On the side of productivity, KPA container traffic increased by 17.2% from 770,804 TEU handled in 2011 to 903,463 TEU handled in 2012.The port performance in terms of throughput for the past five years grew from 16million tons to 22million tons (KPA, 2012,p. 1).

The port's capacity is continually under expansion. In 2011, the port invested in 3 new Ship to Shore (STS) container gantries with twin lift capacities and three mobile habour cranes among other cargo handling equipment. The port's channel depth and turning basin were also increased to 15m and 300m respectively through dredging carried out by Van Oord of the Netherlands (KPA, 2011, p. IV).

The same year also saw the construction of a new berth (Berth 19) and its stacking yard, carried out by China Roads and Bridges Corporation. Three More STS's are currently under procurement and are expected to be commissioned at the start of 2014.

The development of a second container terminal branded Mombasa Port Development Project (MPDP) is also currently underway. The terminal, with a design capacity of 1.2 million TEU is contracted to Toyo Construction Company of Japan and the first phase of berths' number 20 and 21 is expected to be operational in 2015 adding a total of 450,000 TEUs to the current port capacity.

In tandem with the ambitious port capacity expansion is power upgrade. The port power supply is being upgraded from the current medium voltage of 11kV to a High Voltage (HV) of 132kV by Consolidated Power Projects (Pty) Ltd of South Africa at a cost of 6.4 Million USD. The contract duration is 18 months and the expected contract completion date is 14th February, 2014 (See appendix 1). Once operational, the substation will have an installed capacity of 30Megawatts and with the current maximum demand of 5 Megawatts, the expanded capacity is large enough to offer sustainable supply of onshore power to vessels at the berth.

The utility generating company, Kenya Electricity Generating Company (KENGEN), expects to supply half of the total power requirements in Kenya by geothermal power and the remaining from Hydro and emergency generating stations. The estimated geothermal potential in Kenya is between 7,000 MW and 10,000 MW out of which only 200 MW is exploited (http://thinkgeoenergy.com).Currently, Hydro power accounts for more than 60% of total power production.

The development of the fourth phase of Olkaria geothermal power project is currently in progress with companies from China, Korea and Japan all having signed agreements to be parties to the geothermal exploitation programme.

The Port of Mombasa has been offering onshore power supply albeit on a minor scale. Although not done in a sustainable way, this service is offered to naval forces patrol ships, which dock once in a while at the port, while on their mission of keeping pirates at bay in the troubled waters off the East Coast of Somalia.

The port tug boats, mooring boats and pilot boats are also supplied with onshore power temporarily while at the berths awaiting their next assignments. In so doing, the exercise ensures a clean and quiet atmosphere for the staff manning these small crafts.

According to the Global Logistics Indicators (2012), poorer countries take longer to process trade transactions than the developed nations. The average time for a typical import transaction in Africa is 58 days compared to 14 days in OECD countries. Kenya, for example, does routine inspection of all containers and is ranked between 78 to 117 LPI (Logistics Performance Index). The effect of this is the longer time it takes to make ready the cargo handling procedures once the ship is at the berth. This results in long Average Service Times (AST), high Berth Occupancy Rates (BORs) and high Average Grade of Waiting (AGW) for the port.

The main determinant of the ship pollution effect while at the port is the time it takes while at the berth (AST). The longer the time at berth, the longer auxiliary engines are run, the more fuel is consumed in running these engines and hence the more the environmental pollution impacts.

The Mombasa port container terminal and general cargo berths had a BOR of 75.7% and 60.9% respectively (KPA, 2012, p 15). The average waiting time as per the same report was 2.78 days for all ships handled. With the increase in port capacity, and, consequently the number of ships handled, and given the long average service time for the vessels, a measure to reduce ship sourced pollution while at berth is a timely idea.

Courtesy of the shift of power production to sources with smaller carbon footprints from the utility suppliers, sufficient installed power capacity at the port terminal, long average service times (AST) and a growing number of ships visiting the port, (then) the conditions necessary for implementation of onshore power supply are fulfilled. This is further augmented by international pressures and requirements on pollution reduction measures.

1.5 Scope of Research

This dissertation aims at carrying out an in-depth cost benefit analysis of implementing an onshore power supply project versus the benefits of reduced emissions and savings on fuel costs in a developing nation and particularly in the port of Mombasa. The project appraisal will be carried out using the modern appraisal methods of Internal Rate of Returns (IRR) and compared with Net Present Value (NPV) and Payback period method for the expected period of operation. Recommendations and conclusion will then be made on the viability of the project and advised to the port authority.

The dissertation in structured into nine main Chapters, with Chapter one being the introduction, where the research questions and thesis objectives are discussed. Chapter two is a comprehensive literature review of the contemporary issues on pollution prevention primarily being the regulatory framework advanced by IMO and its effect on shipping and the way the industry embraces new pollution reduction technologies. The next Chapter is the methodology, which summarizes the data collection methods and analysis procedures to be followed. Chapter four delves into the empirical analysis of the collected data, with emphasis on the different vessels' power and property profiles culminating in a relationship analysis of these features and the vessels' hotelling needs. Technical designs of OPS systems and the total OPS project costs follow in Chapter five and six respectively with Chapter seven dealing with the OPS Opportunity Costs. Chapter eight is the project appraisal by the different appraisal methods while Chapter nine draws conclusions from the analysis findings with emphasis on whether the research objectives and solutions to the problem statement have been met. The contributions of this research and its remaining issues for future study together with recommendations are also pointed out in this chapter. The last sections of this report include the references and a list of appendices.

1.6 Delimitation

This report considers the expenditure for installing OPS as the opportunity cost of the cost of externality and port stay fuel cost from the view point of the port. The scope includes all associated costs from design, testing, installation and commissioning of a state of the art OPS system capable of supplying power to vessels on both 50 and 60 Hz frequencies.

The report will, however, not consider the cost of the reconstruction to be made onboard the vessels for adaptation to the OPS. Other supplementary costs, including the cost of the flexible cable reel to be mounted on board the vessels and the synchronizing panels for phasing out power before changing over from Onboard to Onshore power, will also not be considered.

Also omitted in the report is a description of the detailed communication procedures and protocols necessary for effective and safe connection and termination on both ends of the supply system. Further, it is expected in the component design section that the reader has some basic knowledge regarding electrical power engineering in order to understand the models and the methods used in the handmade calculations.

2.0 LITERATURE REVIEW

2.1 Introduction

Maritime transport involves three main disciplines; Maritime economics, maritime technology and maritime environment. Ship operation and management involves complex economic principles of financing, costs, revenues, risks and cash flows all of which go to the heart of the business; making profits. Maritime technology, on the other hand, provides the buoyancy support systems through which the transport vehicle (vessels) are designed and optimized to achieve transport efficiency to move trade from one region to another. Tightly interwoven between these two disciplines is the maritime environment (protection and sustainability). The transport vessels release sludge, heat and ballast water to the sea affecting plants, microbes and animals in the marine ecosystem while the associated exhaust systems release GHG gases to the atmosphere (air), affecting the very livelihood of the people the maritime transport proceeds should be supporting. This relationship is shown in Figure 2.1.

2.1.1 Maritime Legislation and Directives on Pollution

The scope of maritime environment and the means to achieve sustainable shipping measures so as to prevent and control pollution caused by ships and to mitigate the effects of any damage that may occur as a result of maritime operations and accidents is a wide area of study. The scope of this study narrows down to pollution effects as a result of airborne emissions from ships while at berth. Various studies have been carried out on means to reduce these emissions. Key among them is the study on GHG emissions from ships in 2000. This study was initiated after the 1997 MARPOL Conference, convened by IMO, which adopted Resolution 8 on "CO_2 emissions from ships", inviting IMO to undertake a study of emissions of GHG from ships as a means of taking stock of the percentage of the global inventory of GHG gases contributed by ships.

In October 2006, MEPC 55 agreed on an update of the above study to provide a better platform for future decisions on GHG emissions as a means of follow up to Resolution A.963(23) and which came to be commonly known as the "Second IMO GHG study 2009" (IMO, 2009, p.2). The study envisages a reduction of carbon dioxide emissions per ton-mile by the use of two approaches: Technical approach and Operational approach.

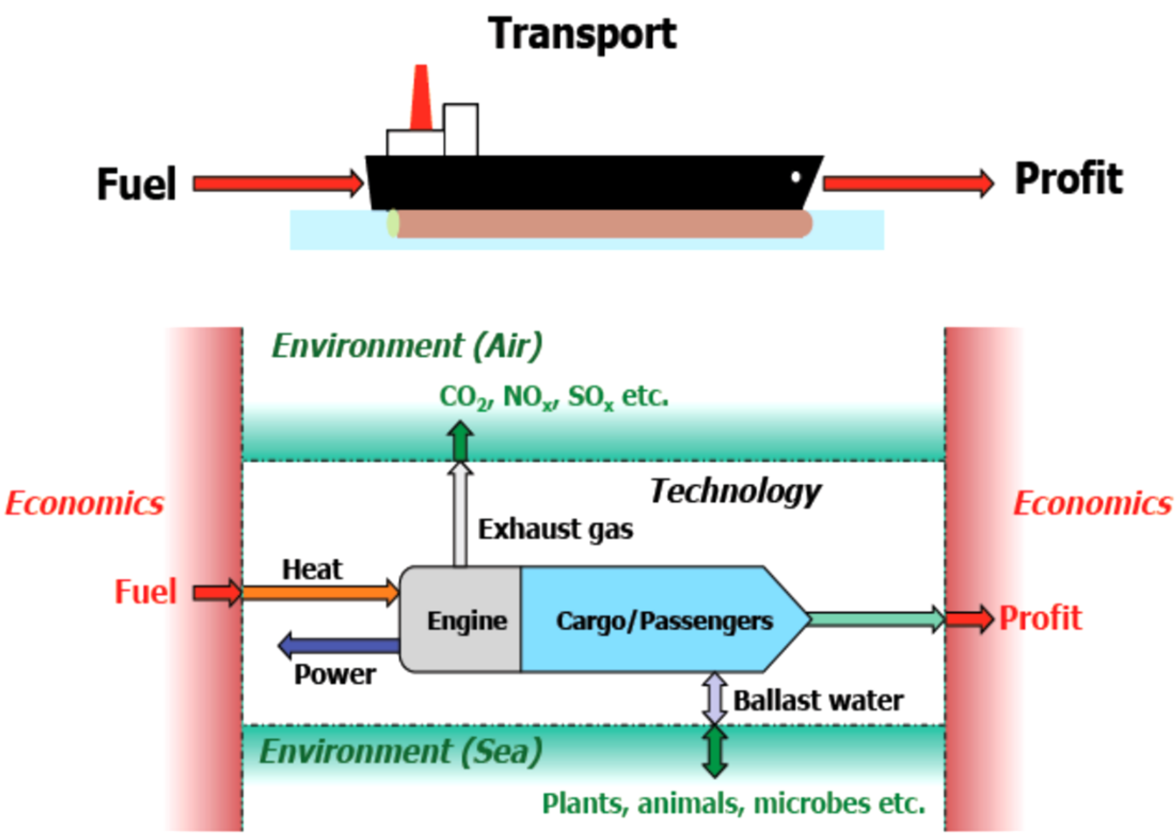


Figure 2.1 Maritime Economics, Technology and Environment in Maritime Transport

Source: Maritime Technology handout by Professor T.Nakazawa (2013)

Through its circular MEPC.1/Circ.681 (EEDI), IMO promulgated the technical approach towards CO_2 reduction. This was done "in order to stimulate innovation and technical development of all elements influencing the energy efficiency of ship from its design phase"[2]

EEDI is an indicator of the efficiency expected of a ship to achieve, based on the ship's specifications. This index is calculated taking into account Engine Power, Specific Fuel Oil Capacity (SFOC), Deadweight (Dwt) and Speed. The index is expressed as-:

$$EEDI = \frac{Engine\ Power\ x\ SFOC\ x\ C_f}{DWT\ x\ Speed} (gCO_2/ton - mile) \text{ ……………………..Equation 2.1}$$

Where C_f is a non-dimensional conversion factor.

The operational approach for reduction of CO_2 includes a mandatory or voluntary reporting of Energy Efficiency Operational Indicators (EEOI) (IMO, 2009, p.5). This tool is intended to standardize fuel efficiency for ships in operation and has a direct relation to bunker consumption. The guideline for the voluntary use of the ship EEOI was brought into effect by Circular MEPC.1/Circ. 684(EEOI).

EEOI expresses actual CO_2 efficiency in terms of emissions of CO_2 per unit of transport work, using the formulae in Equation 2.2, as per MEPC/Circ.471

$$\mathrm{EEOI} = \frac{\sum_i^n \mathrm{CF_i\ x\ C_{carbon}}}{\sum_i^n \mathrm{m_{Cargo,i} x\ D_i}} (\mathrm{gCO_2/ton - mile}) \text{……………………………..Equation 2.2}$$

Where:- FCi denotes fuel consumption on voyage i;

C_{carbon} is the carbon content of the fuel used;

$m_{cargo,i}$ is the mass of cargo transported on voyage I; and

D_i is the distance of voyage i.

As a means of ensuring sustainability in the use of the EEOI, another tool known as Ship Energy Efficiency Management Plan (SEEMP) was adopted through circular MEPC.1/Circ. 683(SEEMP). SEEMP incorporates best practices for the fuel efficient

[2] Full guidelines on the interim method of calculation of the Energy Efficiency Design Index for new ships available in Circular MEPC.1/Circ.681(EEDI)

operation of ships. Measures aimed at reducing fuel consumption and consequently reduction in CO_2 emissions such as voyage optimization and sailing at recommended speeds are monitored and a self-evaluation and improvement procedure enacted through the PDCA[3] Cycle with EEOI being the primary monitoring tool (Nakazawa, 2012, p. 10).

The Marine Environment Protection Committee (MEPC) at its 62nd session, from 11th to 15th of July 2011, through member states who are Parties to MARPOL Annex VI, adopted amendments to the MARPOL Annex VI, by adding a new Chapter 4 on regulations on energy efficiency for ships, to make mandatory the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all operational ships (www.imo.org).

An update to the current (second) IMO GHG Study of 2009 is also envisaged. MEPC 65 at its sitting in May, 2013, gave a nod to have the update study carried out. The committee also approved the terms of reference on the methodology and assumptions to be applied, and agreed to initiate the study, which focuses on updating key figures on greenhouse gas (GHG) emissions' estimate for international shipping in the current document.

2.1.2 Regulatory versus Market Based Instruments

Apart from the technical and operational approaches, market based approaches or economic instruments have been touted as better environmental protection instruments than their regulatory counterparts advanced by IMO and UNFCCC.

From the point of view of the market, the exclusivity, transferability and protection of property rights are the cornerstones of market economy. In the absence of such property rights, markets will fail (Ma, 2012, p.158). This case also applies to environmental goods which have the characteristics of public goods. Pollution by ships, either on the high seas or on the shore may be the cause of acidic rain, hence harm to plants and people's health. "Obviously, the ship owner and the sufferers do not have

[3] PDCA Cycle is a sustainable concept for self-evaluation and improvement. It's an acronym for Plan, Do, Check and Act mostly advanced in regulations and international standards such as SEEMP and ISO

any contractual relationship between them and the environment product, or the emission, is not priced and stays outside the market" (Ma, 2012, pp158). The victims cannot identify the exact polluter and the responsible shipping company does not include this as production costs, leading to more production than the optimal one and hence market distortion, unfair competition and badly allocated resources.

Figure 2.2 illustrates the shift in production level and pricing if the costs of externalities are included in the production cost. The marginal production cost with externality (MC_E) is always higher than the marginal costs of production without environmental costs consideration (MC_P). The effect is that the shipping company or port authority will maximize its profitability by keeping its productivity at Q rather than Q_E, creating a net externality cost of (P_T - P). "Such externality costs are paid for by the victims of pollution, their families, insurance and social security companies where applicable" (Ma, 2012, pp159).

If mandated to internalize the cost of externality in its production, the shipping or port company will have a new marginal production cost MC_E at the current demand with the optimal production cost being increased from P to P_E. This shows an increase in the production cost with the total cost of the externality being (P_E - P) which is less than the former externality cost of (P_T - P).

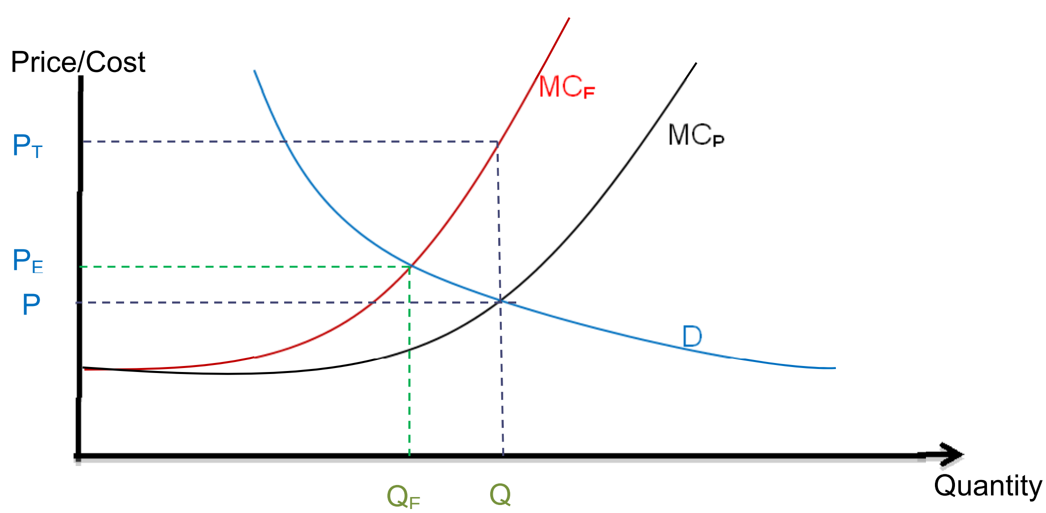


Figure 2.2 Effect of Externality in a Competitive Market

Source: Maritime Economics Lecture Handout by Prof. Shuo Ma (2012)

One of the main drawbacks of regulatory control, which market based instruments seek to address, is that with two different ships using different technologies and with Marginal Control Costs given as illustrated in Figure 2.3, if regulations set the permitted emission levels at $E_{O,}$ then company 2 with a marginal cost control curve MCC-2, will have to spend much higher costs, P2, to comply with the directive compared to company 1, which only needs to use a control cost of P1 to meet the regulations. The overall pollution control cost would have been lower if company 1 controlled more than E_O units and company 2 was allowed to control less, but rather compensate company 1 for the over and above control cost it incurred above E_O. Optimum control costs for the two companies are achieved when the pollution control costs are the same for both companies.

This is the basis for the United Nations (UN) Clean Development Mechanism (CDM). "The CDM is defined in the Kyoto Protocol and allows a country with an emission-reduction or emission-limitation commitment to implement an emission-reduction project in developing countries. Such projects can earn saleable certified emission reduction (CER) credits, each equivalent to one tonne of CO_2, which can be counted towards meeting Kyoto targets" (Korean Register for Shipping, 2013).

Other market players propose a global contribution fund as a model of market based solution to GHG emissions. According to this model, "every time a ship buys fuel, it would be required to pay a specified contribution per tonne to an international fund" (Mikkelsen, Olsen & Rud, 2012*).* These funds would then be used to finance climate projects and combat the effects of climate change in developing nations. Key among the proponents of this model is the Danish government which is of the opinion that such a model would provide "a unique opportunity to reconcile the IMO principle of equal treatment of all ships with the UNFCCC principle that the developed nations should finance the climate issues".

The choice of which market based model IMO should adopt has pitched the different proponents into a political contest and the debate towards an agreement is far from over. However, there is consensus that the "Social Cost of Carbon (SCC) must be internalized in the prices that consumers and firms actually see and pay", and that, in time to come, as more is unearthed about the true size of SCC, the carbon tax can be increased or decreased accordingly (Pindyck, 2013).

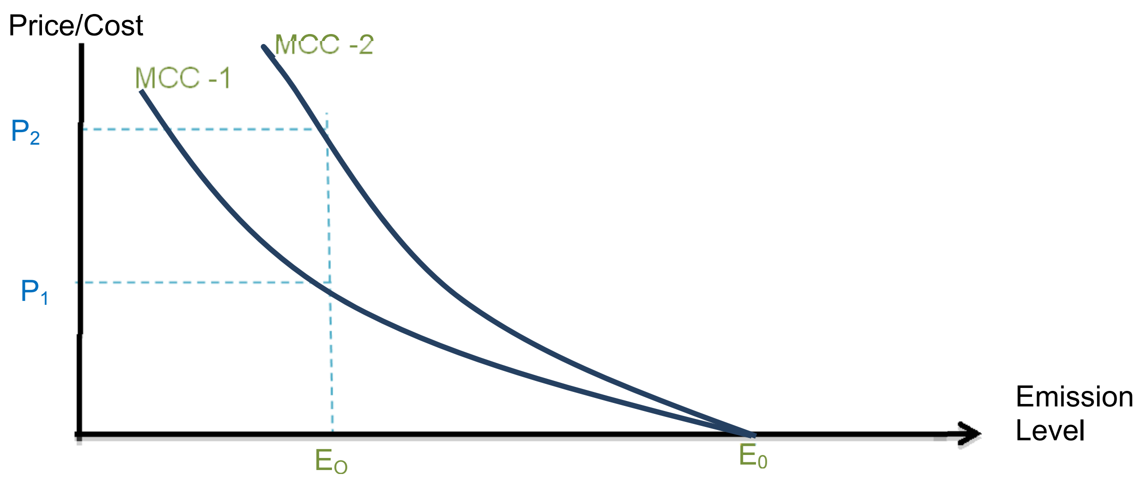


Figure 2.3: Ineffectiveness of Regulatory Method for Firms with Different MCCs

Source: Maritime Economics Lecture Handout by Prof. Shuo Ma

Another, yet distinctive, drawback of regulatory instruments is their counterproductive factor in promoting new innovation and technological advancements likely to cause reduction in control costs at improved emission rates. This is as illustrated in Figure 2.4.

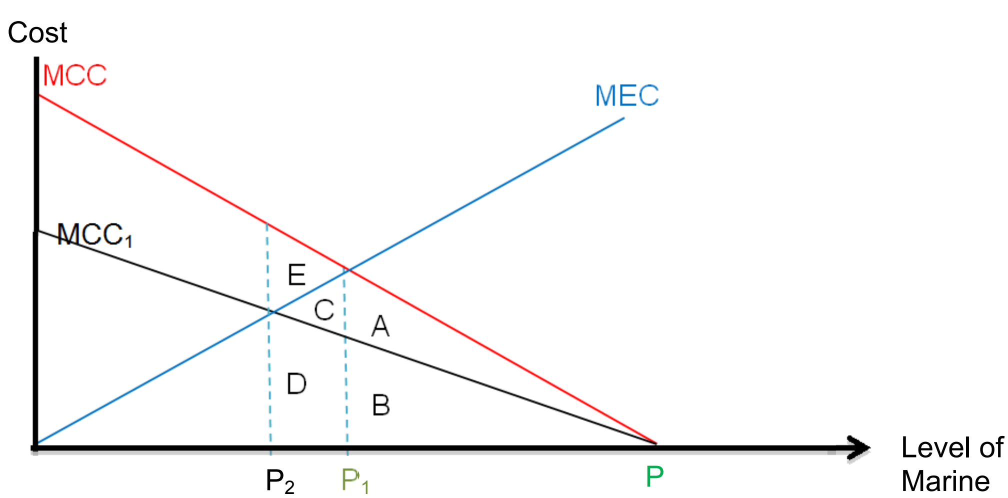


Figure 2.4 The Effect of Regulatory Instruments on Use of New Innovations

Source: Maritime Economics Lecture Handout by Prof. Shuo Ma (2012)

If the Marginal External Costs from environmental pressure groups and regulatory bodies interact with the marginal pollution control costs as shown, then the company's optimum pollution level will be set as $P_{1.}$ In this case, the company has a pollution control cost of A+B. If, by investing in modern technologies, the company can shift the control cost from MCC to $MCC_{1,}$ the net saving would be A.

Most companies would, however, be discouraged from such initiatives because of their knowledge that once the regulatory bodies and advocates of environment get wind of such innovations, they will agitate for a shift in allowable pollution levels to P2 to satisfy the principle of equilibrium at intersection of MCC_1 and MEC by making the emission standards even more stringent. As such, the total cost saving for the company from implementing the new technological innovation would be given as A-D.

With even more advanced technological advancements and reduced MCCs from their use at almost static MEC, the implication is even stricter regulations with D becoming bigger to a point where it becomes greater than A implying a total disincentive for embracing new technologies. For this reason, most companies refuse or delay adopting any new developments in technologies or embrace the innovations and use them discreetly. As regulations tighten, the impetus to fulfill the mandatory EEDI and SEEMP conditions becomes a necessary evil. Though EEDI only applies in the design stage, SEEMP ensures use of best practice in ship operation throughout its life cycle by monitoring the EEOI values. It makes use of the PDCA cycle hence acting as a motivation for better performance in the next cycle of operation. This is as shown by Figures 2.5 and 2.6 respectively.

The SEEMP is a sustainable and efficient pollution prevention monitoring tool. Apart from sea leg optimization, the control of pollution while a ship is staying in port can have significant effects on the level of SEEMP attainable. Although not controlled by the above regulatory controls, a port that guarantees a saving on the pollution aspect of a ship during ship operation at the quay has a competitive edge against others during these times when the port business is facing stiff competition. The concept of Green

Port has and is being fronted by many ports as a show of their commitment to environmentally friendly operation.

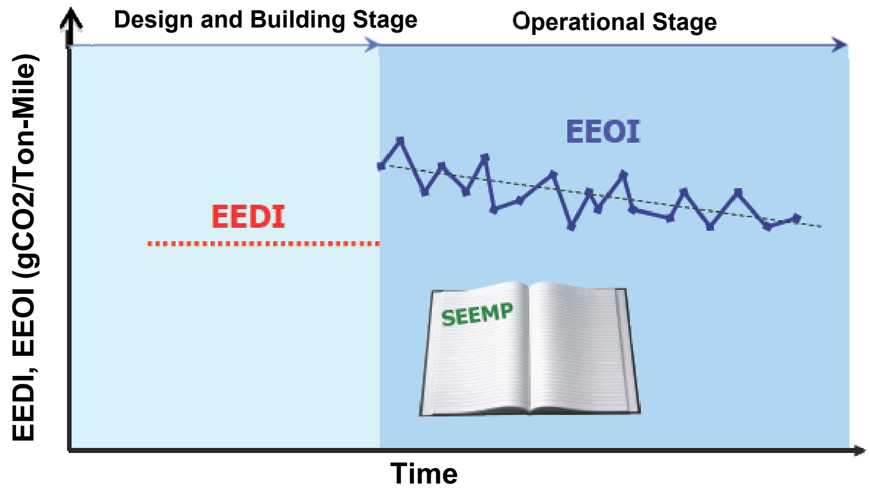


Figure 2.5: EEDI, EEOI and SEEMP Application in a Ship's Life Cycle

Source: Maritime Technology Handout by Prof. Nakazawa T. (2012)

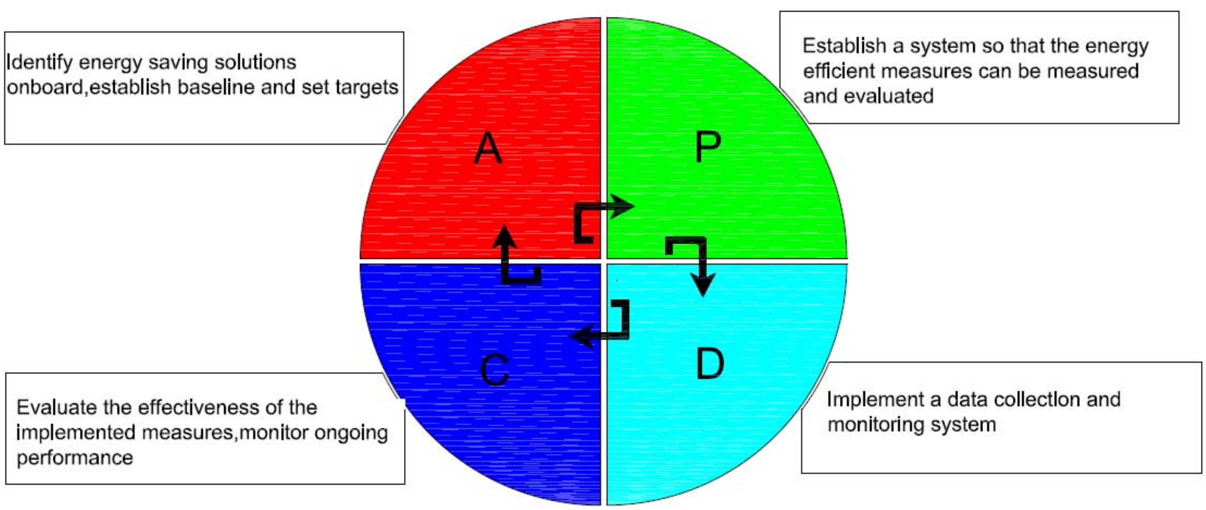


Figure 2.6: The PDCA Cycle in SEEMP Application

Source: Maritime Technology Handout by Prof. Nakazawa T. (2012)

2.1.3 Green Port –Onshore Power Supply Concept

The provision of onshore power is one such green port initiative in many ports. The World Port Climate Initiative recommends the use of Onshore Power Supply (OPS) as a strategy for reducing environmental impacts of sea going vessels in the port. This technology is known by a variety of names: The IEC/ISO/IEEE standard uses the term High Voltage Shore Connection (HVSC) system. Other popular names include Cold Ironing, Shore Side Electricity and Alternative Maritime Power (AMP). For the purpose of this study, the abbreviation OPS will be used.

In this concept, once a ship is berthed, the power for supporting activities such as loading, unloading, lighting, heating, air conditioning, hotelling and other onboard activities is supplied by the shore utility provider rather than running the auxiliary engines. "The use of shore-side power allows ships to shut off their diesel engines while docked in port. This results in reductions in greenhouse gas and noise emissions as well as vibrations, improving environmental conditions for people in and around the port. It also allows an opportunity window for maintenance work on the engines" (www.abb.com).

The concept can only provide net gain on positive environmental impact if the utility supply providers use more efficient power producing systems, or renewable energy sources, or cleaner sources of fuel, which are less polluting compared to the effects of running the onboard auxiliary engines. OPS, though not a new concept, has only found application in the developed nations, mostly on the west coast of the USA and northern Europe. There is, however, a flurry of activities in this direction currently, and interest in this technology is growing fast, spurred by tougher environmental legislation, greater focus on emissions in ports from shipping, and more recently, rising fuel prices.

In the year 2008, The World Ports Climate Declaration and Endorsement Ceremony in Rotterdam adapted a declaration to encourage shore-side supply of (renewable) electricity as part of the initiatives to reduce CO_2 emissions from port operations and development (http://www. wpci.nl/docs/Declaration).

The impetus has nonetheless been hampered by prohibitive installation costs, differences in voltage levels and, more so, differences in power frequencies. Lack of international standards regarding shore-side power supply, up to July 2012, made the implementation of OPS even more difficult. The electricity frequency in different parts of the world differs from place to place as shown in Figure 2.7.

The European Union grid, for example, is 50 Hz while that of the US is 60Hz. The frequency used onboard ships can also be either 50 or 60 Hz. A ship designed for 60 Hz may be able to use 50 Hz for some equipment, such as lighting and heating, but this is a small fragment of the total power demand on the ship. Equipment such as pumps and cranes, which are driven by either single or 3phase motors, and which rely on frequency level for the determination of their speed of operation, will not be able to run at their design speed, which will lead to damaging effects on the equipment. A ship using 60 Hz electricity will therefore require that the frequency in the European grid be converted from 50 to 60 Hz before connection (Ericsson & Fazlagic, 2008).

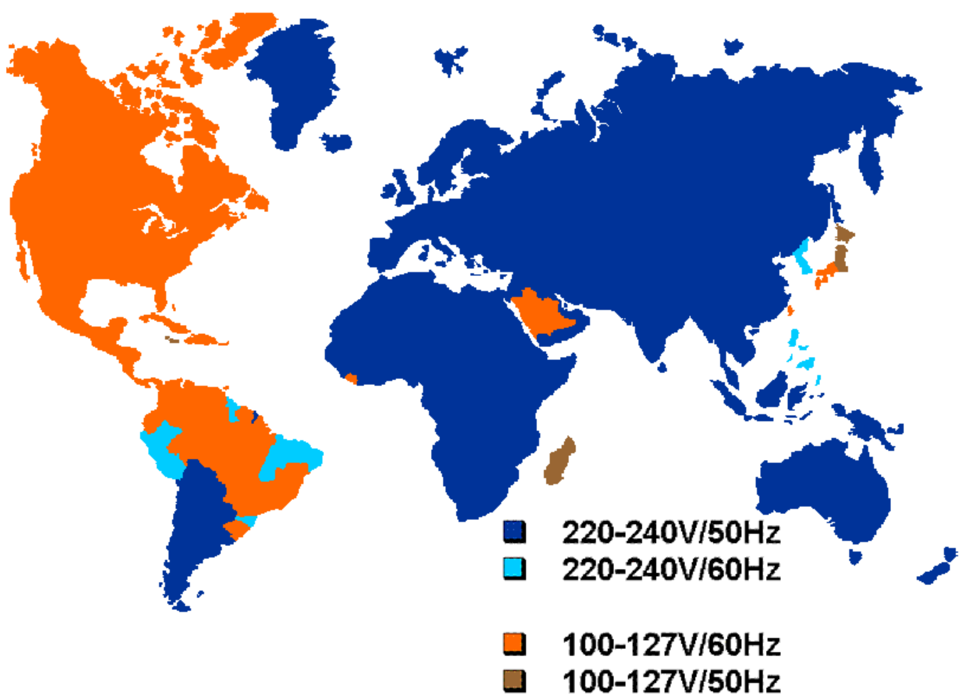


Figure 2.7 World Map Showing the Different Frequency Zones

Source: http://electricaloutlet.org/frequency

Table 2.1 shows a list of ports that have embraced the OPS technology. The Principle of Substitution can be used to explain the reason ports in developed nations have been in the forefront to implement the concept. According to this principle, the production cost is minimized when the marginal product of each factor to its price is the same for all factors (Ma, 2012, pp16). This can be illustrated as-:

$$\frac{MPfuel}{Pfuel} = \frac{MPops}{Pops} \quad \text{……………………………}\textit{Equation 2.3}$$

From the equation, most players will accept OPS if the relative Marginal Productivity of running auxiliary generators by fuel to the price of fuel and environmental effect, is the same as the ratio of the marginal productivity by installing an OPS system to the price of OPS service quality. For example, the European Union directive that limits the sulphur content in marine fuel from 4.5 % to 0.1 % in order to reduce the emission discharge from vessels is likely to spur ports in the region to invest in OPS. As countries develop, community pressure and social responsibility increases and concurrently, regulations tighten. The willingness to accept versus willingness to pay gets higher and companies are more willing to accept to pay for their pollution or to invest to avoid the likelihood of pollution.

Table 2.1 Sample List: Ports That Have Adopted OPS and Their Rating

Year of introduction	Port name	Country	Capacity (MW)	Frequency (Hz)	Voltage (kV)	Ship types making use of OPS
2000-2010	Gothenburg	Sweden	1.25-2.5	50 & 60	6.6 & 11	RoRo, ROPAX
2000	Zeebrugge	Belgium	1.25	50	6.6	RoRo
2001	Juneau	U.S.A.	7-9	60	6.6 & 11	cruise
2004	Los Angeles	U.S.A.	7.5-60	60	6.6	container, cruise
2005-2006	Seattle	U.S.A.	12.8	60	6.6 & 11	cruise
2006	Kemi	Finland		50	6.6	ROPAX
2006	Kotka	Finland		50	6.6	ROPAX
2006	Oulu	Finland		50	6.6	ROPAX
2008	Antwerp	Belgium	0.8	50 & 60	6.6	container
2008	Lübeck	Germany	2.2	50	6	ROPAX
2009	Vancouver	Canada	16	60	6.6 & 11	cruise
2010	San Diego	U.S.A.	16	60	6.6 & 11	cruise
2010	San Francisco	U.S.A.	16	60	6.6 & 11	cruise
2010	Karlskrona	Sweden	2.5	50		cruise
2011	Long Beach	U.S.A.	16	60	6.6 & 11	cruise
2011	Oslo	Norway	4.5	50	11	cruise
2011	Prince Rupert	Canada	7.5	60	6.6	
2012	Rotterdam	Netherlands	2.8	60	11	ROPAX
2012	Ystad	Sweden	6.25-10	50 & 60	11	cruise
2013	Trelleborg	Sweden	0-3.2	50	10.5	

Source: http://www.ops.wpci.nl/ops-installed/ports-using-ops/

2.2 Overview of Green Port Initiatives in Different Ports

Ports world over have embraced "greening initiatives" for various reasons specific to the ports. Some ports engage in these initiatives for compliance to regulatory requirements in their areas of operation, while others consider environmentally friendly operation as a promotional tool to market their product (service) as "green" and gain a competitive edge from environmentally conscious ship owners and operators. This is used as one way of product differentiation.

2.2.1 Port of Singapore-The Green Marketing Strategy

The Port of Singapore, for example, has the Maritime Singapore Green Initiative advanced by the Maritime Port Authority of Singapore (MPA). The port community has been mobilized to a greening program called the "Maritime Singapore Pledge". The driving force for the Singapore initiative is "a green marketing strategy". According to the Port of Singapore, "as a responsible member of the international maritime community, our pledge is to support and promote clean and green shipping in Singapore" (www.mpa.gov.sg).

The initiative seeks to reduce the environmental impacts of shipping and related activities. The initiative is comprehensive and comprises three programmes – Green Ship Programme, Green Port Programme and Green Technology Programme. MPA pledged to invest up to 110million Singapore Dollars to fund the initiative for a 5 year period from 2011 (MPA, 2011).

The Green Ship Programme encourages the use of energy efficient ship designs compliant with EEDI. The initiative rewards ships that meet and surpass IMO specifications on EEDI, and which have pre-verification reports, by offering a 50% reduction on initial registration fees and a 20% rebate on annual tonnage tax payable by qualifying Singapore flagged ships (MPA, 2011).

The Green Port Programme, on the other hand, encourages ocean going ships calling at the port of Singapore to reduce the emission of pollutants. The incentive for this is the granting of 15% rebate in port dues for vessels that use type-approved abatement/scrubber technology[4] or clean[5] fuel during the entire port stay.

The last initiative, the Green Technology Programme encourages local maritime companies to develop and adopt green technologies. It provides grants of up to 50% of total qualifying costs to co-fund the development and adoption of green technology with a capping of 2million Singapore Dollars per project.

2.2.2 Port of Gothenburg-Supplier "Green Logistic Concept "Initiative

The port of Gothenburg uses a different initiative to promote green port operation; the onshore power supply (OPS). The port boasts being "the first port to introduce a high-voltage onshore power supply for cargo vessels" in the year 2000. The drive for the green initiative was also different. The high-voltage system was initiated by Stora Enso, a paper and forest product supplier (in collaboration with port of Gothenburg and shipping companies Wagenborg and Cobelfret) as a way of achieving a green logistic concept via the port of Gothenburg (http://www.ops.wpci.nl/ops-installed/gothenburg/).

This first initiative is used by Six Ro-Ro vessels adapted to use the OPS. The vessels also use OPS in the Port of Zeebrugge in Belgium showing synergy between ports and ship managers in the greening initiative.

A second system was installed in 2003 and a third one in 2006 by Stena Line. The port further installed two wind turbines to further "green" the electric power supplied to the vessels.

2.2.3 Port of Los Angeles; Regulatory Initiative (NNEI programme)

Another Port implementing OPS, but on a different motivation is the Port of Los Angeles. This port on its part "boasts" it was the first port to supply containerships with OPS in the year 2004. This initiative was necessitated by the "No Net Emission Increase programme (NNEI) for the port initiated by the Los Angeles municipal

[4] The abatement/scrubber technology should be type approved in accordance with IMO guidelines for reducing sulphur oxides emission.

[5] Clean fuels are defined as fuels with sulphur content of less than 1% m/m in this programme.

authority. To meet the associated emission target the port implemented the OPS programme" (http://www.ops.wpci.nl/ops-installed/los-angeles/). To ensure full utilization of the programme, the port, through an attractive compensation scheme, offered ships up to USD800,000 compensation to install the onboard equipment and make the vessels ready to receive the OPS. This compensation saw a total of 52 new-build, 5000 TEU container vessels being fitted out ready for OPS between 2005 and 2008.

2.2.4 Port of Antwerp-Crew Working Conditions and Environment Enhancement

The port of Antwerp offers OPS in what started as "a project to improve onboard working conditions for crew and reduce the environmental impact of berthed ships" (www.ops.wpci.nl). The Independent Maritime Terminal, which is owned by the Independent Container Lines company, implemented the project to supply its vessels with green power once at berth. The Antwerp Port Authority and the Flemish government together subsidized 45% of the costs of the project, the total cost of which was 1.1million Euro.

2.2.5 Port of Hueneme-Synergy between Port and Public Institutions

Many other ports offer OPS for different motivations, giving different incentives to the vessels and with the initiative coming from either the private, public or port side or a synergy between them. The port of Hueneme OPS project is one such example. Located in Ventura County in the southern part of the U.S. State of California, the Board of Harbor Commissioners approved the key funding agreement to help vessels plug into electrical power at berth and reduce GHG emissions. The project is a model of strong public policy working for the betterment of the surrounding community and region as a whole. The Air Resources Board (ARB), South Coast Air Quality Management District (SCAQMD) working with the Port, cohesively stepped up to facilitate compliance with the shore side power mandate.

"The Port is currently installing a state-of-the-art shore power infrastructure system on Wharf 1 to provide shore power to Berths 1, 2 and 3. The project includes the design and construction of six shore power outlets (SPOs) (two SPOs per berth) via two sets of transformers and switchgear" (http://www.marinelink.com). This configuration will allow the port to plug in two vessels at any two of the three electrified berths simultaneously. According to California ARB Chairman, "When these large vessels turn off their diesel engines and connect to shore power, the whole region benefits, especially nearby coastal communities which can be severely impacted. Using shore power helps clean the air and fight climate change because it cuts smog-forming chemicals, fine particle pollution and greenhouse gases" (http://www.marinelink.com).

2.3 Feasibility Studies on OPS in Third and Fourth Generation Ports

2.3.1 Feasibility Study on OPS Implementation - Port of Amsterdam: August 2012

Several ports have carried out feasibility studies on OPS; the port of Amsterdam carried out a *"Feasibility study: Onshore Power Supply for Sea Going Vessels"* in August 2012 (Breemen, 2012). The report, carried out under the framework of the Port of Amsterdam Environmental Policy Plan delved into the study of OPS and a pilot project named Advanced Maritime Emissions Control Systems (AMECS) for sea going vessels. Issues investigated included the technical feasibility, environmental benefits, financial requirements and likely support by terminals and shipowners.
The study came out with the following four conclusions-:

1) OPS for cruise vessels is feasible for the port of Amsterdam. OPS contributes to better local air quality in densely populated areas and is technically feasible.
2) OPS for cargo ships is technically feasible, but the environmental benefits to the port area of Amsterdam are too low for the high costs of OPS. The number of calls per year by the same ships and/or the relatively short time of stay in the port render the project less feasible.
3) Use of clean (low sulphur) fuel for seagoing vessels has an important effect on the global emissions. This is because of the long shipping hours involved in International shipping.

4) Port of Amsterdam will closely follow the developments regarding OPS for sea cruise and is ambitious to join the fore-fighters on OPS for these vessels.

2.3.2 Study on the Feasibility of OPS for the Ports of the Hanseatic City of Bremen.

In 2009, a study was undertaken to find out whether the sulphur reductions in ship fuels used during a stay in the harbour and which are specified by EU-Directive 2005/33/EG from 2010 onwards, would affect ship waste accumulation. The study also aimed at identifying other measures, apart from the sulphur reductions, which would be technically feasible and sensible including OPS.

According to the sulphur directive as from 2010, only fuels with a maximum sulphur concentration of 0.1% are allowed to be used within port operations in the Baltic region. "Vessels can only be relieved of this directive if they turn off all engines in the berth area and use electric power from a shore-side supply" (GAUSS mbH, 2009).

The study found that the viability of shore-side electricity for ships in the harbour depends on a number of criteria, the most important being whether the surrounding of the port is inhabited, as it is in the immediate surroundings where the potential danger of emissions is the largest for people.

The other determinant of net gain from OPS as found by this study is the electricity mix. The power supplied to the city of Bremen is largely generated from fossil fuel (82%). "This is accordingly accompanied by high carbon dioxide emissions. Therefore, vessels berthing in the harbours of Bremen and using shore-side electricity would cause higher carbon dioxide emissions compared to using an auxiliary diesel engine" (GAUSS mbH, 2009, p.2). The same cannot be said for the City of Bremerhaven. The electricity mix in Bremerhaven contains a high amount of renewable energy (18%) and 36% nuclear energy. The result is that this mix causes only minor differences between shore-side power and the use of auxiliary diesel engines. However, the amount of nuclear waste calculated turned out to be considerably higher than in Bremen.

2.4 Current Trends in OPS Field-First International Standard for OPS Systems

A milestone in the OPS field was marked in July 2012 with the introduction of the first ever international standard for OPS systems called IEC/ISO/IEEE 80005-1; Utility connections in port – Part 1: High Voltage Shore Connection (HVSC) Systems. The standard was developed by the Institute of Electrical and Electronics Engineers (IEEE) jointly with the International Organization for Standardization (ISO) and the International Electro-technical Commission (IEC). This standard is applicable to the design, installation and testing of HVSC systems and addresses the following areas of standardization-:

a) Design, installation and testing of high voltage OPS systems.
b) Definition of a nominal voltage of 6.6 or 11 kV.
c) Onshore as well as on board equipment and also shore-to-ship connection and interface equipment.
d) Reference to both the application of international electrical standards already available and installation guidance.
e) A high share of requirements related to safety aspects like emergency shut downs.
f) Additional requirements for Ro-Ro/passenger ships, cruise ships, containerships, tankers and LNG carriers.

The standard, however, does not apply to the following issues which appear somehow related to OPS systems.

a) Electrical power supply during docking periods including dry docking and other out of service maintenance and repair.
b) Definition of a specific frequency.
c) Low voltage systems.

The standards stipulate that the OPS for Ro-Ro and container vessels will be a 6.6 kV, 7.5 MVA systems. Only one ship per transformer is permitted. The onboard utility systems for these vessels are 60Hz, implying that a frequency converter is required on shore for these vessels in most of the world (with the exception of the USA and half of Japan which have 60Hz in their mains). Cruise ships Onshore Power Supply on the other hand are 6.6 kV or 11 kV systems depending on the vessel's electricity requirement. The standards also require more contact breakers than today's pilot installations, which have varying designs of construction (Wilske, 2012, p.15).

The standardization work for onshore power supply has subsequently been divided into three main components:

- IEC/ISO/IEEE 80005-1; The onshore power supply standard
- IEC/ISO/IEEE 80005-2; Communication protocol
- IEC SC 23H; Terminal contacts

2.5 Conclusion

Most studies on OPS were carried out before the release of the international standards. Even then, the first and second generation ports in developing countries have not taken initiatives to carry out studies on the viability of OPS systems and neither have they implemented OPS. This can be seen in Figure 2.8 and Table 2.2 by their being conspicuously absent in the map and table. Additionally, most of these ports have not embraced technologies to counter negative environmental impacts from shipping. This can be associated with low "willingness to accept" given their development status and a weak port community whose priorities do not include green ports or ships.

The impact of OPS in ports of developing nations is not fully understood. Ports in the developed countries have fast turnaround times for vessels compared to the long periods taken to load and discharge vessels in the 2nd and 1st generation ports. The effects of long service time could have influential effects on the viability of OPS systems in these ports compared to the 3rd or 4th generation ports. As such, the principle of one size fits all cannot apply and studies carried out in developed countries cannot be said to be applicable in ports in developing nations. Earlier academic works on this issue like "*Assessment of alternative maritime power (Cold Ironing) and its impact on Port management* "(Fiadomor, 2009) concentrated mostly on the project costs and the environmental pollutants from the maritime sector and failed to quantify the cost of pollution as a factor to consider in evaluating the project viability. This research will take cognizance of the existing OPS standards coming just after their publication and an all-inclusive cost analysis in determining the viability of implementing an onshore power supply in a developing nation.

Figure 2.8 Regions Implementing Onshore Power Supply in Ports

Source: Susan Dutt (Manager Sustainability; Port of Gothenburg)

Table 2.2 Ports Considering Investing in Onshore Power Supply

Ports considering OPS	• Amsterdam • Barcelona • Bergen • Civitavecchia • Georgia • Genoa • Helsinki • Hong Kong • Houston • Kaohsiung • Le Havre • Livorno	• Marseille • Nagoya • Oakland • Richmond • Riga • Rome • South Carolina • Tacoma • Tallinn • Tokyo • Yokohama

Source: Susan Dutt (Manager Sustainability; Port of Gothenburg)

3.0 METHODOLOGY

To achieve the above objectives, information on the total number of vessels that called at the port of Mombasa in the year 2012 and their port dwell time were collected from the Commercial Division of the port. According to the port data, a total of 1913 vessel visits were recorded. The Main Engine (ME) and Auxiliary Engine (AE) sizes together with the length overall (LOA), flag state, year of build (YOB) and deadweight (Dwt) of these vessels were collected from the Lloyds Registers (2006-2008) available at WMU Library and augmented with updated online information from Clarkson register database and Equasis. Data not available from these sources was searched in other website links, which proved helpful and are, therefore, documented in the electronic sources in the list of references. IMO and Classification societies do not require owners to provide the AE details and for this reason, several web based databases had to be referred to for collection of all data required on AE sizes for different vessels.

The analysis of the above vessel details was achieved courtesy of three main softwares; Microsoft Excel, especially the descriptive statistics of the data analysis functionality, the well-used econometric software, the EVIEWS and the ARENA modeling and simulation software. In addition, drawings in the OPS design section have been produced using AutoCAD® Electrical 2011, Student Edition under the permission of Autodesk Global Business Services

Hotelling load, mostly supplied by AE while the vessel is at the berth, is primarily the power needs of lights, heating/ventilation/air conditioning systems, communications, computers, ship cranes, pumps, reefer load, and various other power demands while the vessel is at dock.

Based on the installed AE power capacities and a loading factor provided by the Starcrest Consulting Group Inventory, the actual engine power outtake will be determined. A product of the individual ship engine power outtake, with the service time in port (ST) and the number of ships will give the cumulative annual energy outtake in kilowatt-hours (kW.h). This research will give an allowance for time presumably likely to be taken to connect the vessels to the shore power and the disconnection time before departure so as to be as realistic as possible. This time will be deducted from the ST.

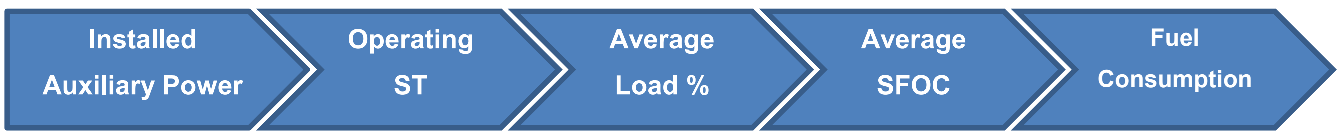


Figure 3.1 Activity Based Calculation of Fuel Consumption

Source: Second IMO GHG Study 2009

From these results, and by dividing with the respective Specific Fuel Oil Capacity, the approximate fuel quantity consumed is calculated. By using this procedure, emissions per ship call can be determined using Equation 3.1

$$FC = P \times LF \times A \times SFOC \text{ ....Equation 3.1}$$

$$E = P \times LF \times A \times SFOC \times EF$$

$$E = FC \times EF$$

Where-: E = Emissions (grams [g])

FC=Fuel Consumed

P = Maximum Continuous Rating Power (kilowatts [kW])

LF = Load Factor (percent of vessel's total power)

A = Activity (hours [h])

SFOC= specific Fuel Oil Capacity

EF = Emission Factor (grams per kilowatt-hour [g/kWh])

The figure FC will then be used to calculate the approximate cumulative cost of fuel consumed in the port by all the visiting vessels by multiplying by the cost of fuel. This cost will be added to the cost of fuel for running the port tug boats, pilot boats and mooring boats while at berth so as to get the overall cost spending on fuel.

The figure for the total fuel consumed will be used to calculate the total emissions and consequently the cost of externalities. Total emissions will be calculated by multiplying the associated fuel consumed of the different fuels with an emission factor for the pollutant in question.

These emission factors are sourced from an Entec[6] 2002 report to the EU on Quantification of Emissions from Ships associated with ship movements between ports in the European Community. This activity based data collection and pollution computation is advanced by IMO as more accurate than the one based on fuel statistics used in earlier studies (IMO, 2009, p.24).

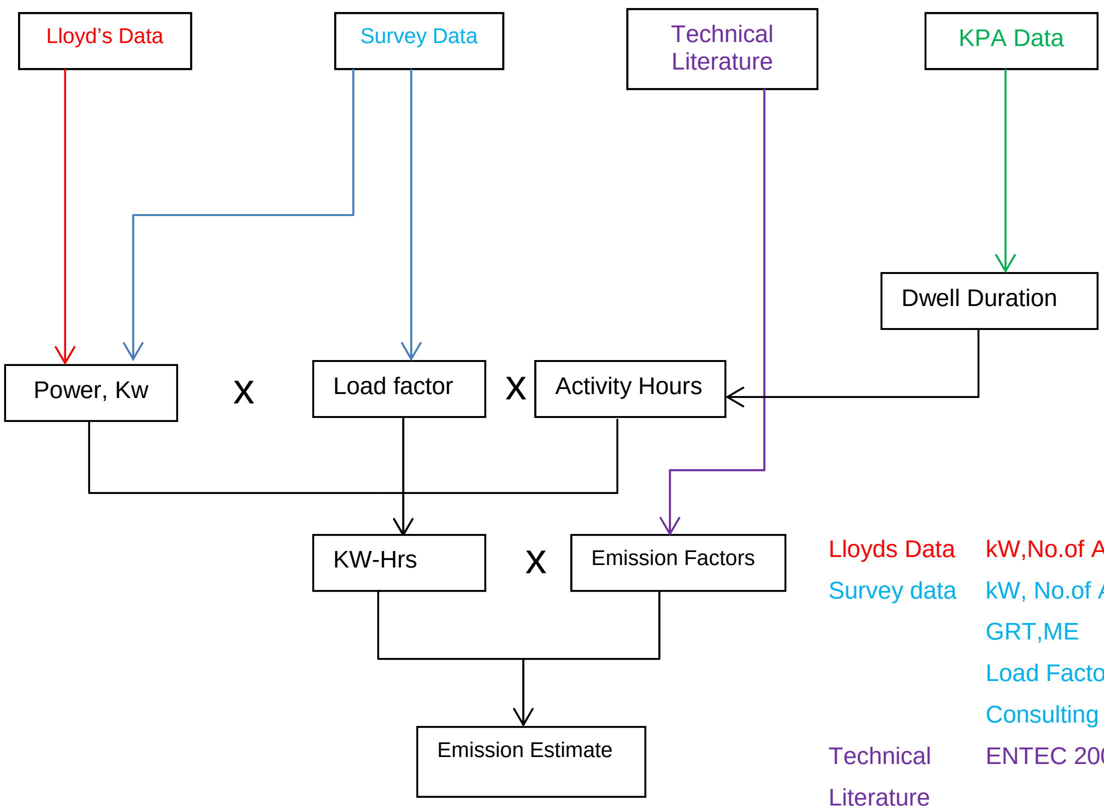
The flow diagram illustrated in Figure 3.2 gives the Emission estimation process from the AEs. The IMO Greenhouse Gas Study 2009 used the same approach and hence, to maintain an industry standard approach on pollution cost calculation, the same methodology will be used in this research paper. This will then serve as the basis for calculation of pollution cost from the total vessels.

The Onshore power supply cost will then be evaluated as an opportunity cost of the above two costs. Quotations of the required products will be sourced from the leading industry players; Schneider Electric and ABB through a Request for Quotations (RFQ) in form of Bill of Quantities (BOQ) (See Appendix II). The other associated costs include the cost of cables. Cable requirements will be determined by the measured cable lengths and multiplied by the cost per meter of a cable. Cable size in terms of crossectional area (mm^2) will be based on calculated current requirements of the ship loads as per IEEE regulations. Cable costs are directly proportional to length, crossectional area and voltage rating of the cables. The cables will have to be laid in ducted trenches along the quay lengths and connected to the substations as shown in

[6] Entec UK Limited is currently known as AMEC Environment & Infrastructure UK Limited after its name change in June 2011. The company provides environmental and engineering consultancy services to businesses. It offers, among others, environmental impact assessment and appraisal, environmental management and compliance, sustainable place-making, waste management, and water engineering and management services. The company serves central government and agencies, regional and local government, and defense markets of the government sector.

Figure 5.10. The trenching costs will be evaluated as per the proposed cable ducts routes and the currently applicable trenching rates applied.

Installation, Testing and commissioning costs will then be added to the above costs; a summation of which will form the total costs of implementing OPS for the port of Mombasa.



Lloyds Data	kW,No.of AE,LOA, TEU GRT,ME
Survey data	kW, No.of AE,LOA,TEU GRT,ME Load Factors from Starcrest Consulting
Technical Literature	ENTEC 2002
KPA Data	No.of Vessels, AST

Figure 3.2 AE Emission Estimation Flow Diagram

Source: Starcrest Consulting Group

The project cost will then be appraised using the three available appraisal techniques; Payback Period, Net Present Value (NPV) and Internal Rate of Return and the outcomes used to determine the viability of the project. The cost of pollution and the estimated OPS power bill will be factored-in in appraising the project viability.

The results will thus be an appraisal of a project not only taking into consideration the marginal productivity cost, but also the cost of externalities.

3.1 Methodology Limitations

The following limitations are inherent in the computations carried out in this thesis report-:

1) It is very difficult to determine the actual loading factor of the auxiliary engines of the vessels. This is due to the variability in ship power demands and operating practices. The expert judgment used in this report, which is the same as the one used in the IMO GHG study of 2009, gives an informed approximation of the loading factors, but the actual factor varies from vessel to vessel. As in all scientific studies, however, assumptions have to be made. The assumptions only need to be realistic, logical and relevant.

2) Only Auxiliary engine fuel consumption while at berth is considered in this report. Other fuel consuming functions like boilers are considered negligible and their contribution to total costs of fuel is ignored.

3) The environmental costs, also known in this report as cost of externalities, considered the carbon credit equivalence as the basis for calculation of the other gases' environmental impacts. This is because in ships' exhaust gases,97% of the GHG gases is CO_2 with all the other gases comprising a paltry 3% as illustrated in Figure 3.3.

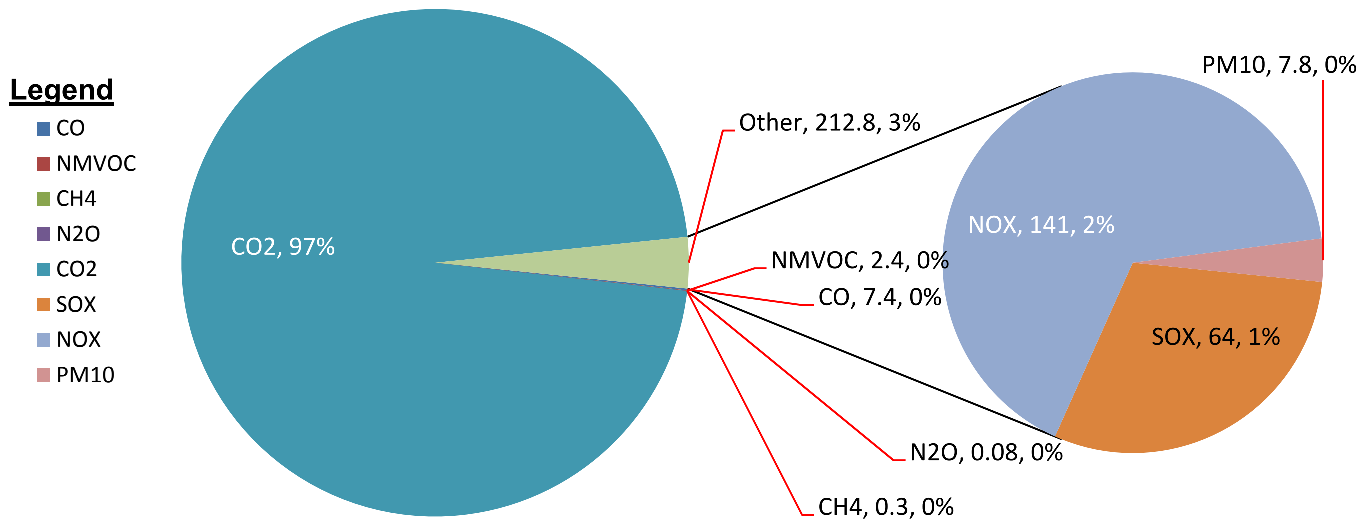


Figure 3.3 Relative Quantities of Pollutants in a Ship's Exhaust Gas

Source: Second IMO GHG Study 2009

4.0 EMPIRICAL ANALYSIS OF VESSEL POWER DEMAND

4.1 Introduction

This Chapter's objective is to paint a picture of the different onboard power requirements by different vessels and clearly show the diverse system voltages and frequencies for the vessels while at berth. The Chapter will also strive to show a correlation between the main vessel characteristics and come up with empirical formula specific to the port of Mombasa concerning the inter-relativity of the different vessel specifications and the hotelling requirements. The results of this Chapter will be used as the main points of consideration identifying the design parameters for the OPS system to be designed.

An analysis of productivity and Power related vessel characteristics of 1913 port visits by different vessels and the 17 KPA tugs, mooring boats and pilot boats was carried out. For ease of analysis, the vessels are grouped into six main categories; Container Ships, Bulk Carriers, General Cargo ships, Tugs, Ro-Ro and Product Carriers. This categorization was based on several factors, key among them being the auxiliary power requirements, quay requirements and the berthing terminal locations.

The categorization "General Cargo" vessels includes all the general cargo ships, suction dredgers, research vessels, offshore supply ships, cable layers, hopper dredgers and heavy load carriers. The year 2012 saw the dredging of the port approach channel and delivery of three Post-Panamax STS cranes and thus many dredging vessels and a heavy load carrier found their way into the port berths. In addition, the same year saw a section of the deep sea fibre optic cable, located in the Red Sea, cut by a cargo ship between the EASSy landing stations at Port Sudan and Djibouti and hence the many cable layer vessel visits to the general cargo berths of KPA.

All passenger ships, Ro-Ro vessels, Pure Car Carriers (PCC) and cruise liners that visited the port have been categorized as “Ro-Ro Vessels” while the “Tugs and Patrol Vessels” category includes all the tugs, crew boats, mooring boats, support vessels and patrol vessels. It should be remembered that the war on pirates intensified in 2012 and many of the world´s naval patrol ships came to the port of Mombasa for replenishing of victuals and medical supplies. The Port also received frequent visits by chartered Bulk Carrier vessels in the trade of Clinker, Fertilizers, Bulk Cement and Grains, all in the category of “Bulk Carriers”.

The last categorization is the “Product Carriers”. This class includes the crude oil carriers, the product tankers and LPG tankers, all of which berth at the port’s two oil jetties; Shimanzi Oil Terminal (SOT) and Kipevu Oil Terminal (KOT).

By the end of this Chapter, a summary of the ME and AE characteristics of all vessel and a classical linear regression model of the inter-relativity of the vessel characteristics will be given. This model is specific to Mombasa port vessel traffic although ports of similar operational capacity and properties may also find application in the results.

Container Vessel

Ro-Ro Vessel

General cargo

Product Carrier

Bulk Carrier

Tugs

Figure 4.1 The Different Vessel Categories

Source: http://maritime-connector.com/ships/

4.1.1 Main Vessel Propulsion Systems

Power requirements onboard a vessel depend on the vessel type, the propulsion systems and the different kinds of power related applications. Vessels with traditional propulsion systems use diesel driven motors that are linked to the propeller by a shaft. On the other hand, current systems employ electrically driven motors being fed from a common busbar supplied by the different main engines. These vessels, therefore, need higher electricity generation onboard (Ericsson & Fazlagic, 2008, p.39).Figure 4.2 and 4.3 show these different propulsion systems configurations.

One of the main disadvantages associated with conventional propulsion systems is the large transmission losses associated with the mechanical power transfer between the main engine and the propeller via the shaft. The main engine runs the main generator during the voyage journey and once switched off while at berth, the auxiliary generators have to be run for hoteling power requirements and cranes in case of geared vessels.

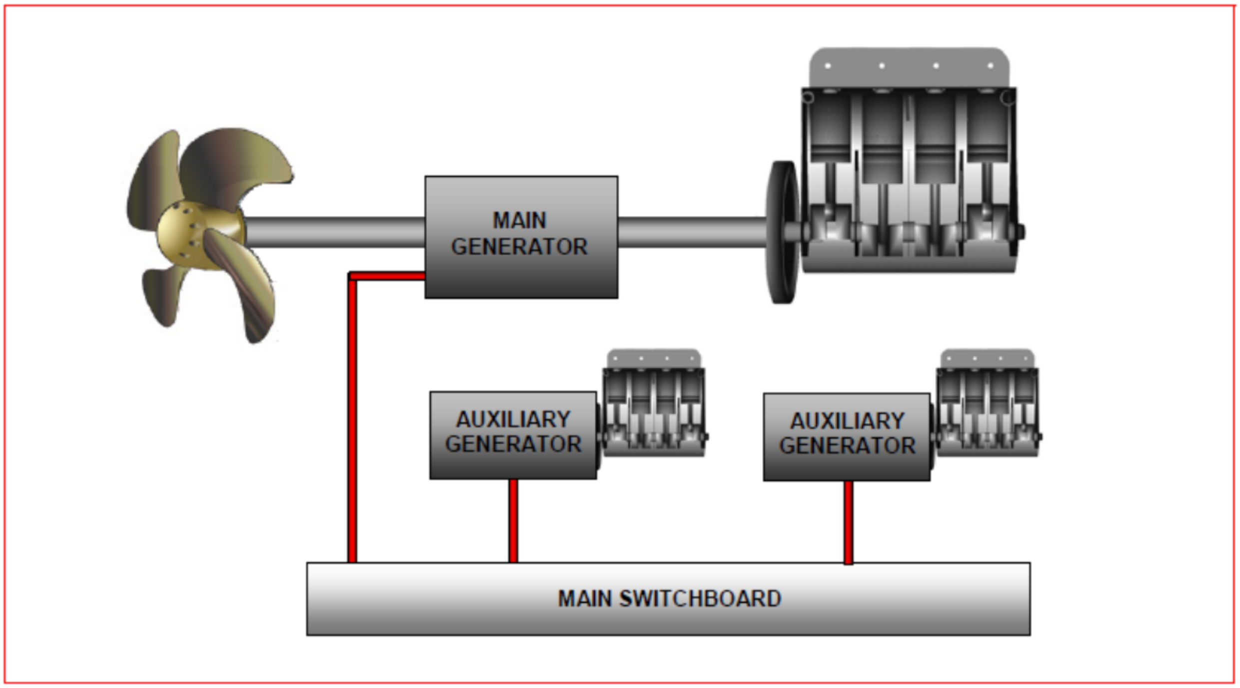


Figure 4.2 Power Generation Onboard Conventional Vessels

Source: Ericsson P. & Fazlagic´ I; Masters thesis on OPS.Case study of Port of Gothenburg

Contrary to the conventional propulsion systems, the modern one utilizes several similar sized generators for both propulsion and hoteling with the number of generators in operation being dictated by the load demand at any given time. This system allows for stocking of less spare parts, hence a reduction in inventory costs as the onboard generation units are capable of utilizing the same type of spares for the similar engine units.

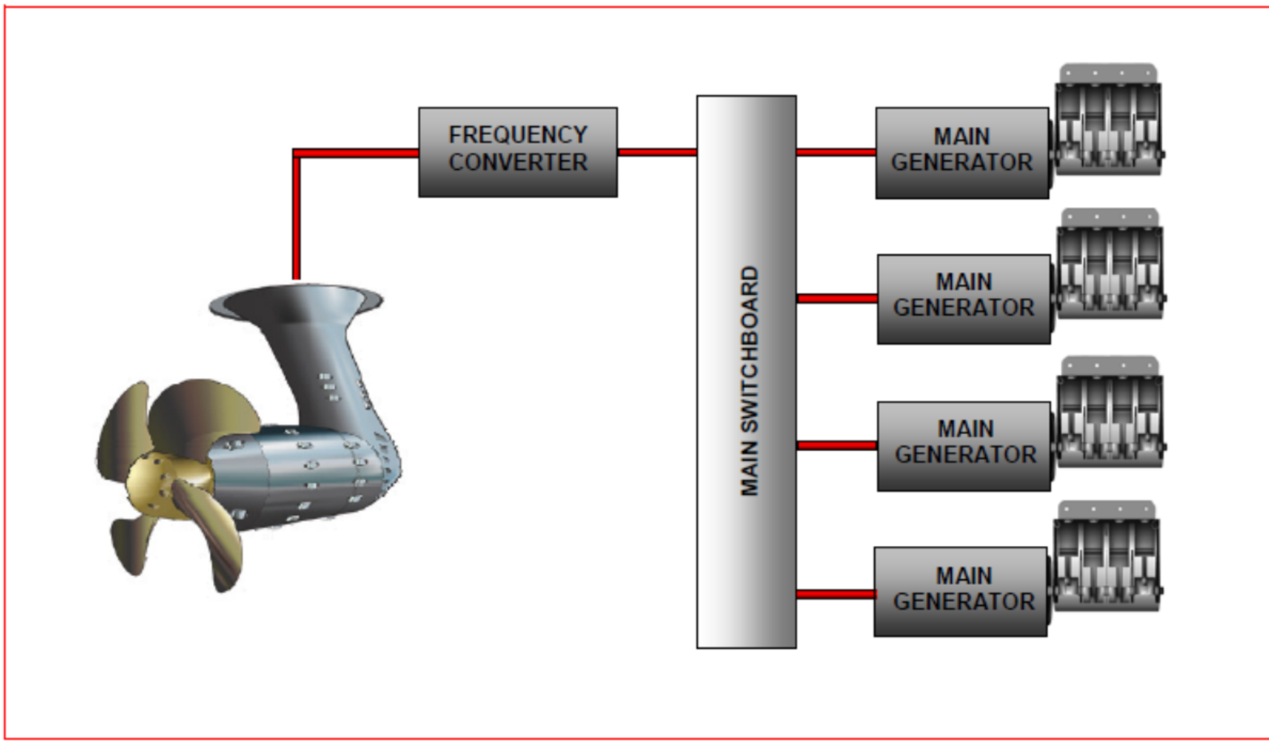


Figure 4.3 Modern Diesel Electric Propulsion System Power Generation

Source: Ericsson P. & Fazlagic´ I; Master's thesis on OPS. Case study of Port of Gothenburg

4.2 Container Vessels

The Containership is the main vessel type used in Liner Trades. The main term used for convenience in describing a container vessel capacity or slots is TEU (Twenty feet equivalent unit). For example, the largest container vessel in operation today, launched in July 2013, is MV Mærsk Mc-Kinney Møller with a capacity of 18,270 TEU. Container sizes and properties are governed by International Standards Organization (ISO) standards with a TEU measuring 20ft by 8ft by 8ft 6inches (Length by width by height). Containers with a length of 40ft are becoming more prevalent and hence the term FEU (Forty feet Equivalent Unit) was coined for their reference. Other container variations in trade today include hi-cube or super cube which have a height of 9ft 6inches.

Containers have revolutionized international trade by the protection nature of steel containers and their inter-modalism. This feature is also called Multi-modalism and speeds up the interface transition period between the different modes of transport.

Container vessels are grouped mostly by reference to whether they serve the main or feeder trade routes and their size relative to the Panama Canal. We thus have Smaller Feeders, Feeders, Feedermax, Panamax, Post Panamax, New Panamax and Ultra Large Container Vessels (ULCV) listed in an increasing size order.

The data analysis captured a total of 488 container vessel visits to the port out of which only one had a frequency rating of 50hz.Only the same Container vessel, MV Vera, was found to have a voltage rating of 380V and visited the port only once.

4.2.1 Power Demand

As evident from Figures 4.4 and 4.5, over 99.9% of the container vessels operate on a frequency rating of 60Hz.These vessels' power systems use low voltage between 380-450V for their hotelling applications.

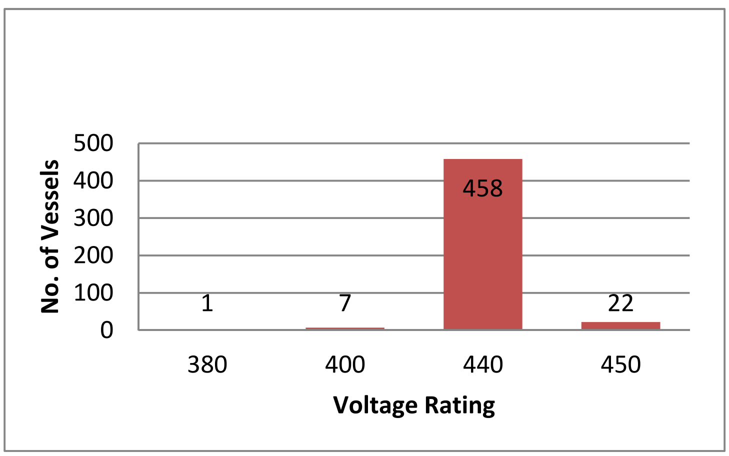


Figure 4.5 Voltage rating for Container Vessels

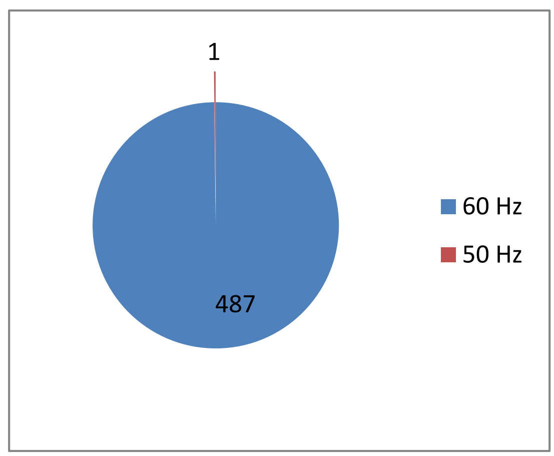


Figure 4.4 Container Vessels' System Frequency

By using Arena software, an analysis of the ME found that Container vessel engine sizes followed a BETA distribution with the expression: *3.82e+003 + 2.12e+004 x BETA(1.25, 0.555).*

The AE on the other hand had the following Distribution Summary-:

Distribution: Beta

Expression: ***1.05e+003 + 6.37e+003 * BETA (1.25, 0.555)***

Square Error: 0.051693

The following was obtained as the Data Summary for AE-:

Data Summary

Number of Data Points = 488

Min Data Value = 1.05e+003=1050kW

Max Data Value = 7.42e+003=7420 kW

Sample Mean = 3.91e+003=3910 kW

Sample Std Dev = 1.52e+003=1520 kW

Organized in a Cumulative frequency distribution table (Table 4.1), a cumulative frequency diagram of the AE sizes was plotted in Figure 4.6 for the AE spread of container vessels-:

Table 4.1 Cumulative Frequency Distribution -AE Sizes for Container Vessels

AE Size Class	Midpoint	Frequency	CF	Relative Frequency
1000-1500	1250	3	3	0.01
1501-2000	1750	28	31	0.06
2001-2500	2250	65	96	0.20
2501-3000	2750	61	157	0.32
3001-3500	3250	58	215	0.44
3501-4000	3750	65	280	0.57
4001-4500	4250	58	338	0.69
4501-5000	4750	51	389	0.80
5001-5500	5250	23	412	0.84
5501-6000	5750	15	427	0.88
6001-6500	6250	13	440	0.90
6501-7000	6750	43	483	0.99
7001-7500	7250	5	488	1.00

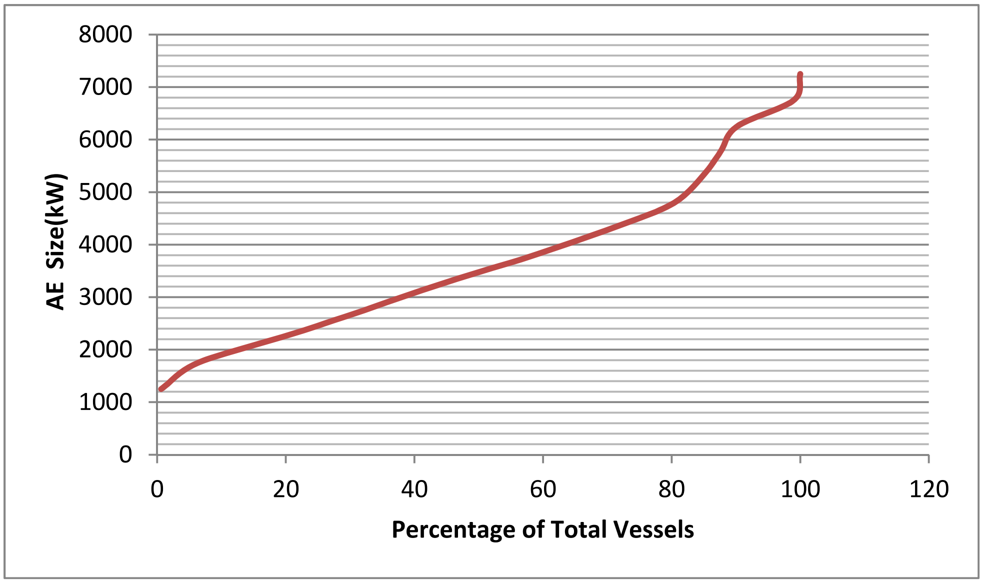


Figure 4.6 Cumulative Frequency Diagram of AE (kW) Rating -Containers

4.3 Bulk Carrier Vessels

These vessels carry homogeneous cargo in bulk as suggested by their name. They belong to a category of ships called Tramps. The most common characteristics of bulk carriers is a single deck with clear holds and large hatches to accommodate as much bulk as possible and facilitate fast loading/discharging operations. Unlike container vessels which are liners and operate on a regular schedule to and from the same ports, Tramp ships are operated either under voyage, time or bareboat charters or in some cases a variation of voyage charter called Contract of Affreightment (COA), and move from port to port without any fixed schedule depending on the availability of cargo. These vessels often sail to the next port where cargo is available in ballast if an outbound cargo cannot be found.

Bulk Carriers are categorized in terms of their deadweight carrying capacity. The small bulk carriers are called Handy size followed by Handymax. These vessels have 5 to 6 holds with capacities ranging between 20-35,000dwt and are most likely to be geared. Panamax is the next category with a capping of 75,500 dwt and 7 cargo holds, being the largest bulk carrier likely to pass through the Panama Canal. Any Bulk Vessel above 76,000dwt is categorized as Capesize. These largest of the bulk carriers have 9 cargo holds of approximately the same size and are rarely, if ever, equipped with gears. Such vessels, when transiting across oceans have to pass via the Cape of Good Hope because of the Panama and formerly Suez Canal size restrictions.

The biggest bulk carriers currently are the Very Large Ore Carriers (VLOC), Valemax, with Capacities ranging from 380,000-400,000dwt. These vessels are owned or chartered by the Brazilian Shipping Company Vale S.A and have been christened Chinamax.

A total of 196 Bulk Carrier visits were recorded at the port of Mombasa in the year 2012. Figure 4.7 shows the Bulk carrier vessel types distribution.

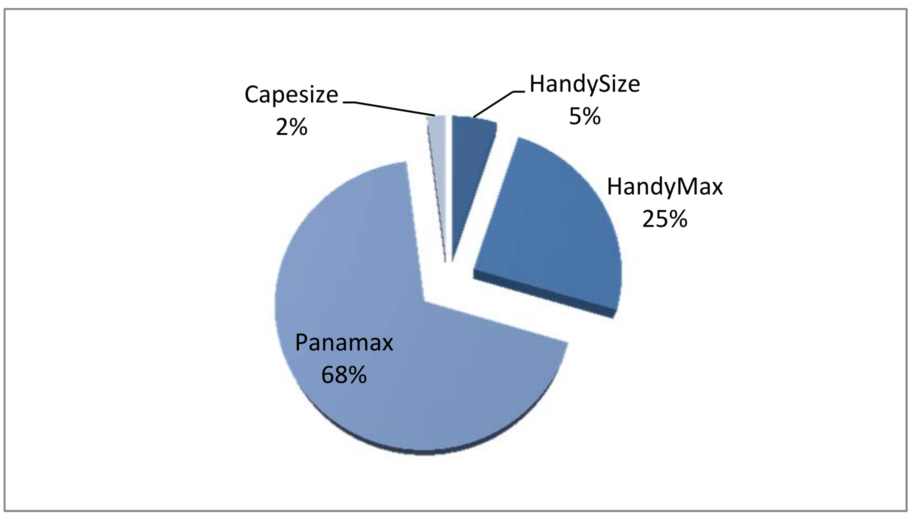


Figure 4.7 Bulk Carrier Vessels Distribution

4.3.1 Bulk Carrier Vessels Power Demand

The frequency and voltage rating for the bulk carrier vessels are given in Figure 4.8 and Figure 4.9 respectively.

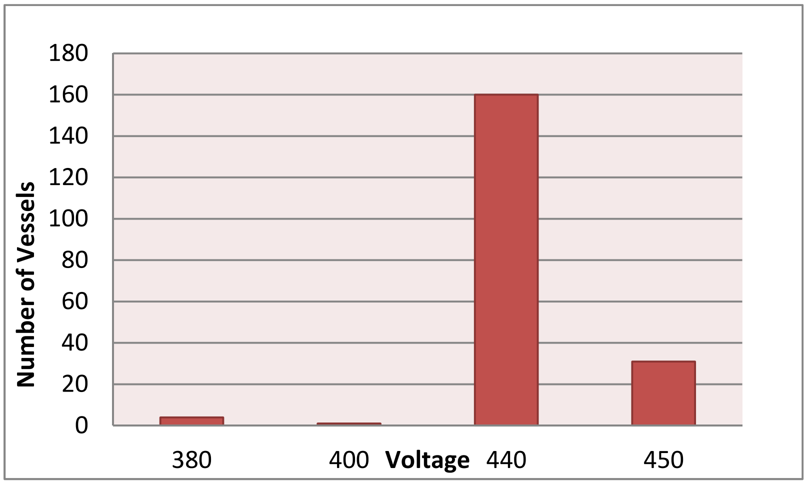


Figure 4.9 Bulk Vessels Voltage Rating

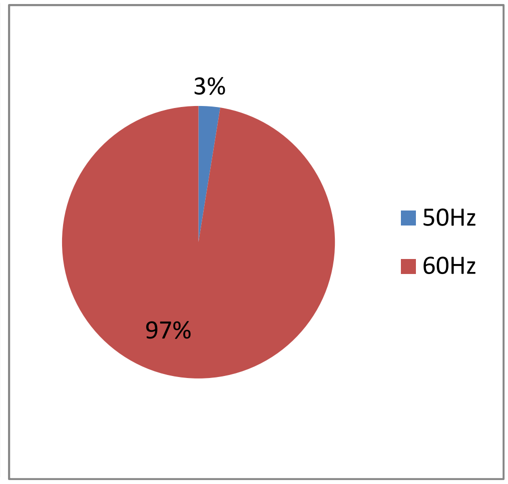


Figure 4.8 System Frequency for Bulk Carriers

The Total installed AE capacity of the Bulk carriers ranged from a minimum of 378kW to a maximum of 2800kW.The relative frequency distribution table and curve are given in Table 4.2 and Figure 4.10 respectively.

Table 4.2 Bulk Carrier AE Relative Frequency Distribution Table

AE Size Class	Midpoint	Frequency	CF	Relative Frequency	percentage
0-250	125	0	0	0.00	0
251-500	375	5	5	0.03	3
501-750	625	0	5	0.03	3
751-1000	875	14	19	0.10	10
1001-1250	1125	28	47	0.24	24
1251-1500	1375	58	105	0.54	54
1501-1750	1625	27	132	0.67	67
1751-2000	1875	46	178	0.91	91
2001-2250	2125	5	183	0.93	93
2251-2500	2375	5	188	0.96	96
2501-2750	2625	7	195	0.99	99
2751-3000	2875	1	196	1.00	100

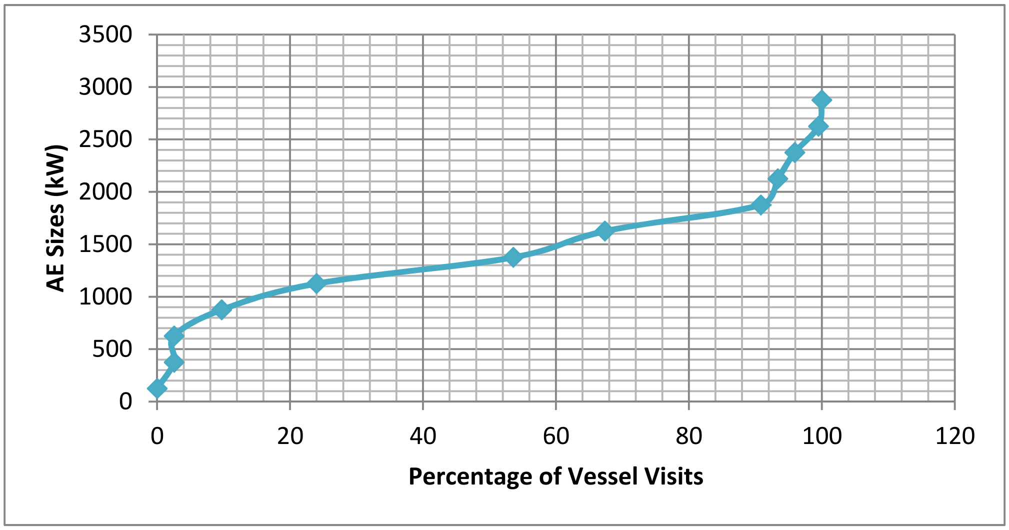


Figure 4.10 Bulk Carrier AE Cumulative Frequency Curve

The bulk carriers' AE were found to have a normal distribution as given by the best fit curve in Figure 4.11. The distribution expression was found to be *NORM (1.54e+003, 427)* while the data summary is as given below-:

Data Summary

Number of Data Points	= 196
Min Data Value	= 378kW
Max Data Value	= 2800kW
Sample Mean	= 1540kW
Data Std Dev	= 428

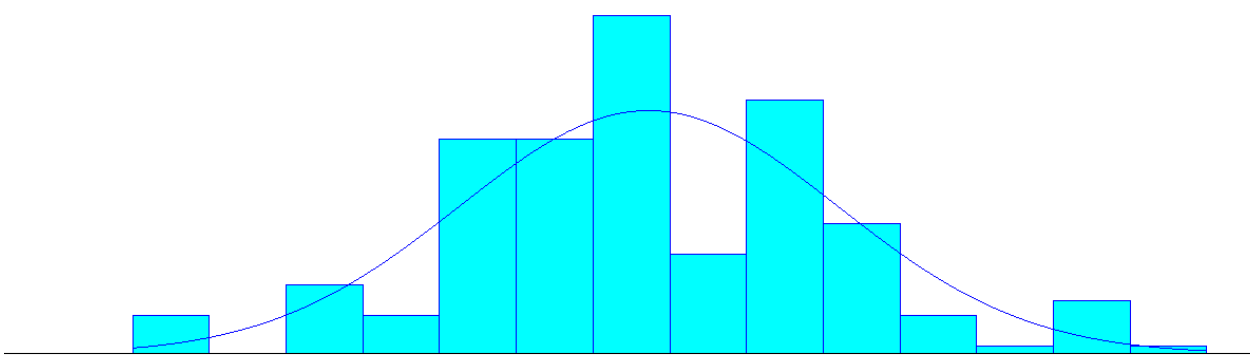


Figure 4.11 The Distribution Curve (Normal) for Bulk Carriers Vessels AE Sizes (kW)

4.4 Ro-Ro Vessels

Ro-Ro is an acronym for Roll-On/Roll Off. As the name suggests, these vessels are designed for any type of wheeled cargo. A common feature of all Ro-Ro vessels is some form of ramp to facilitate driving on or off the vessel during loading or discharging. This is unlike the Lift-On/Lift-off (LOLO) vessels, which make use of cranes for cargo handling operations. Cars, trucks, trailers and preloaded cargo on special trailers are driven in or towed and stowed into the vessels, which usually operate on conventional cargo routes.

Another frequent feature of Ro-Ro vessels is the forward location of the bridge although the engine room remains aft. The reason why other vessels have accommodation placed above the engine is because doing otherwise would make the area under the accommodation inaccessible for cargo handling, a feature that is not applicable to Ro-Ro vessels because of the mobility of their type of cargo that can be moved anywhere under the deck.

Variations of Ro-Ro Vessels include Pure Car Carriers (PCCs), Pure Car and Truck Carriers (PCTCs) and Freight Ferry service vessels called Ro-PAX. Ro-Ro vessel designs have seen a lot of revolution especially in terms of speed with some Catamaran hulled "Fast Ferries" capable of doing 40knots in operation today. According to the categorization of this report, cruise vessels are captured against the Ro-Ro Category with the largest "Ro-Ro" vessel to visit the port of Mombasa in 2012 being MV Crown Princess with a GT of 113,651 tonnes. Other notable large Ro-Ro Vessels to visit the port include the Panamanian flagged MV A, B, C and D Ladybug, all with GTs of above 72,000 tonnes. A total of 234 Ro-Ro Vessel visits were analyzed.

4.4.1 RO-RO Vessels Power Demand

Ro-Ro vessels have the most varied power demands and voltage variations of all vessels analyzed. Only this category of ships had High Voltage power supplies of 6.6kV of all the vessel visits. AE installed Capacity of the vessels ranged from the 1968 built, Tanzanian flagged MV Serengeti with a power Capacity of 170kw to the UK flagged, and 2006 built, 24,480kW MV Crown Princess.

A full analysis of the frequency and voltage distribution is given in Figure 4.12 and Figure 4.13 while Table 4.3 and Figure 4.15 show the Relative frequency Table and Cumulative Frequency Curve respectively.

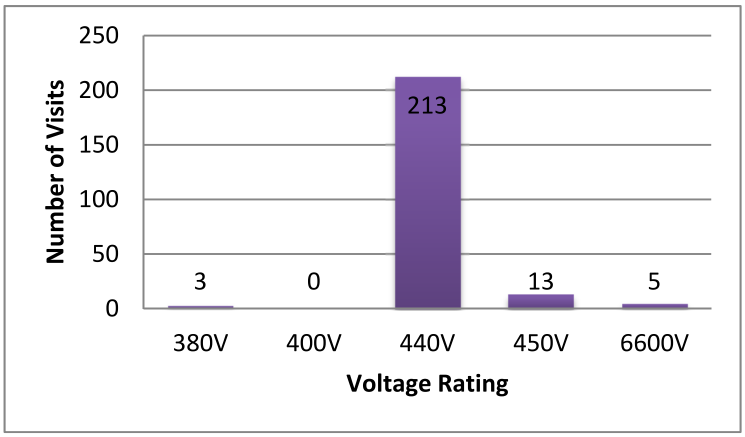


Figure 4.13 Ro-Ro AE System Voltage Rating

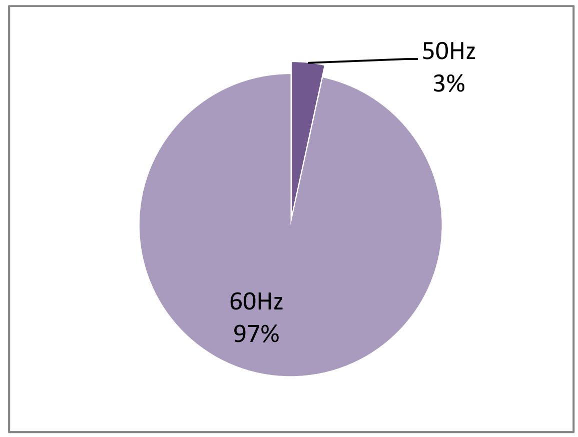


Figure 4.12 Ro-Ro AE System Frequency

An analysis of the AE installed capacity requirements for the Ro-Ro vessels revealed that the sizes followed a Gamma distribution pattern with the expression: *170 + GAMMA (2.11e+003, 1.48)*. The best of fit distribution curve is given in Figure 4.14.

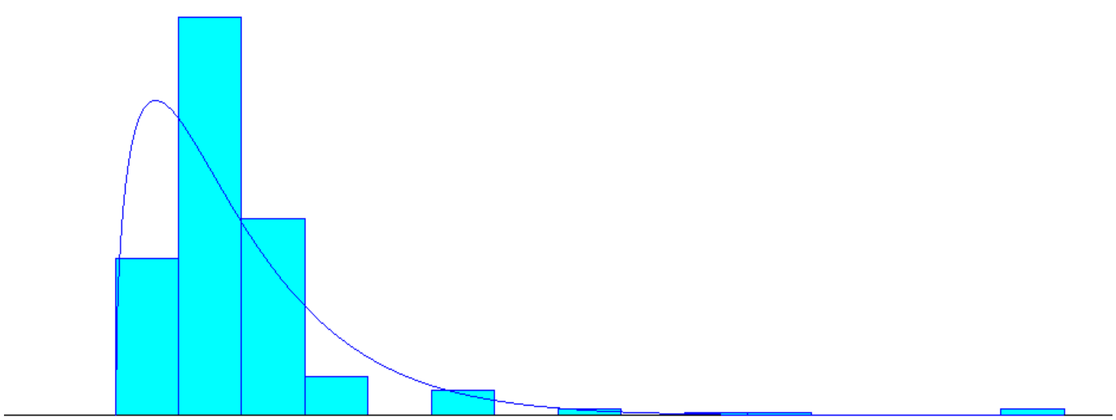


Figure 4.14 Ro-Ro AE Sizes Gamma Distribution Curve

A data summary of the obtained AE of the Ro-Ro vessel visits data is as below-:

Ro-Ro AE Sizes Data Summary

Number of Data Points	= 234
Min Data Value	= 170kW
Max Data Value	= 24,500kW
Sample Mean	= 3,310kW
Sample Std Dev	= 2,900kW

Table.4.3 Frequency Distribution Table for Ro-Ro AE Sizes

AE Size Class	Midpoint	Frequency	CF	Relative Frequency	percentage
1-1000	500	32	32	0.14	14
1001-2000	1500	24	56	0.24	24
2001-3000	2500	65	121	0.52	52
3001-4000	3500	78	199	0.85	85
4001-5000	4500	11	210	0.90	90
5001-6000	5500	9	219	0.94	94
6001-7000	6500	2	221	0.94	94
7001-8000	7500	7	228	0.97	97
8001-9000	8500	0	228	0.97	97
9001-10000	9500	0	228	0.97	97
10001-11000	10500	2	230	0.98	98
Above 12000	12000	4	234	1.00	100

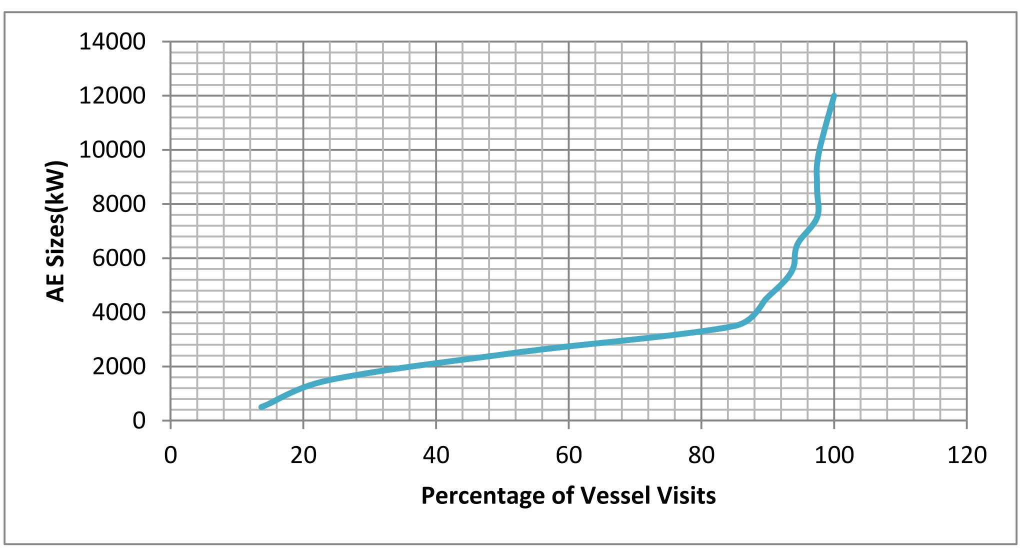


Figure 4.15 Ro-Ro AE Cumulative Frequency Distribution

4.5 Product Carriers

Product Carriers are a type of tanker mostly used to transport crude oil products. Tankers carry liquid bulk and are constructed to a simple but well tested system. The vessels are divided by longitudinal and lateral bulkheads giving the vessels a series of centre tanks flanked by two wing tanks. Liquid bulk cargo can only be carried in the center tanks whereas the wing tanks can be used as designated tanks for fresh and ballast water. Currently, all new tankers have to be double hull to protect against the possibility of sea water oil pollution.

Tankers are divided into Product Carriers, Medium Crude Carriers (MCC), Very Large Crude Carriers (VLCC) and Ultra Large Crude Carriers (ULCC).Other categories of tankers include the Chemical and Parcel Tankers, Liquid Petroleum Gas (LPG) Carriers and Liquid Natural Gas (LNG) Carriers. The world's largest mobile man-made object ever made was a crude carrier called Seawise Giant with a LOA of 458 meters and a capacity of 564,650dwt.

A total of 268 "Product Carriers" visited the port of Mombasa in the year 2012 with the largest being MV Ingeborg with a capacity of 165,187 Dwt. The relative AE Power requirements for these vessels are low compared to Containerships and Ro-Ro Vessels. The range of installed AE Capacities ranges from 54kW for the 1986 built, St Vincent & Grenadines flagged MV Lucy 1 to 4,350kw for the 2011 built, Malta flagged MV Adefines Sun.

4.5.1 Product Carriers Power Profiles and Demand

The range of system frequencies and voltages onboard the Product Carriers are given in Figure 4.16 and Figure 4.17.

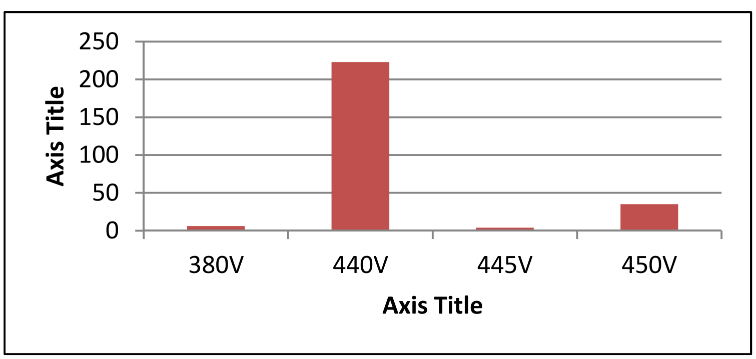


Figure 4.17 Voltage Levels Onboard Product Carriers

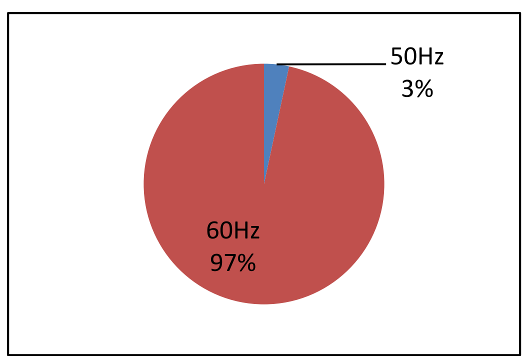


Figure 4.16 Product Carriers' System Frequency

The AE power cumulative distribution curve and frequency table are as shown in Figure 4.18 and Table 4.4 respectively while Figure 4.19 shows the best of fit distribution curve with the Expression *NORM(1.98e+003, 1.13e+003).*

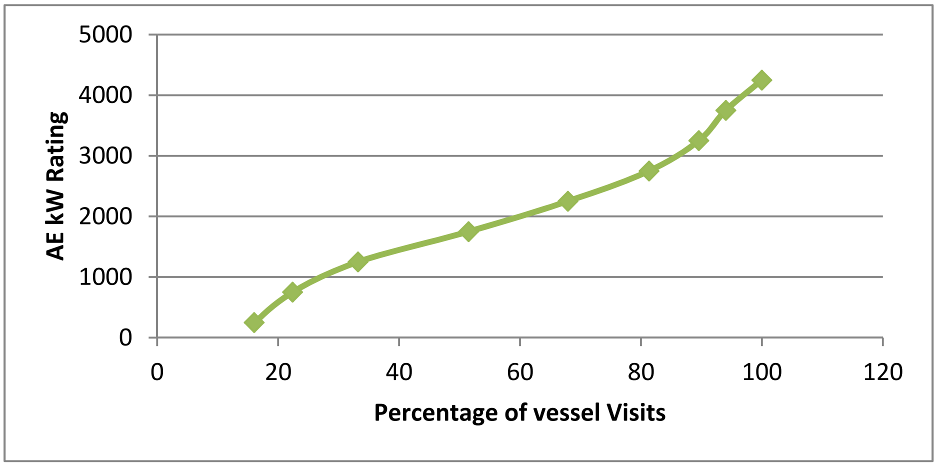


Figure 4.18 Product Carriers' AE Cumulative Distribution Graph

Table 4.4 Product carriers AE Sizes Frequency Distribution table

AE Size Class	Midpoint	Frequency	CF	Relative Frequency	percentage
0-500	250	43	43	0.16	16
501-1000	750	17	60	0.22	22
1001-1500	1250	29	89	0.33	33
1501-2000	1750	49	138	0.51	51
2001-2500	2250	44	182	0.68	68
2501-3000	2750	36	218	0.81	81
3001-3500	3250	22	240	0.90	90
3501-4000	3750	12	252	0.94	94
4000-4500	4250	16	268	1.00	100

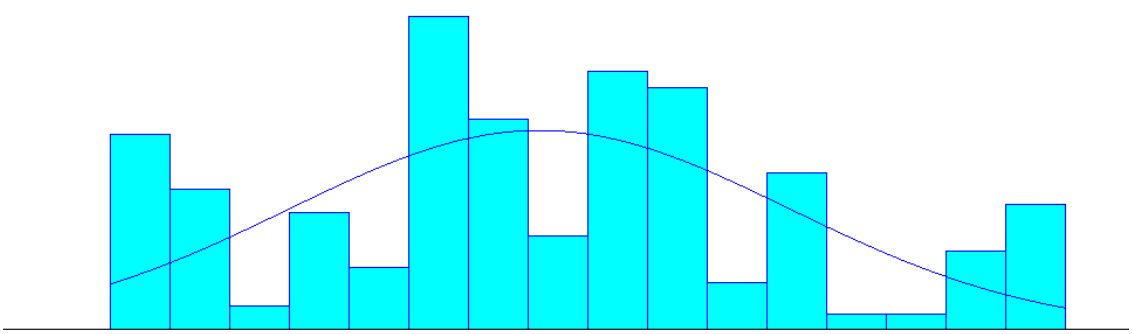


Figure 4.19. Product carriers AE Distribution Curve

4.6 General Cargo Vessels

In today's shipping, dominated by specialized carriers, the fact that a great proportion of the world's trade is still being carried by General Cargo vessels may be overlooked. These vessels are also referred to as Multipurpose ships or Tweendeckers and are almost certainly equipped with cargo handling gear.

Apart from being employed in general cargo liner services, the Tweendeckers are often chartered for tramp voyages to carry cargo that is not easily containerized. As the name suggests, these vessels have two or more decks; the upper weather or main deck and one or more tween decks to add to the variety of cargoes that can be carried as each deck acts as a separation. Additionally, these vessels have movable bulkheads to accommodate variations in stowage factors for different cargoes and for easy adjustment to prevent cargo shift and to allow even further separation of commodities.

Very slight changes have occurred to the design of these vessels in the last decades the most notable being a slight increase in maximum size from around 15,000dwt to 25,000DWCC and speed increase from 14 to 20 knots. These changes are minor compared to the design revolutions that have occurred to Container and Bulk Carrier vessels.

A total of 341 General Cargo vessel visits was recorded in the port of Mombasa with the smallest having a capacity of 56 Dwt and the largest being 48,300 Dwt. Due to the great variation of the General Cargo vessel types witnessed, the onboard installed AE power capacity ranged from 12kW to 5,380kW with two vessels having outlier capacities of 9,609kw and 12,079kW.The last AE capacity, being for a suction dredger vessel, MV Willem Van Orange, will be left out of the design considerations since it does not pay frequent calls to the port as dredging occurs rather infrequently.

4.6.1 General Cargo AE Power Analysis

The AE installed capacity power requirement for general cargo vessels followed an exponential distribution with expression *12 + EXPO (1.4e+003).*The vessels' AE capacities best offFit distribution curve is given in Figure 4.20.

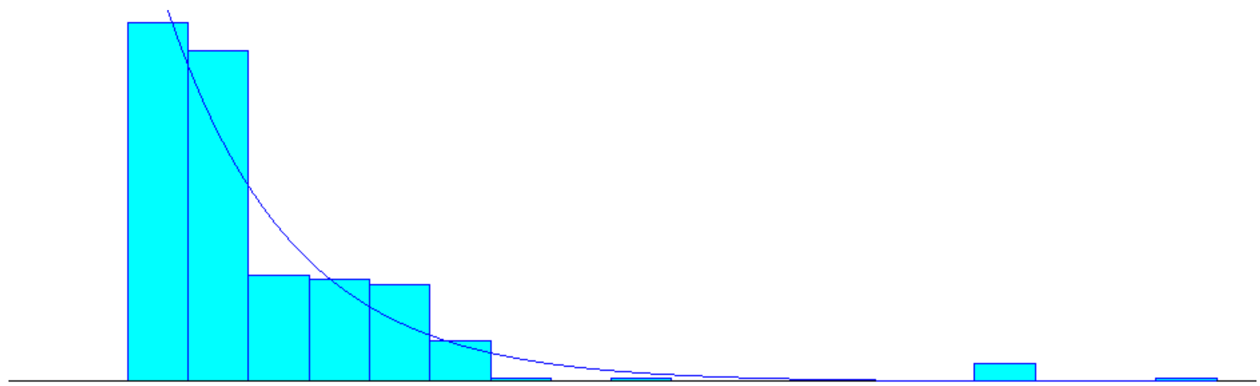


Figure 4.20 Distribution of AE Capacity Sizes for General Cargo Vessels

A brief summary of the AE Capacities is as below-:

AE Data Summary for General Cargo Vessels

Number of Data Points	= 341
Min Data Value	= 12kW
Max Data Value	= 1.21e+004 = 12,100kW
Sample Mean	= 1.41e+003 = 1,410kW
Sample Std Dev	= 1.62e+003 = 1,620kW

The Voltage and Frequency variations of these vessels are as presented in Figure 4.21 and Figure 4.22 with the AE power distribution table and cumulative frequency curve appearing in Table 4.5 and Figure 4.23 respectively.

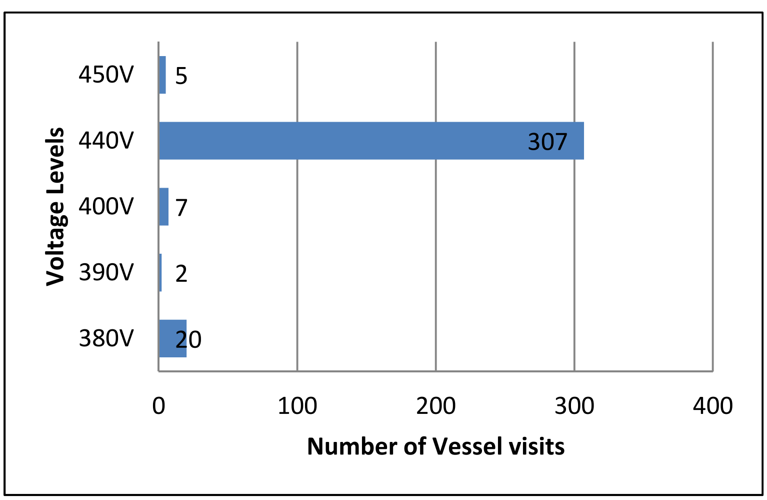


Figure 4.21 General Cargo AE System Voltages

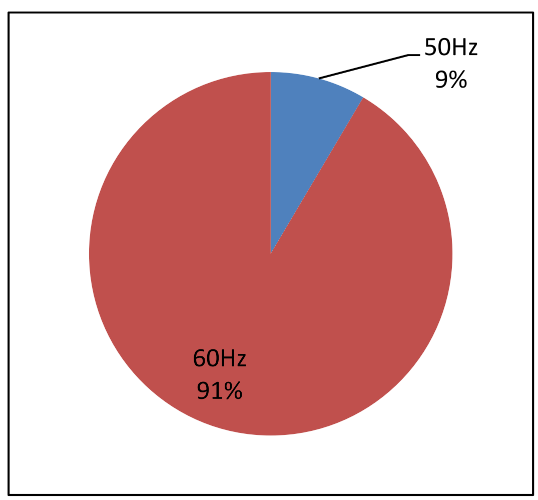


Figure 4.22 General Cargo System Frequencies

Table 4.5 General Cargo AE Power Distribution Table

AE Size Class	Midpoint	Frequency	CF	Relative Frequency	percentage
1-1000	500	213	213	0.62	62
1001-2000	1500	42	255	0.75	75
2001-3000	2500	64	319	0.94	94
3001-4000	3500	13	332	0.97	97
4001-5000	4500	1	333	0.98	98
5001-6000	5500	1	334	0.98	98
6001-7000	6500	0	334	0.98	98
7001-8000	7500	0	334	0.98	98
8001-9000	8500	0	334	0.98	98
9001-10000	9500	6	340	1.00	100
10001-11000	10500	0	340	1.00	100
Above 12000	12000	1	341	1.00	100

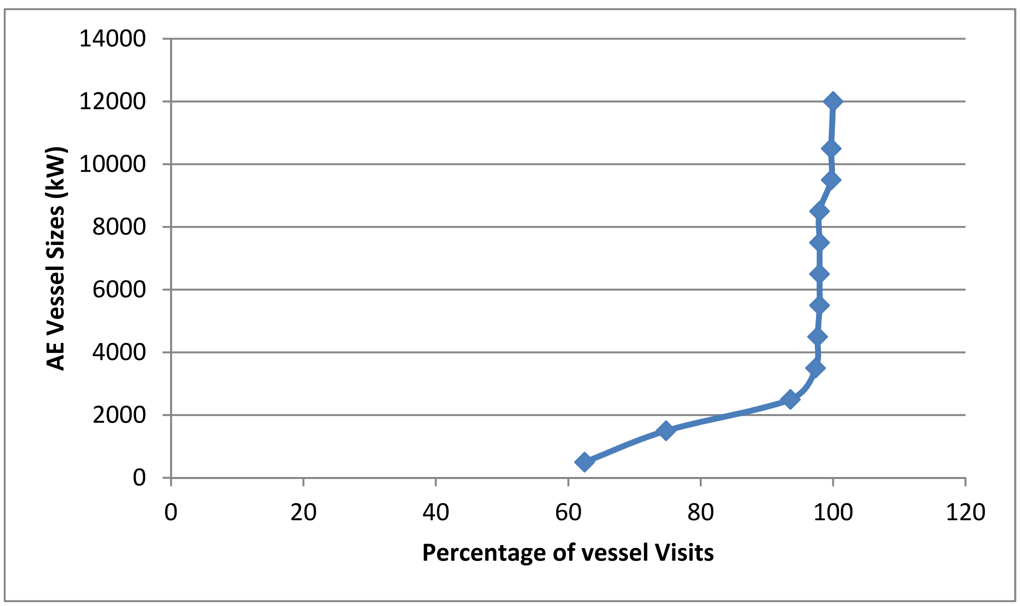


Figure 4.23 General Cargo AE Cumulative Curve

4.7 Tugs and Patrol Boats

This generalization is comprised of Tugs, Patrol Boats, Trawlers, Diving Support Vessels, Utility Vessels, Fishing Vessels, Crew Boats and Supply Ships. It encompassed vessels with short LOA between 16 meters and 96meters and with low hoteling power requirements. Most of these vessels have two main engines which run the vessels and at the same time supply power requirements onboard.

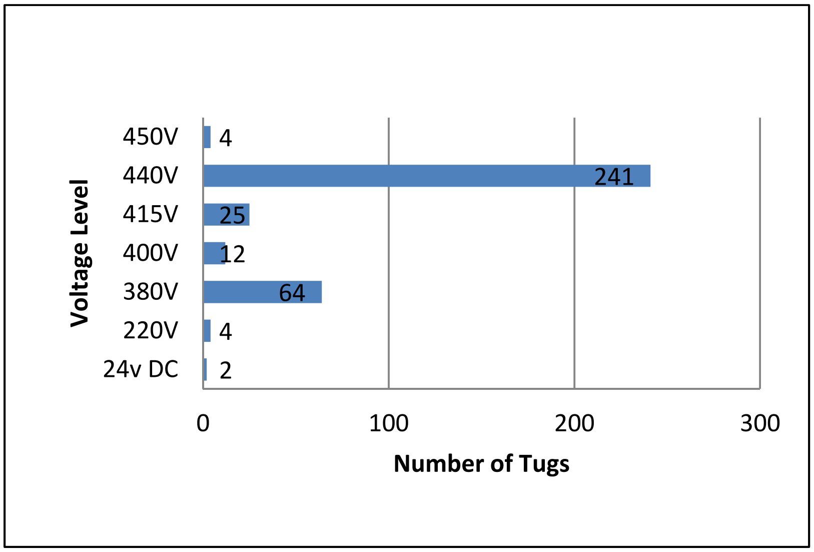
While on shore, the engines charge up some battery banks for the storage of power to be used for critical applications. This leaves the vessel with two options; either run one of the engines for any other power requirements while at the berths or switch off the engines and miss out on comfort associated with onboard power supply. For this reason, KPA port tugs have power plugging points along the berths where they dock during non-operation hours and it is from these points that power for Air Conditioning and other utilities are supplied from the shore.

The same case applies to the most of the world's Navy Patrol Vessels which dock at the port. These vessels always request to be supplied with Shore power for use while at the berth.

4.7.1 Tugs and Patrol Boats AE Power Analysis

Because of lack of AE power details for most of this vessel category, half of the installed ME capacities was taken as the AE power requirements for almost 30% of the vessels. A total of 352 vessels, including the 17 KPA owned Tugs were considered. The frequency levels, system voltages and the cumulative frequency curve are given in Figures 4.24, Figure 4.25 and Figure 4.26 respectively.

The distribution summary revealed a lognormal distribution curve for the Tugs AE sizes as given in Figure 4.27 with the expression *6 + LOGN (457, 1.01e+003).*Table 4.6 is a cumulative frequency table for these vessels' AE.



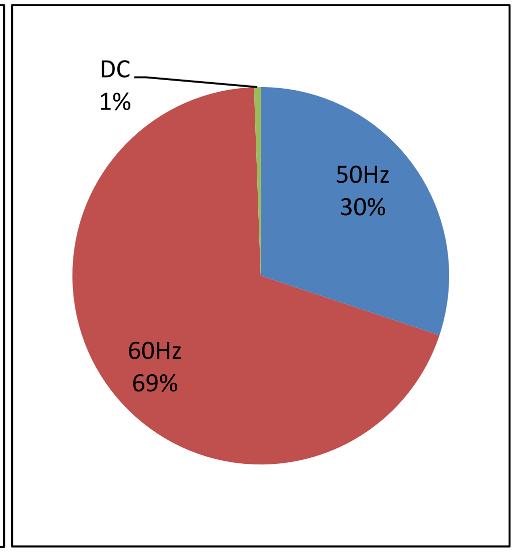


Figure 4.25 Tugs Voltage Levels

Figure 4.24 System frequencies Onboard Tugs

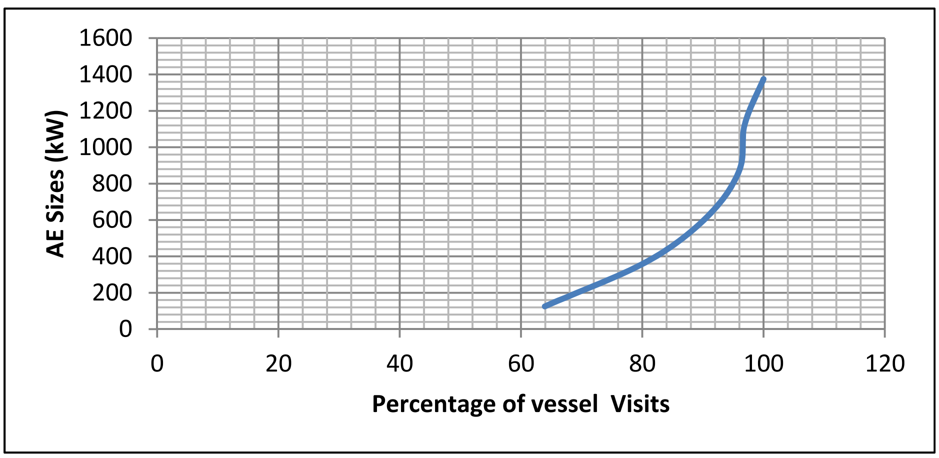


Figure 4.26 Tugs AE Cumulative Frequency curve

Table 4.6 Tugs AE Relative Frequency Distribution Table

AE Size Class	Midpoint	Frequency	CF	Relative Frequency	percentage
0-250	125	225	225	0.64	64
251-500	375	60	285	0.81	81
501-750	625	35	320	0.91	91
751-1000	875	18	338	0.96	96
1001-1250	1125	3	341	0.97	97
above 1250	1375	11	352	1.00	100

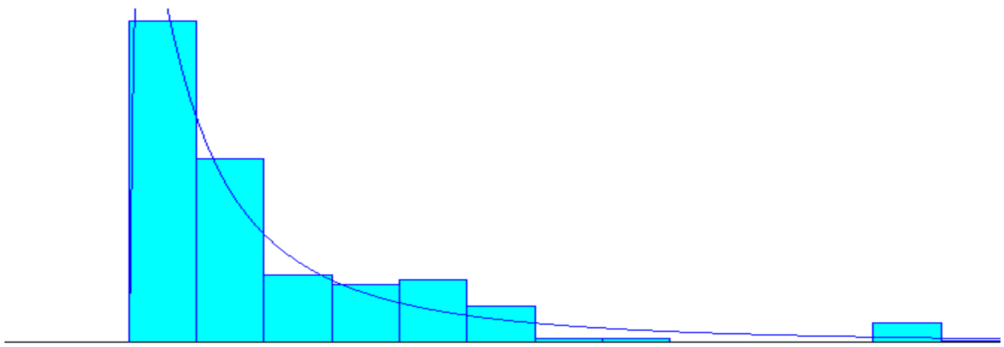


Figure 4.27 Lognormal Distribution Curve for the Tugs AE

The Data summary for the Tugs AE data is as below-:

Data Summary

Number of Data Points	= 352
Min Data Value	= 6kW
Max Data Value	= 2.64e+003 =2640kW
Sample Mean	= 325
Sample Std Dev	= 359

4.8 Cumulative Analysis of Onshore Power Requirements by All vessels

The total vessel visits had a cumulative distribution curve as given in Figure 4.28 and an age profile as shown in Figure 4.29. Figure 4.30 shows the ME Versus AE for the cumulative vessel visits with the Pie Chart in Figure 4.31 showing the relative vessel visits in terms of numbers for each category of vessels. The aggregate vessel characteristics in terms of Dwt, NRT, ME and AE are given in Table 4.7 while Table 4.8 gives a summary of descriptive statistics characteristics for the vessels.

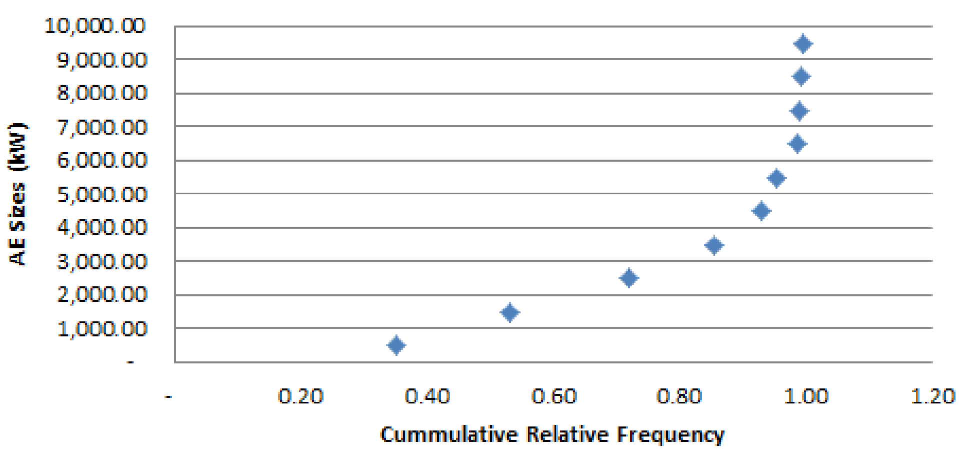


Figure 4.28 Total Vessels Cumulative Distribution Curve

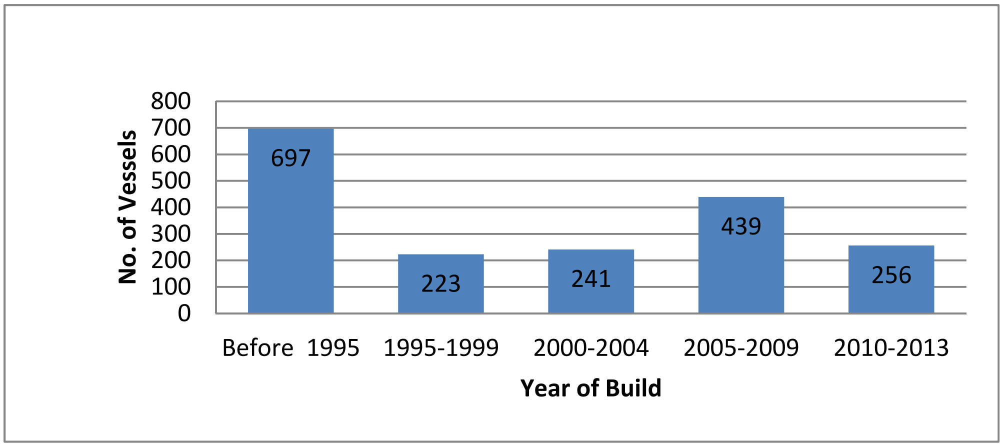


Figure 4.29 Vessel Population YOB Distribution table

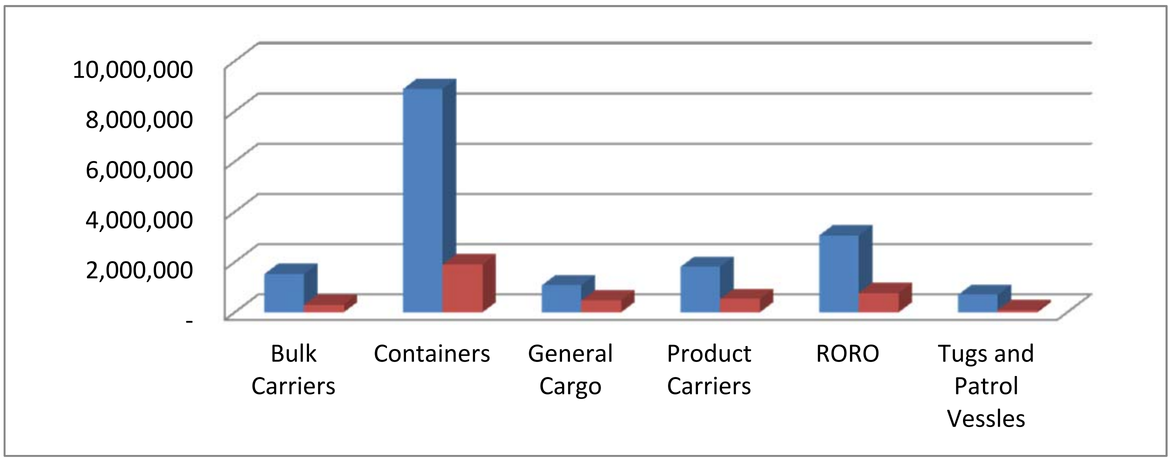


Figure 4.30 Overall Relative ME versus AE for the Different vessels

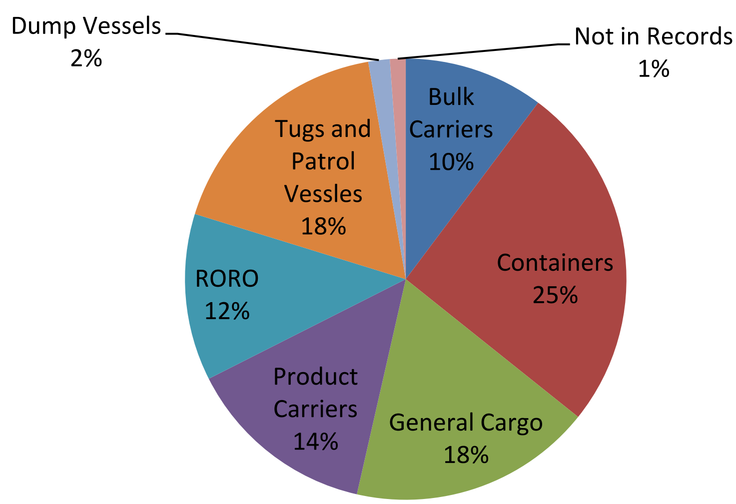


Figure 4.31 Distribution in terms of Number of Vessel Visits

Table 4.7 Aggregate Vessels Characteristics

Type	Numbers	Total DWT	Total NetTonnage	Total ME KW	Total AE KW
Bulk Carriers	196	8,668,887	3,071,746	1,527,867	301,872
Containers	488	14,669,361	1,076,848	8,891,475	1,908,597
General Cargo	341	2,395,953	771,696	1,077,358	479,924
Product Carriers	268	10,765,249	3,269,252	1,811,646	531,786
RORO	234	4,329,194	3,409,636	3,065,598	773,379
Tugs and Patrol Vessles	335			700,923	97,112
Dump Vessels	30				
Not in Records	21				
Total	1913				

Table 4.8 Summary of vessels Descriptive Statistics

Vessel Type	Characteristics	YOB	DWT	LOA	ME (KW)	AE (KW)
Bulk Carriers	Mean	2000	44229	185	7795	1540
	Median	2003	45451	190	8208	1478
	Mode	2011	18286	190	9480	1200
	Standard Deviation	11	14611	17	1748	428
	Minimum	1973	6198	102	2354	378
	Maximum	2013	76945	225	12356	2800
	Count	196	196	196	196	196
Container	Mean	2000	30060	196	18220	3911
	Median	2002	33110	202	18065	3720
	Mode	2002	26000	208	21560	2160
	Standard Deviation	8	6413	20	4892	1519
	Minimum	1977	5207	101	3825	1050
	Maximum	2012	45643	249	25000	7424
	Count	488	488	488	488	488
General Cargo	Mean	1992	7026	93	3159	1407
	Median	1988	2166	75	1834	990
	Mode	2009	1800	65	740	990
	Standard Deviation	15	9637	44	3256	1624
	Minimum	1953	50	32	221	12
	Maximum	2012	48293	340	14058	12079
	Count	341	341	341	341	341
Product Carriers	Mean	1997	39908	160	6727	1976
	Median	2002	27020	169	7275	1800
	Mode	2009	3290	183	11300	2700
	Standard Deviation	13	39673	64	4414	1131
	Minimum	1965	643	51	375	54
	Maximum	2012	165187	289	18623	4350
	Count	268	268	268	268	268
Roro	Mean	1998	18501	184	13101	3305
	Median	2002	18009	200	14280	2990
	Mode	1979	2570	200	2385	744
	Standard Deviation	12	11097	42	5542	2901
	Minimum	1968	290	60	1324	170
	Maximum	2013	73666	288	31200	24480
	Count	234	234	234	234	234

4.9 Analysis of the Relationship between AE and Other Vessel Characteristics.

This research sought to come up with an empirical relationship between vessel AE sizes as the dependent variable and other vessel related independent variables, which were believed to be strongly correlated to the dependent variable. These independent variables include the ME, NRT Capacity (CAP) , Deadweight (DWT),Gross Registered Tonnage (GRT), Length Overall(LOA) and Year of Build (YOB).

Regression analysis was carried out using EVIEWS software to establish, describe and evaluate the movement of the regressand; AE, by reference to movements in the six other regressors. The relationship between these variables was given by the regression model-:

$y_b = ß_0 + ß_1 x_1 + ß_2 x_2 + ß_3 x_3 + ß_4 x_4 + ß_5 x_5 + ß_6 x_{6+U}$ ………………*Equation 4.1*

Table 4.9 shows the results of the first regression confirming that five out of the six variables were statistically significant.

Table 4.9 Regression Analysis AE against six other Independent Variables

Dependent Variable: AE				
Method: Least Squares				
Date: 09/11/13 Time: 17:39				
Sample: 2012 3553				
Included observations: 1542				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-28792.33	6154.886	-4.677963	0.0000
ME	0.274577	0.010513	26.11727	0.0000
CAP	0.121688	0.009429	12.90511	0.0000
DWT	-0.034104	0.002783	-12.25466	0.0000
GTR	-0.040941	0.005365	-7.631457	0.0000
LOA	-0.60153	1.645004	-0.365671	0.7147
YOB	14.75616	3.095822	4.766477	0.0000
R-squared	0.580321	Mean dependent var		2590.871
Adjusted R-squared	0.57868	S.D. dependent var		2008.255
S.E. of regression	1303.541	Akaike info criterion		17.18809
Sum squared resid	2.61E+09	Schwarz criterion		17.21233
Log likelihood	-13245.01	Hannan-Quinn criter.		17.1971
F-statistic	353.7594	Durbin-Watson stat		0.726911
Prob(F-statistic)	0.000000			

Five out of the six variables had the probability values for the T- Test carried out below the 5% significance levels and thus their coefficient values were taken as significant and a reflection of the influence these regressors have on the regressand. LOA was, however, found to have a probability figure of 71% meaning it does not statistically influence the value of AE sizes (Visvikis, 2013).

A repeat regression was carried out without LOA and the results confirmed all the remaining variables to be significant.

Table 4.10 Final Regression Analysis; AE against Five Regressors

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-28790.89	6153.149	-4.679049	0.0000
ME	0.272495	0.008837	30.83672	0.0000
CAP	0.121751	0.009425	12.91767	0.0000
DWT	-0.034646	0.002354	-14.71607	0.0000
GTR	-0.041571	0.00508	-8.18385	0.0000
YOB	14.73183	3.094234	4.761061	0.0000

From the regression analysis, the value of R-Squared is 58%.This means an absolute R value of 7.6. The standards for R are as shown in Figure 4.32. A value higher than 7 shows a strong correlation between the regressand and regressors and thus the regressors' coefficients in the regression model can be relied upon in determining the values of the AE sizes.

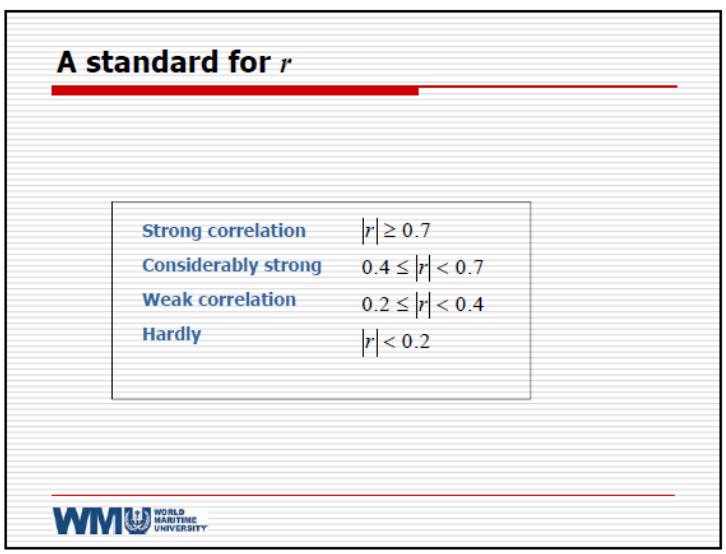


Figure 4.32 Standards for R Values and their Significance

Source: Prof. T. Nakazawa-WMU

As a result of the regression analysis, the following formula was obtained:

$$AE = -28970 + 0.27ME + 0.12CAP - 0.03DWT - 0.04GRT + 14.7\,YOB \qquad \text{Equation 4.2}$$

High values of regression determination coefficient and correlation coefficient confirm good accuracy of the formula in Equation 4.2 and its usability in calculation of onboard installed AE power station. The formulae can, however, be tailor-made for each specific vessel type in order to improve the value of R squared and hence attain higher AE calculation accuracy from the other vessel parameters.

The fact that the LOA was found not to be statistically significant in explaining AE could be explained by the fact that some vessels with short LOA have powerful engines due to their specialty of operation compared to other vessels with very long LOA but small engines like the Bulk carriers.

4.10 OPS Design Parameters

To assess the design parameters for the OPS system, the industry standard loading factors for the vessels were considered. This is because the installed capacity of the AE is not always fully utilized during the hoteling applications. The Loading factors used are a preserve of *Starcrest* Consulting Group LLC, arrived at through interviews with Ship captains, Chief Engineers and Pilots. The *Starcrest* Group experience portfolio in the air quality field includes development of emission inventories and emissions forecasts for traditional pollutants and greenhouse gases and evaluation of supply chain and logistics efficiencies as they relate to energy consumption and air emission.

Table 4.11 gives the average load factors for AE of different vessel types and their sub-classes in transit, maneuvering and hotelling functions.

Table 4.11 Auxiliary Engine Loading Factors for Different Vessels

Vessel Type	Total Aux Eng Power (kW)	Load Defaults (%)			Load Defaults (kW)		
		Sea	Maneuvering	Hotelling	Sea	Maneuvering	Hotelling
Auto Carrier	2,850	15%	45%	26%	428	1,283	741
Bulk	2,850	17%	45%	10%	485	1,283	285
Container - 1000	2,090	13%	50%	18%	272	1,045	376
Container - 2000	4,925	13%	43%	22%	640	2,118	1,084
Container - 3000	5,931	13%	43%	22%	771	2,550	1,305
Container - 4000	7,121	13%	50%	18%	926	3,561	1,282
Container - 5000	11,360	13%	49%	16%	1,477	5,566	1,818
Container - 6000	13,501	13%	50%	15%	1,755	6,751	2,025
Container - 7000	13,501	13%	50%	15%	1,755	6,751	2,025
Container - 8000	13,501	13%	50%	15%	1,755	6,751	2,025
Cruise	na	na	na	na	na	na	na
General Cargo	1,776	17%	45%	22%	302	799	396
Ocean Tug	600	17%	45%	22%	102	270	134
Miscellaneous	1776	17%	45%	22%	302	799	396
Reefer	3,900	15%	45%	32%	585	1,755	1,248
Ro/Ro	2,850	15%	45%	26%	428	1,283	741
Tankers - All Small	1,911	24%	33%	26%	459	631	497
Tankers - Panamax	2,520	24%	33%	26%	605	832	655
Tankers - Afranax	2,544	24%	33%	26%	611	840	661
Tankers - Suezmax	2,865	24%	33%	26%	688	945	745
Tankers - VLCC	3,388	24%	33%	26%	813	1,118	881
Tankers - ULCC	3,667	24%	33%	26%	880	1,210	953
Tankers (D/E)	1,985	24%	33%	26%	476	655	516

Source: Starcrest Consulting Group

From the vessel power characteristics, the installed power AE capacities covering over 96% of the vessels were considered. The respective Loading Factors from Table 4.11 were then used in obtaining the calculated AE Loading. These are the respective power demands from the vessels while at berth to be supplied by OPS. Table 4.12 gives the expected maximum loading levels from the OPS by the different vessels.

As for the system frequency, 100% of the containerships' power systems had 60Hz frequency rating. Bulk carriers, Ro-Ro and Product carrier power systems had 97% of the vessel visits with 60Hz frequency. This implies that the system designs for these vessel berths could be supplied with only a 60Hz frequency.

As for general cargo and tugs, the percentage of 60Hz frequency systems onboard these vessels were 91% and 69% respectively. For these two categories of vessels, it would make economic sense to have a dual frequency OPS system to service the two different vessel systems.

Table 4.12 Different Calculated Power Demand by Different Vessels

Vessel Type	AE Requirements	Percentage Covered	Load Factor	Calculated Loading
Tugs	875	96%	22%	193
General cargo	5500	98%	22%	1210
Product carriers	4250	100%	26%	1105
RoRo	7500	97%	26%	1950
Bulk Carriers	2625	99%	10%	263
Containers	6750	99%	22%	1485

Because of the small power requirements by Tugs and Patrol Vessels, power supply to these vessels by a Low Voltage (LV) system would be appropriate since single flexible cables would be adequate to supply them. This is unlike the high power demands of the other vessels, which would require High Voltage (HV) supply cables and an onboard galvanic transformer for transforming the voltages to the required voltage levels onboard.

5.0 TECHNICAL DESIGN

The technical designs presented in this Chapter are based on the investigated onboard vessel power demands as examined in Section 4.9 on OPS Design Parameters.

As evident from the results of the technical survey analysis and as per the prevailing standard for OPS systems, there will be a need of frequency converters in the port substations designs so as to be able to supply vessels with 60Hz since the utility power supply in Kenya and the larger part of Africa as a whole is 50Hz (See Figure 2.7). The standard design advanced by the recently launched international standard IEC/ISO/IEEE 80005-1 on OPS is to supply vessels with High Voltage (HV) cable for ease and flexibility of shore side connection. This luxury of smooth and fast connection comes at a cost since most utilities are at 400V (3 phase) or 240V (single phase) implying that an onboard transformer has to be installed to adapt the HV to the onboard system requirements. Figure 5.1 is a typical OPS system showing the basics of the components involved.

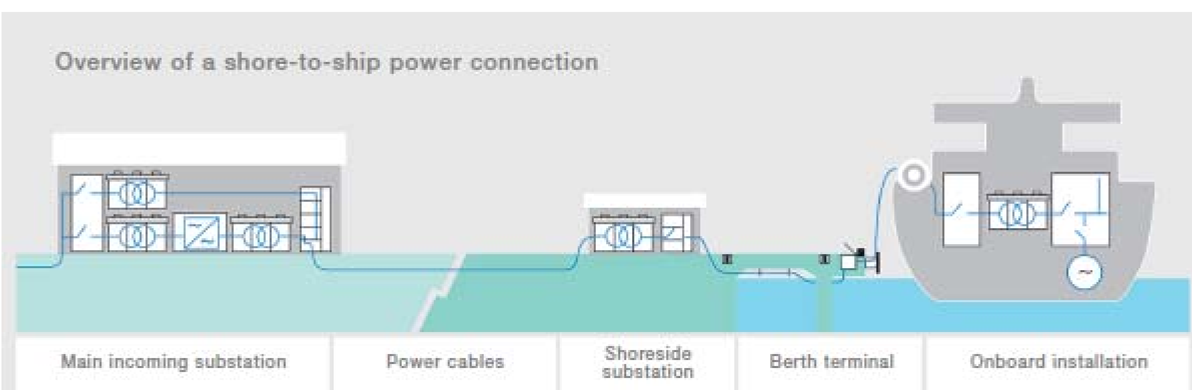


Figure 5.1 Overview of a Typical Onshore Power Supply System

Source: ABB Review 4/2010 - Shore-to-ship power

This research explores two main designs; a topology based on EU recommendations to their member states regarding shore-side supply and an author proposed and evaluated design.

5.1 EU Recommended Shore Side Supply Design.

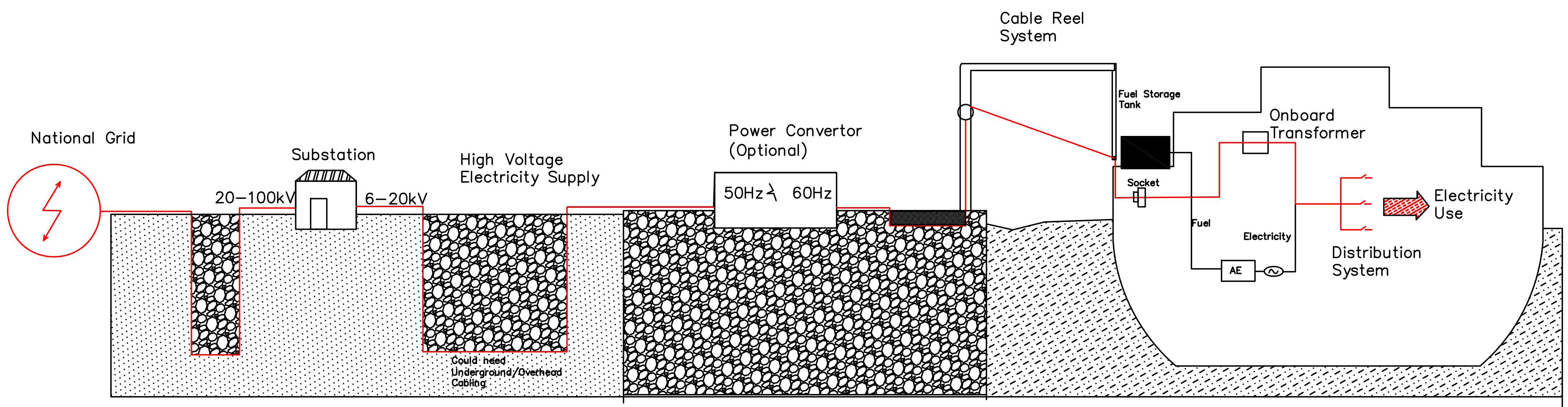
One of the EU's strategies for reducing and regulating air emissions from ships is through recommendation 2006/339/EG of 8th May, 2006 on promotion of shore-side electricity for use by ships while staying at berth in their ports. This recommendation is supported by Directive 2003/96/EC concerning the taxation of energy products and electricity and a subsidy program on shore connection programs. These efforts are in a bid to meet and surpass the MARPOL Annex VI IMO regulations on pollution.

Figure 5.2 shows a reproduced overview of Shore-side electricity connection according to EU recommendations. The design advocates for a decentralized supply system where each individual vessel that calls is allocated a corresponding frequency converter located at the berth side. The pros and cons of this model can be discussed at length but one of the outstanding features is that the converter dimensioning has to be done to cater for the actual power demand of the largest vessel visiting the port. The down side of this is that once connected to a vessel with smaller power demand, the overcapacity of the frequency converter cannot be utilized.

The design also does not exemplify the paramount importance of galvanic protection separation of the onboard and onshore power systems. Vessels with similar power characteristics with the land electricity system, and with no galvanic transformer onboard, experience high short circuit fault levels and are more likely to be prone to damage to the internal system power distribution panels and connecting cables. This is because the levels of bolted 3-phase symmetrical RMS fault current at a point of fault is dependent on the upstream transformer percentage impedance and power rating, which in this case is a land based utility transformer and likely to be of high capacity.

The recommendation 2006/339/EG, however, advises member states to evaluate the environmental benefits and the cost-effectiveness of their designs and proposals on a case to case basis (EU Commission, 2006).

FIGURE 5.2 OVERVIEW OF SHORE–SIDE ELECTRICITY CONNECTION ACCORDING TO EU RECOMMENDATION 2006/339/EG



Position	1	2	3	4	5	6	7	8	

Description of the shore–side electricity connection according to EU recommendation 2006/339/EG

1. A connection to the national grid carrying 20–100 kV electricity from a local substation, where it is transformed to 6–20 kV.

2. Cables to deliver the 6–20 kV power from the sub–station to the port terminal.

3. Power conversion, where necessary. (Electricity supply in the Community generally has a frequency of 50 Hz. A ship designed for 60 Hz electricity might be able to use 50 Hz electricity for some equipment, such as domestic lighting and heating, but not for motor driven equipment such as pumps, winches and cranes. Therefore, a ship using 60 Hz electricity would require 50 Hz electricity to be converted to 60 Hz).

4. Cables to distribute electricity to the terminal. These might be installed underground within existing or new conduits.al.

5. A cable reel system, to avoid handling of high voltage cables. This might be built on the berth supporting a cable reel, davit and frame. The davit and frame could be used to raise and lower the cables to the vessel. The cable reel and frame could be electro–mechanically powered and controlled.

6. A socket onboard the vessel for the connecting cable.

7. A transformer on board the vessel to transform the high voltage electricity to 400 V.

8. The electricity is distributed around the ship, and the auxiliary engines switched off.

REPRODUCED FROM THE OFFICIAL JOURNAL OF THE EUROPEAN UNION ON THE PROMOTION OF SHORE–SIDE ELECTRICITY FOR USE BY SHIPS AT BERTH.

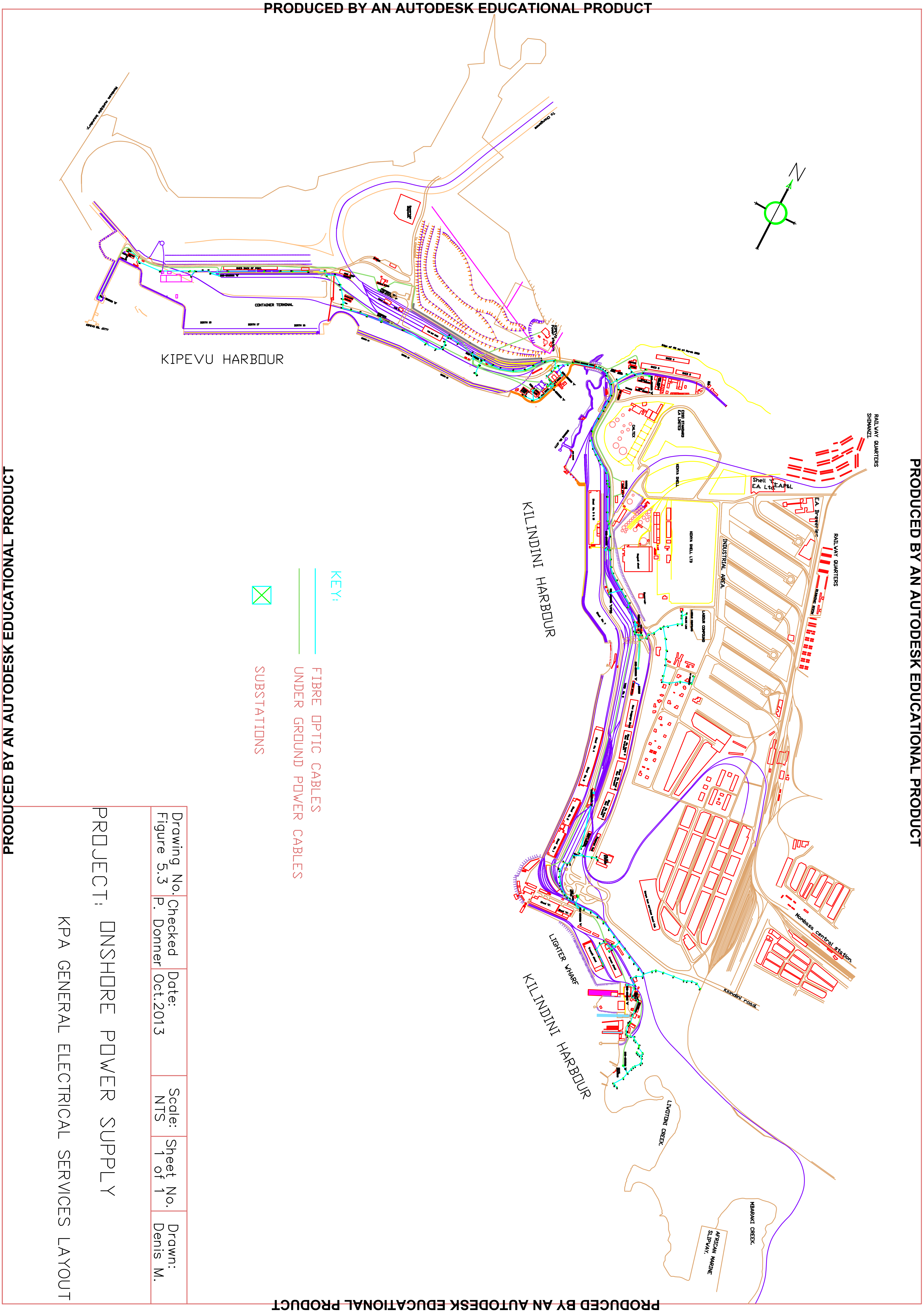
5.2 KPA Substations

All the drawings in this section are produced using AutoCAD® Electrical 2011, Student Edition under the permission of Autodesk Global Business Services. The drawings are designed for plotting on A2 or A3 paper and thus legibility on A4 printout may be blurred. Reading of a softcopy of the same is advised as the designs could be zoomed in and out depending on the point of interest under consideration.

Figure 5.3 and Figure 5.4 show the General KPA Electrical Services Layout and a Single Line Diagram (SLD) showing the Port Power Reticulation Network respectively. The reticulation network shows all fourteen (14) 11kV Substations and the supply matrix within the port including the ring main loops, the respective distances between the different substations and viable substation sites for the location of the proposed OPS system equipment. Also shown in this diagram are the proposed positions of the berths' OPS termination points. The Port is currently fed by two feeders with the Kipevu feeder, Substation M (SSM), being the main one and Shimanzi, (SSK), being the alternative supply line. The ongoing upgrade of power supply feed line from 11kv to 132kV is located near SSM. Figure 5.5 shows a typical 11kV substation layout in the port.

The March 2013 inaugurated Berth 19 saw an increase of the container terminal quay length to 840 meters making it possible to berth three Panamax container vessels at the same time (KPA, 2013, p.3). This design will consider simultaneous occupancy of the four berths by three vessels, and hence, three connection points along the quay lengths are proposed. This will cater for Berths 16, 17, 18 and 19 all of which are container terminals. The proposal is to feed this section with shore power from expanded substation T, which currently feeds the 3.3kV rated STS cranes. In this section, only the housing for the Transformers and the Frequency converters will be required as the substation is large enough to accommodate the required switchgears.

The next section will be Berth 11 to berth 15. Similarly, three OPS termination points will be considered with the power feeder coming from expanded Substation U. This section is very near to the Headquarters and OPS will greatly reduce both noise and emission pollution from the vessels.



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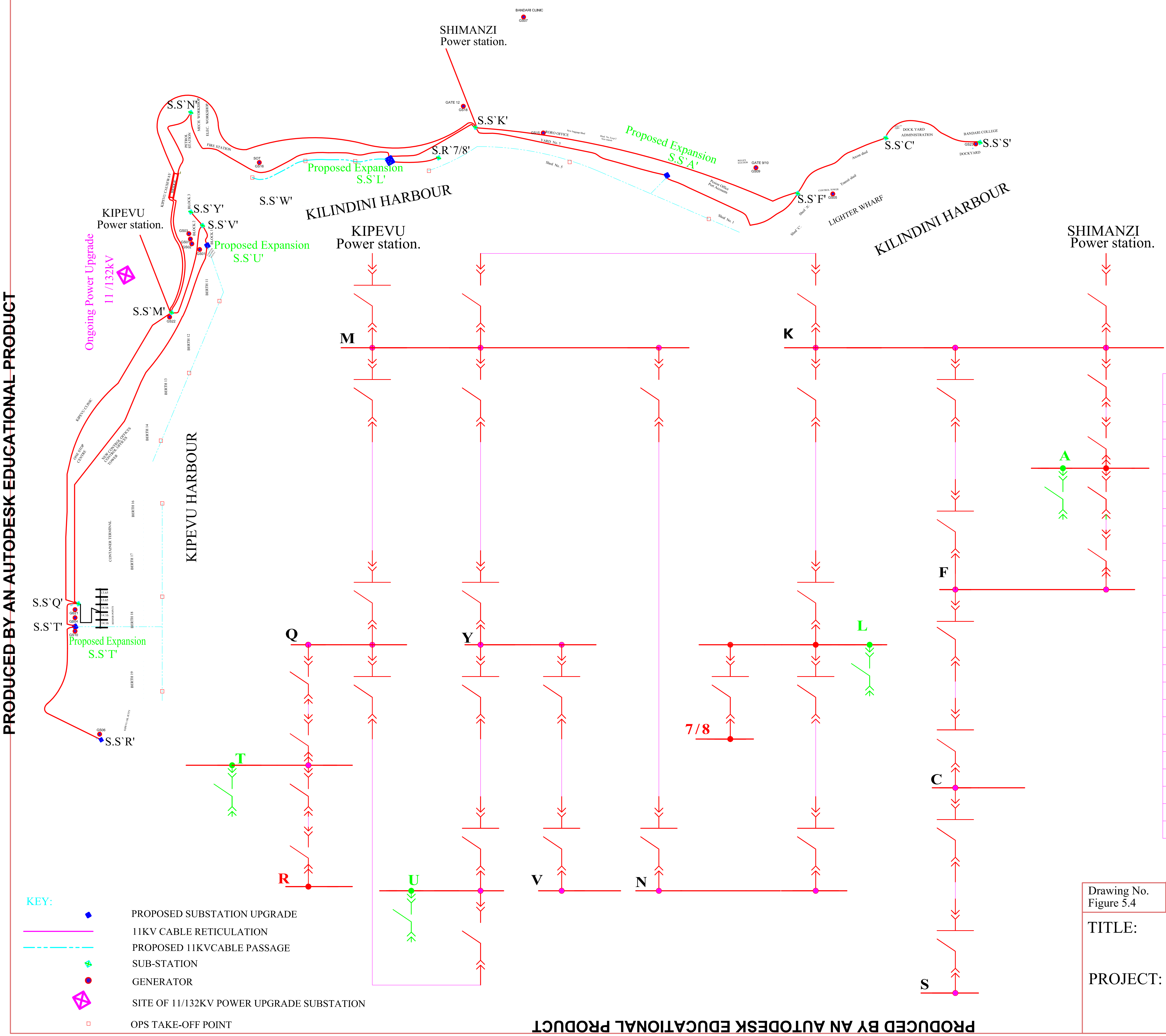

CABLE LENGTHS (FEET)

R-Q = 2142'
Q-M = 5113'
M-U,V,Y = 1235'
M-N = 3608'
N-E = 2502'
E-L = 1390'
L-7/8 =681'
L-K = 1489'
K-D = 742'
K-A = 3442'
A-F = 3447'
F-C = 2525'

ITEM	EQUIPMENT DESCRIPTION	LOCATION	SIZE
GS-01	GENERATOR SET NO.01	BLOCK 2	500KVA
GS-02	GENERATOR SET NO.02	BLOCK 3	500KVA
GS-03	GENERATOR SET NO.03	BLOCK 1&4	365KVA
GS-04	GENERATOR SET NO.04	SSQ 1	500KVA
GS-05	GENERATOR SET NO.05	CONTROL TOWER	220KVA
GS-06	GENERATOR SET NO.06	KOT	100KVA
GS-07	GENERATOR SET NO.07	BANDARI CLINIC	200KVA
GS-08	GENERATOR SET NO.08	GATE 18/20	50KVA
GS-09	GENERATOR SET NO.09	GATE 9/10	210KVA
GS-10	GENERATOR SET NO.10	SSQ-2	1000KVA
GS-11	GENERATOR SET NO.11	BANDARI COLLEGE	60KVA
GS-12	GENERATOR SET NO.12	MAKUPA WELFARE	145KVA
GS-13	GENERATOR SET NO.13	OLD PORT	40KVA
GS-14	GENERATOR SET NO.14	MBARAKI SPORTS CLUB	50KVA
GS-15	GENERATOR SET NO.15	RORO	50KVA
GS-16	GENERATOR SET NO.16	SOT	70KVA
GS-17	GENERATOR SET NO.17	ELECTRICAL WORSHOP	50KVA
GS-18	GENERATOR SET NO.18	GATE 12	27.5KVA
GS-19	GENERATOR SET NO.19	ELECTRICAL WORSHOP	17KVA
GS-20	GENERATOR SET NO.20	RAS SERANI	27.5KVA
GS-21	GENERATOR SET NO.21	SSQ 2	610KVA
GS-22	GENERATOR SET NO.22	SSM	610KVA
GS-23	GENERATOR SET NO.23	BANDARI COLLEGE	610KVA
GS-24	GENERATOR SET NO.24	ELECTRICAL WORKSHOP	15KVA
GS-25	GENERATOR SET NO.25	OLD PORT ACCOUNTS	40KVA

Drawing No. Figure 5.4	Checked P. Donner	Date: Oct.2013	Scale: NTS	Sheet No. 1 of 1	Drawn: Denis M.

TITLE: SINGLE LINE DIAGRAM
HIGH VOLTAGE RETICULATION

PROJECT: KENYA PORTS AUTHORITY
PROPOSED ONSHORE POWER SUPPLY

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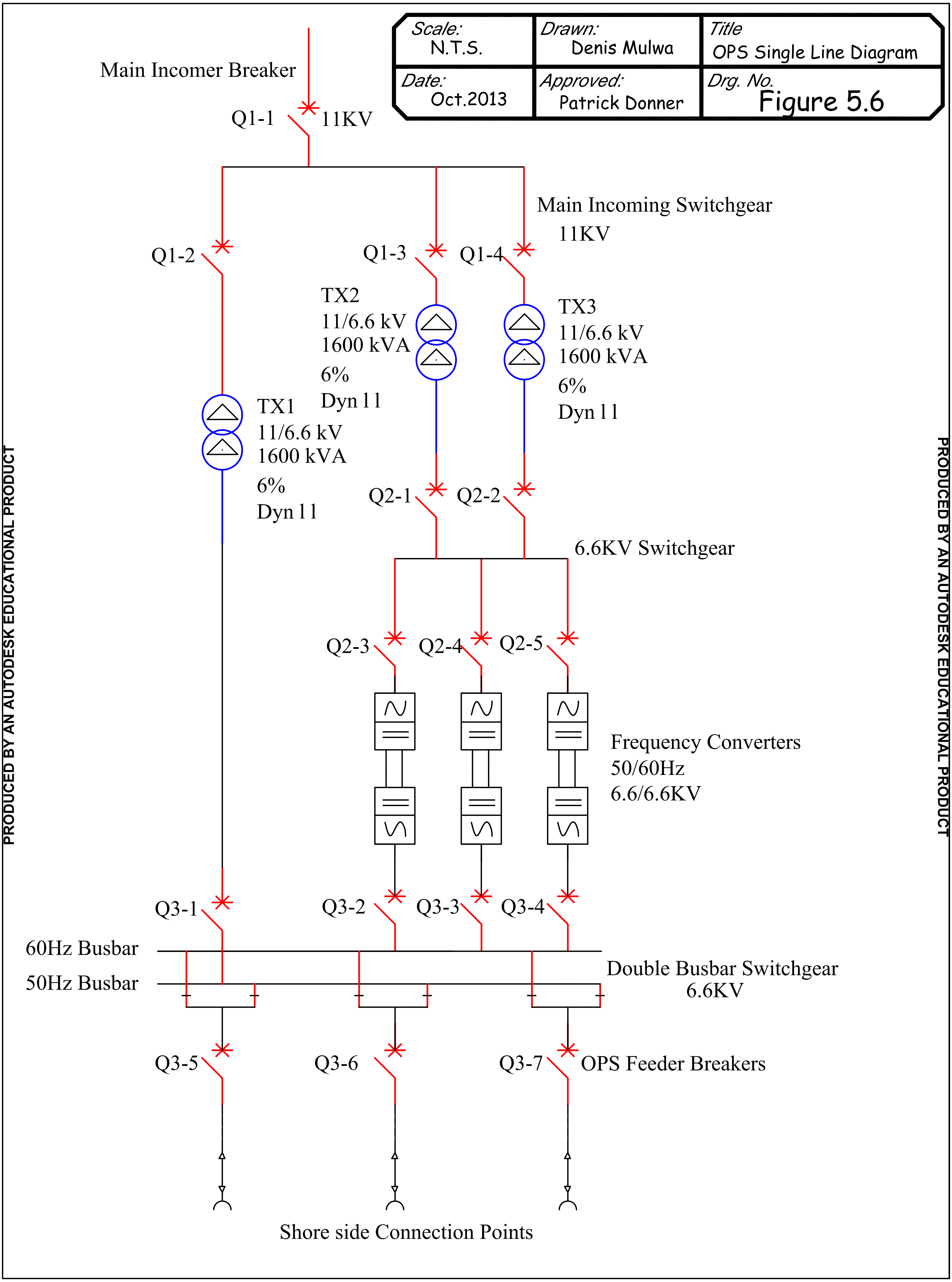
Figure 5.5 A Typical 3.3/11kV Substation in the Mombasa Port under Construction

Source: Author

The Shimanzi Oil Terminal (SOT) used for product carriers and Berths 9/10 normally used for bulk carriers will both be provisionally supplied from substation L while Substation A will supply the conventional cargo, Ro-Ro and tug berths.

The tugs berths' will be supplied with Low voltage (LV) 415V, 50Hz supply lines from Substation A, while the rest of the vessels will be provided with 6.6kV lines with the expectation that the vessels will each have a onboard installed 6600/440V transformers to act as both galvanic protection and to adapt the high voltage to the vessel system voltage. Figure 5.6 and Figure 5.7 show the proposed OPS Single Line Diagram and the power substation Switchgear Panel Layout respectively.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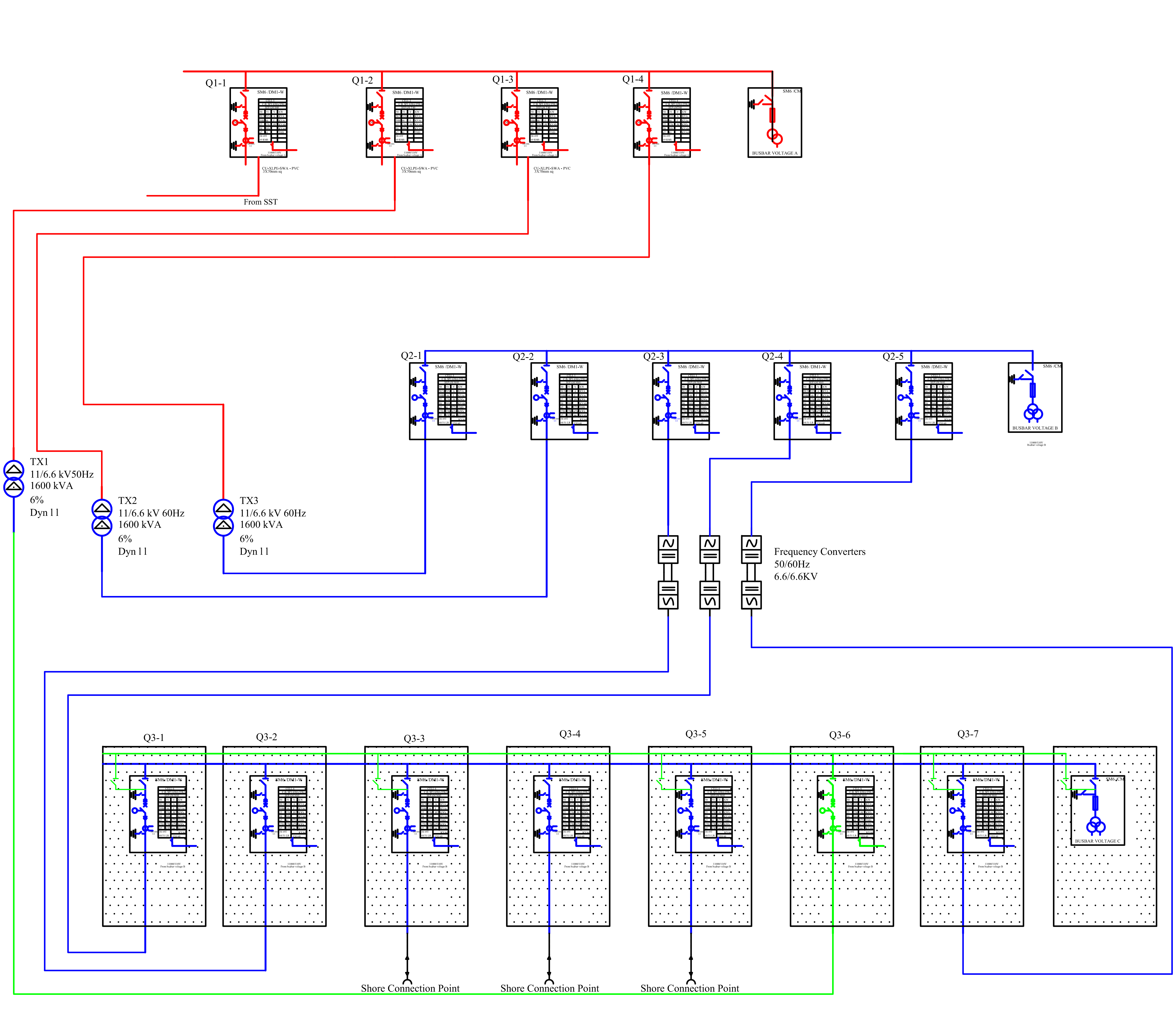
Drawn:
Denis Mulwa
Title
OPS Single Line Diagram
Date:
Oct.2013
Approved:
Patrick Donner
Drg. No.
Figure 5.6
Main Incomer Breaker
Q1-1
11KV
Main Incoming Switchgear
11KV
Q1-2
Q1-3
Q1-4
TX2
11/6.6 kV
1600 kVA
6%
Dyn 11
TX3
11/6.6 kV
1600 kVA
6%
Dyn 11
TX1
11/6.6 kV
1600 kVA
6%
Dyn 11
Q2-1
Q2-2
6.6KV Switchgear
Q2-3
Q2-4
Q2-5
Frequency Converters
50/60Hz
6.6/6.6KV
Q3-1
Q3-2
Q3-3
Q3-4
60Hz Busbar
50Hz Busbar
Double Busbar Switchgear
6.6KV
Q3-5
Q3-6
Q3-7
OPS Feeder Breakers
Shore side Connection Points



LEGEND:
RED-11KV 50Hz
GREEN 6.6KV 50Hz
BLUE-6.6KV 50/60Hz
11/3.3 CABLES -CU XLPE -SWA-PVC
IN PVC CONDUITS 150mm DIAMETER THROUGH

6.6KV 50/60HZ SWITCHGEAR

11KV 50HZ SWITCHGEAR

EARTING SYSTEM:TN-C-S (ICE 60364-5-54) UK:PME

Rev.	Date	Revision

KENYA PORTS AUTHORITY

Project title:
PROPOSED ONSHORE POWER SUPPLY

Drawing title:
SUBSTATION LAYOUT DIAGRAM

Scale: N.T.S.	Drawn: Denis Mulwa	Checked: Denis Mulwa
Date: Oct.2013	Approved: Patrick Donner	Drg. No. Figure 5.7

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5.3 Analysis of Required Transformer, Converters, Switchgears and Cables

5.3.1 1600kVA Transformer

The design adopted 1600kVA transformer sizes to be able to supply 99% of the container vessels visiting the port as per Table 4.12 on the calculated loading demand by the different vessels. The transformer shall be oil immersed core type and shall be manufactured and tested as per IEC 76. It shall be provided with a conservator, an isolating valve and a dehydrating breather. The oil conservator should have an Oil Level Indicator. The HV cable box shall be suitable for terminating three core cables of up to 300 mm^2 XLPE cable. The MV cable box shall be suitable for terminating up to 7No. single core PVC cables of 600 mm^2 on a stud of 12 mm diameter.

The Transformer HV and LV current ratings are calculated as-:

Full Load Amps (F.L.A) : 1600kVAtransformer (HV Side)

$$I = \frac{\text{kVA X 1000}}{\text{VLine x}\sqrt{3}}\text{A} \qquad \text{..............Equation 5.1}$$

$$I = \frac{\text{1600 X 1000}}{\text{11000 x}\sqrt{3}}\text{A} \qquad \text{=83.9A (HV Side)}$$

Full Load Amps (F.L.A): 1600kVAtransformer (LV Side)

$$I = \frac{\text{1600 X 1000}}{\text{6600 x}\sqrt{3}}\text{A} \qquad \text{=140.0A (LV Side)}$$

Other transformer specifications are as found in the BOQ in Appendix II

The transformer protection shall include winding temperature alarm and trip as well as oil level alarm and trip and Bucholz alarm and trip. The breathing type transformers shall be fitted with a glass breather containing silica gel. The silica gel shall be changeable before turning from blue to pink to protect the transformer core against the ingress of moisture.

5.3.2 6.6KV 50/60Hz Frequency Converters

Availability of clean and efficient, high power rated, economic and efficient frequency converters with a clean sine wave voltage output and rated for High Voltages is not easy.

The features considered in the selection of the converters include-:

- High availability and reliability with low maintenance and remote diagnosis capability
- Scalable modular solutions ranging from 0.5 MVA up to 6 MVA
- High efficiency on partial-load conditions
- International supplier with local support with all round service concept

Compact design with high power density ensuring small foot prints to economize on substation space was a major requirement.

ABB static frequency converters, internally configured as an arrangement of modular rectifiers and inverters, controlled by a power electronic controller, suit the above selection criteria. These converters produce sine wave voltage to supply the output load adjusting the grid electricity to the appropriate ship frequency. The Model selected for this design is PCS 100 SFC-1250; a 1250kVA, 1000kW converter unit containing 10 module pairs and with dimensions of 2.3x 4.4x 0.8 Meters. The converters utilize the latest high performance Insulated Gate Bipolar Transistor (IGBT) power switching devices controlled by a micro controller.

Other specifications include-:

Input

Typical grid voltage	0.4kV -30 kV
Frequency	50 / 60 Hz
Input section	IGBT voltage source converter
Converter voltage	200 .. 480 VAC
Total harmonics distortion	< 3 %

Output

Typical ship voltage	480 V / 6.6 kV
Frequency	60 / 50 Hz
Output section	IGBT voltage source converter
Converter voltage	400 .. 480 VAC
Total harmonics distortion	< 3 %
Efficiency	95% typical
Max overload capacity	30 seconds 150%
Short circuit limit	0.5 seconds 200%

Mechanical

Enclosure	IP 20 or IP 23 Standard color RAL 7035
Cooling	Forced ventilation

Figure 5.8 ABB Modular Frequency Converter Picture

Source: ABB Website

5.3.3 HV Switchgear

All the 14 HV substations in the port have Schneider Electric switchgear. The 11KV and 6.6kV metal-clad switchgear panels and all the protection relays, measuring and indicating instruments and the control and monitoring devices and accessories, including current transformers and voltage transformers of these switchgears all comply with the provisions and requirements of the standards of the International Electro-technical Commission (IEC).

For reduction on spare parts inventory costs and uniformity and ease of expansion, this research settled on Schneider Electric Modular switchgear. This is also to ensure that most of the players in the OPS arena have their products considered in this design.
Figure 5.5 shows these switchgears under installation in a newly constructed substation in the port. The respective standards for the switchgear components are-:

	Component	Applicable Standards
i.	Circuit Breaker	IEC 62271-100 & IEC 60298.
ii.	Switchgear panels	IEC 60294
iii.	Current Transformers	IEC 60044-1
iv.	Voltage Transformer	IEC 60044-2
v.	Protection Relays and Measuring and Indicating Instruments, IEC 60255	

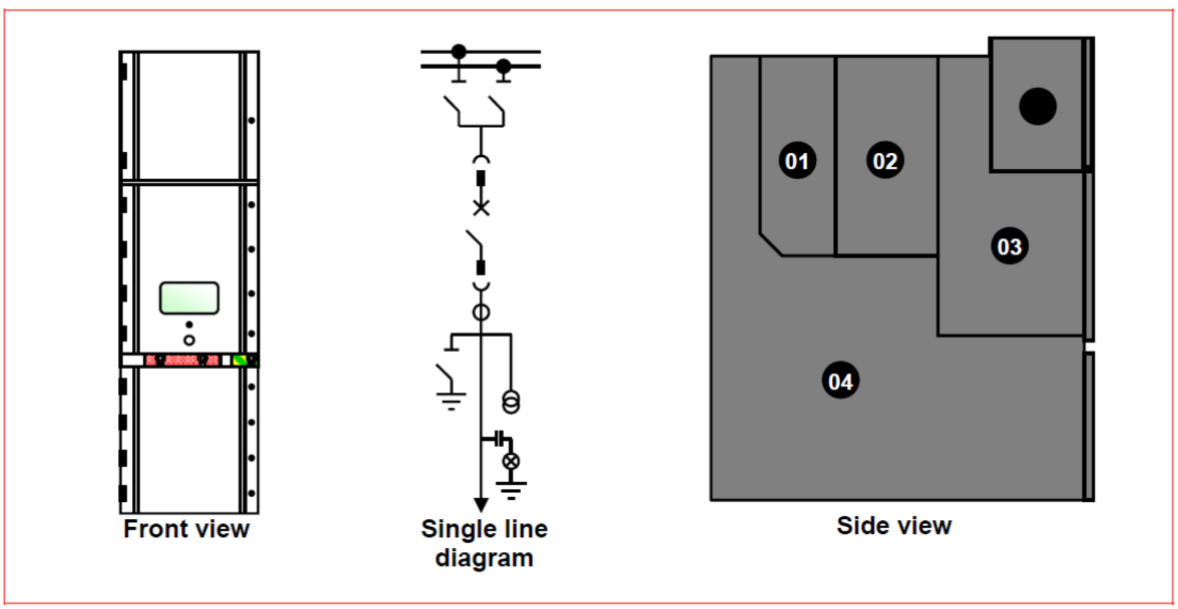
The specifications of these switchgears include extensible, metal clad pattern as per British Standards IEC 62271 and IEC 694. The panels have separate compartments for the busbar, cable box, fixed isolator contacts, current and/or voltage transformers and instrument panels (low voltage section). The complete switchboard is usually flush-front design.

The Circuit breakers are three poles operated, indoor type, with Sulphur Hexafluoride gas (SF6) insulation and interrupter and comply with the requirements of IEC56. These switchgears have withdrawable, horizontal type circuit breakers and are clearly visible when in withdrawn position. The breakers are of mechanical and electrical trip-free type with built-in interlocks incorporated to prevent any mishandling and provisions for key locking and padlocking are made. The main busbar connections and their support are all rated 2000 A as required for continuous operation under ambient conditions and are capable of carrying the short-time Short Circuit Current (Isc) associated with the short circuit ratings of the circuit breakers, for 3 Seconds.

In terms of protection, the switchgears have integral circuit earthing which also doubles as the busbar earthing. The means of earthing is by a purposely built earth switch. Mechanical interlocks ensure correct switching operation is provided. It is never possible to close the earth switch on the incomer panel, when the incoming 11KV cable is live.

The Schneider Electric HV panels are equipped with the SEPAM series Numeric Design relays in accordance with IEC 255. The protective ANSI Code protection function of these relays include50,51,50N,51N,50BF,46,27,27S,59,59N,47,81,67N,27D,

27R,37,32P,66,38/49T,48/51LR,32Q/40 while the measurement functions include 49RMS, KW, KVA, KVAR, KWH, KVAH, and KVARH.



Compartments: 01 Busbar 02 Busbar 03 CB Compartment 04 Feeder

Figure 5.9 Front View, Side View and a SLD for a Double Busbar Switchboard

Source: Ericsson P. & Fazlagic´ I; Masters thesis on OPS. Case study of Port of Gothenburg

5.3.4 HV Cabling System

The cabling systems transfer the 6.6kV power system network between the different system nodes and between the nodes and the final connection points at the berths. Figure 5.4 shows the Port Reticulation Network and the distances between the substations, acting as the reference points for cable length measurements.

The cable has to be able to carry the maximum rated current levels for the loads (read Vessels), accommodate a de-rating factor based on the operating conditions and be able to accommodate the maximum short circuit currents commensurate with the upstream transformer rating.

Appendix III shows a IEEE extract of the cable carrying capacities of copper and Aluminum cables. The specifications of the selected cable are as herein included-:

General Data

Type of cable:	CU/XLPE/GSWA/PVC
Standard specification applied to cable	IEC 60502-2
Nominal voltage	3.6 / 6 kV
No. of cores	3
Shape of conductor	Round Circular Compacted
No. of conductor strands	19
Diameter of strands (approx.) (Before Compaction)	2.54 mm
Cross-section area of conductor	95 mm²
Material of conductor	Copper

Electrical Data

Minimum bending radius of cable	840 mm
Maximum D.C. resistance of conductor/km at 20°C	0.193 Ώ/km
Maximum A.C. resistance of conductor/km at 90°C	0.242 Ώ/km
Max. continuous current rating at:	
1.2 °C m/w Soil thermal resistivity & 0.8 m depth	
in ground at 30°C	266 A
in air at 45°C (free air & shaded area)	259 A

Figure 5.10 shows the required cable lengths for one of the projects to be used as the reference project for the rest of the projects. Three cables run from the extended substation T to the container berths where they run along the berths to the three OPS connection points. The required substation civil works extension layout is also shown in Figure 5.11.

Drawing No.	Checked	Date:	Scale:	Sheet No.	Drawn:
Figure 5.10	P. Donner	OCT.2013	NTS	1 of 1	Denis M.

TITLE: OPS CABLE DISTANCES
FEEDER S TO CONTAINER TERMINAL CONNECTION POINTS

PROJECT: KENYA PORTS AUTHORITY
PROPOSED ONSHORE POWER SUPPLY

Total Distance From Man Hole 200 Up to Boland 138

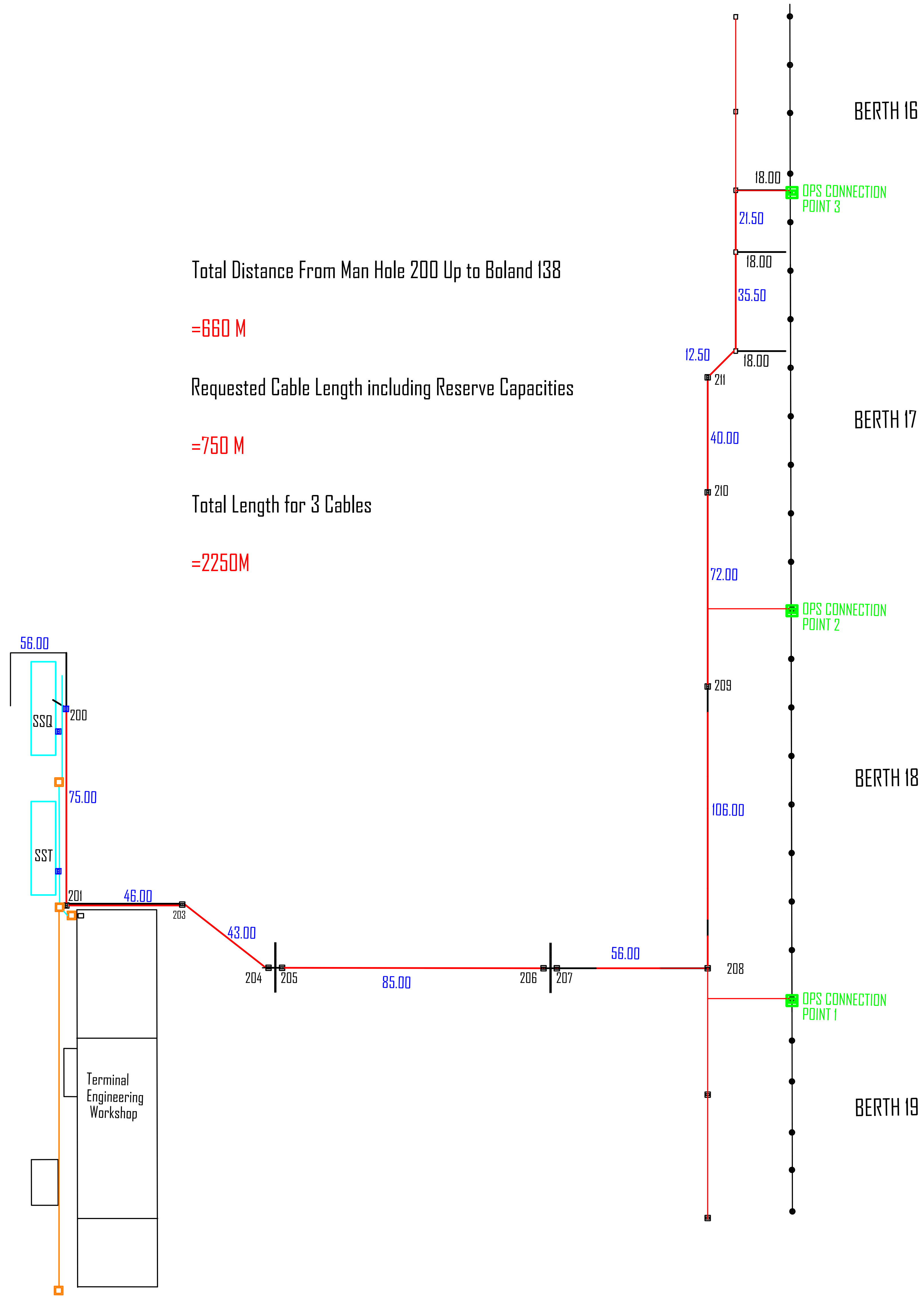
=660 M

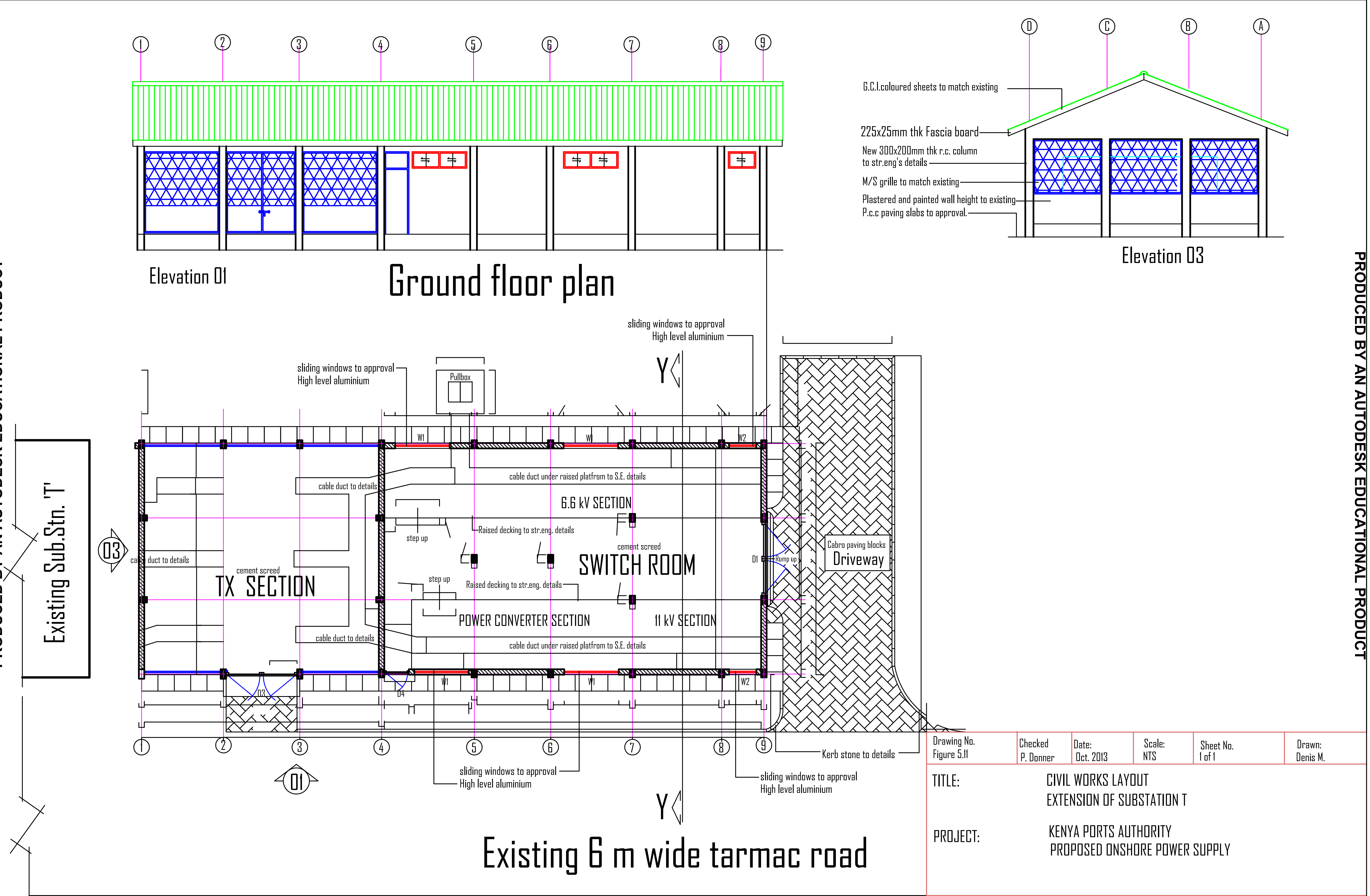
Requested Cable Length including Reserve Capacities

=750 M

Total Length for 3 Cables

=2250M





Drawing No. Figure 5.11	Checked P. Donner	Date: Oct. 2013	Scale: NTS	Sheet No. 1 of 1	Drawn: Denis M.

TITLE: CIVIL WORKS LAYOUT EXTENSION OF SUBSTATION T

PROJECT: KENYA PORTS AUTHORITY PROPOSED ONSHORE POWER SUPPLY

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6.0 TOTAL OPS PROJECT COSTING

The total OPS project costs, whose summary is given in Table 6.1 and breakdown given in the BOQ (Appendix II) is approximately USD.14.3 Million. The item costs given are the provisional budgetary costs provided by the respective product manufacturers while other costs are the current rates applied by the Port of Mombasa in recent similar projects. Appendix IV is a recent quotation of the proposed HV panels provided by the Schneider Electric global partner and official distributor in Eastern Africa; Power Technics Limited.

Prices given in Euro by the product companies have been converted into USD using the exchange rate of 1.35 for uniformity. This is because shipping is Dollar dominated and costs in USD will be easily appreciated by many players in the maritime industry.

The costs have been divided into three parts: 1) The transformer supply, installation and testing costs; 2) The switchgears supply installation and testing and finally; 3) Civil works dominated tasks including substation housing, cable laying and trenching works.

The costing has allowed for a 5% of the total project sum as contingency and includes a VAT charge of 16% which is the current tax applicable in Kenya.

Total OPS Project Costing

Table 6.1 Total OPS Installation Costs

OPS COST SUMMARY	CURRENCY-USD
COST FOR PART 1 : SUPPLY, INSTALLATION AND COMMISSIONING OF TRANSFORMER3	167,400.00
COST FOR PART 2 : SUPPLY, INSTALLATION AND COMMISSIONING OF 11KV,6.6KV AND FREQUENCY CONVERTER SWITCHGEAR	2,334,325.00
COST FOR PART 3 : SWITCHROOMS, CABLES,CABLE DUCTS AND ASSOCIATED ACCESSORIES	426,825.00
SUB TOTALS	2,928,550.00
5% CONTIGENCIES	146,427.50
TOTAL	3,074,977.50
ADD 16% VAT	491,996.40
TOTAL INCLUSIVE OF VAT	3,566,973.90
COST FOR FOUR SIMILAR OPS INSTALLATIONS	14,267,895.60

7.0 OPS OPPORTUNITY COSTS: COST OF FUEL AND EMISSIONS

7.1 Introduction

This section uses the AE Estimation flow diagram given in Figure 3.2 to come up with the total fuel consumed (FC) by the visiting vessels while staying in the port and, consequently, the cost of fuel consumed.

The procedure for calculating the KWH capacity used was by having the AE kW installed capacity of each vessel visit multiplied by the actual Service Time. Though the Actual Time of Completion (ATC) for every vessel is given in the vessel data analyzed, it was noted that vessels stayed quite long before departure from the berths after berth operation, a time within which the vessels could still make use of shore power for their hotelling services. This led to this report making use of the Actual Departure Time (ATD) and allowed a 30 minute period between the time a vessel is berthed and the time OPS is connected. A similar period is allowed for internal AE power reconnection and synchronization with the OPS before eventual disconnection of the OPS and vessel departure. The formula used for the total KWh calculation is given in Equation 7.1 while Figure 7.1 shows the Total GWh capacity used for every category of vessels.

$\text{Total KWH Utilised} = \sum_{k=1}^{n}(AST-1)^{k}AE^{k}$…………………………..Equation 7.1

Where -: $(AST - 1)^k$ is the Actual Service Time for the K_{th} Vessel Minus 1 hour
AE^k is the K_{th} Vessel AE size in kW

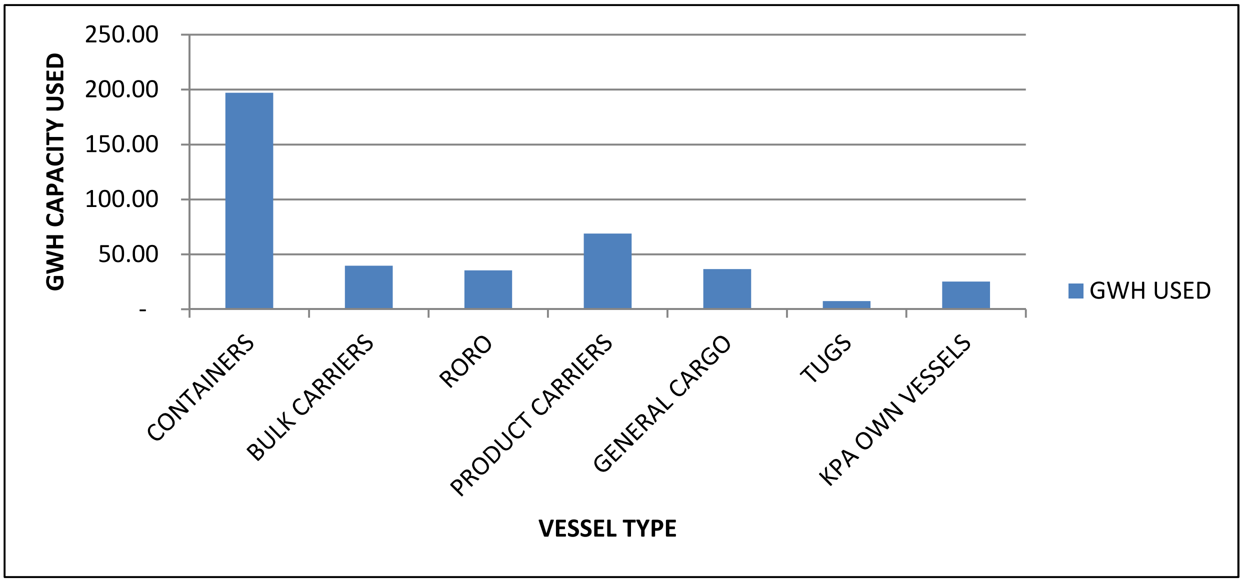

Figure 7.1 Graph Showing the Total GWh Capacity Used

7.2 Fuel Costs and Costs of Externalities

According to Starcrest Consulting Group (2007),Table E-1 of the Puget Sound Emissions Inventory study for Ocean going vessels, 2005 data, most vessels use HFO (2.5% S) fuel oil for their auxiliary engines while tugs use Off-road Diesel.

Table 7.1 lists the Greenhouse gas Emission Factors used for the medium speed auxiliary engines (AE) sourced from Entec 2002 report to the EU on Quantification of emissions from ships associated with ship movements between ports in the European Community while Table 7.2 lists the values of specific fuel consumption in g/kWh of auxiliary engines as used in the IMO GHG study 2009.

Table 7.1 Entec 2002 Emission Factors (g/kWh) for AE

ENGINE	CO_2	NOx	SO_2	PM
Medium Speed Diesel	722	14.7	12.3	1

Table 7.2 IMO GHG Study 2009 Specific Fuel Consumption (g/kWh)		
ENGINE AGE	**Above 800kW**	**Below 800Kw**
Medium Speed Diesel	220	230

These values are then used in calculating the total fuel consumed as tabulated in Table 7.3 and, consequently, the GHG gases produced as given in figure 7.4.

The equation for calculation of the fuel used is

$\text{Total Fuel used} = \sum_{k=1}^{n} (kWh)^k x\ LF^k\ x\ SFOC^k$ ……………………………*Equation 7.2*

Where-: $(kWh)^k$ is the cumulative kW-h for vessel type k

LF^k –Load factor for Vessel type k

$SFOC^k$ –Specific Fuel oil Capacity for the Fuel used by vessel type K

Similarly, the emission value, for each pollutant, is calculated from equation 7.3.

$\text{Emission Value} = \sum_{k,j=1}^{n} (FC)^k x\ EF^j\ /1{,}000{,}000$ ………………………..*Equation 7.3*

Where-: FC^k is the fuel consumed by vessel type k

EF^j is the emission factor for Pollutant j

Emission factors are given in g/kW-h and the figure is divided by 1 million to get the value of the pollutant in tonnes.

Table 7.3 Calculated Fuel Used (HFO &Off-road Diesel) using SOF, LF and kWh

VESSEL TYPE	ANNUAL KWH USED	ANNUAL GWH USED	FUEL TYPE	LOAD FACTORS	LOAD KWH USED	SOF g/kW-H	FUEL USED (Tonnes)
CONTAINERS	197,105,103.78	197.11	HFO(2.5% S)	22%	43,363,122.83	220.00	9,539.89
BULK CARRIERS	39,638,311.52	39.64	HFO(2.5% S)	10%	3,963,831.15	220.00	872.04
RORO	35,388,696.33	35.39	HFO(2.5% S)	26%	9,201,061.05	220.00	2,024.23
PRODUCT CARRIERS	68,958,132.07	68.96	HFO(2.5% S)	26%	17,929,114.34	220.00	3,944.41
GENERAL CARGO	36,652,407.77	36.65	HFO(2.5% S)	22%	8,063,529.71	220.00	1,773.98
TUGS	7,501,201.90	7.50	HFO(2.5% S)	22%	1,650,264.42	220.00	363.06
KPA OWN VESSELS	25,300,340.00	25.30	Offroad Diesel	22%	5,566,074.80	230.00	1,280.20
Total HFO(2.5% S) Fuel Used(Tonnes)		18,517.60					
Total Offroad Diesel Used(Tonnes)		1,280.20					

Table 7.4 Emission values (Tonnes) Analyzed Using Emission Factors and Utilized Power

VESSEL TYPE	CO_2	NOx	SO_2	PM
CONTAINERS	31,308.17	637.44	533.37	43.36
BULK CARRIERS	2,861.89	58.27	48.76	3.96
RO-RO	6,643.17	135.26	113.17	9.20
PRODUCT CARRIERS	12,944.82	263.56	220.53	17.93
GENERAL CARGO	5,821.87	118.53	99.18	8.06
TUGS	1,191.49	24.26	20.30	1.65
KPA OWN VESSELS	4,018.71	81.82	68.46	5.57
TOTAL	**64,790.11**	**1,319.13**	**1,103.77**	**89.74**

7.2.1 Total Cost of Fuel Consumed

The fuel figures in Table 7.3 have direct impact on the cost of fuel consumed. The cost of bunker fuel is highly fluctuating, which may affect the project appraisal results depending on the time the appraisal is made.

Figure 7.2 shows the fluctuating nature of 380Cst bunker fuel prices in the bunkering port of Singapore. This project used the current cost of fuel as of August 2013 of USD.601 per Tonne for HFO (2.5% S) and USD.890 for Off-road Diesel

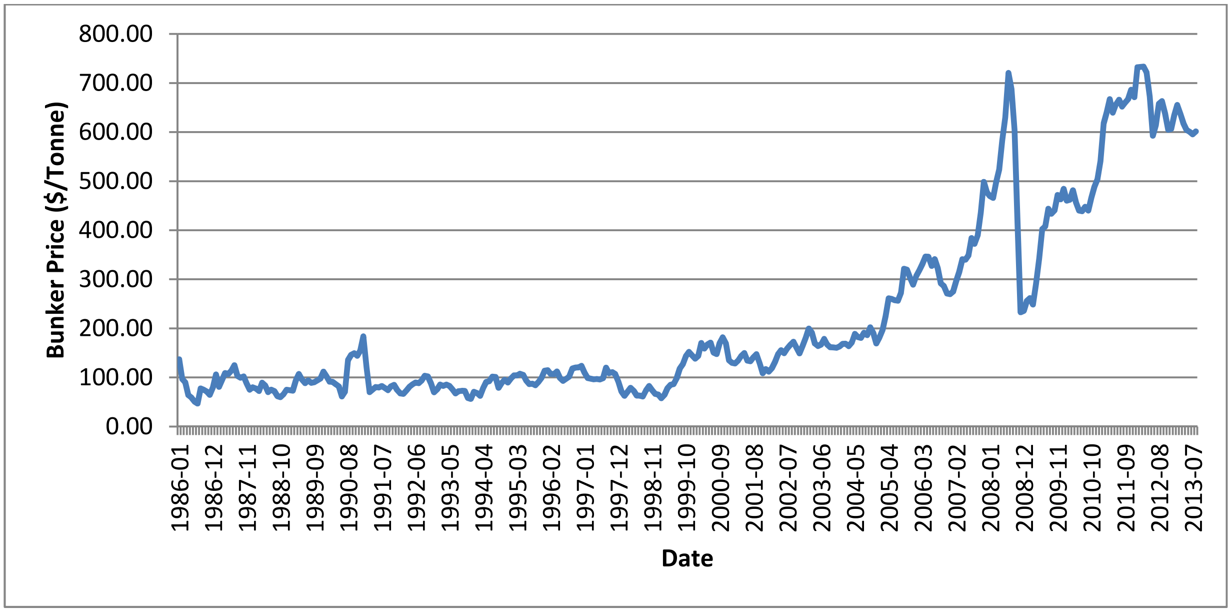

Figure 7.2 380 Cst Bunker Prices, Singapore ($/Tonne)

Source: Clarksons Shipping Intelligence

The cost of fuel is, therefore, given as the summation of the product of fuel volume consumed and the cost per unit volume for every fuel type. This is given in Table 7.5, which gives the summary cost of all fuel costs.

Table 7.5 Total Cost of Fuel Consumed

FUEL TYPE	AMOUNT CONSUMED (TONNES)	COST PER TONNE	TOTAL COST(USD)
HFO(2.5% S)	18,517.60	601	11,129,079.50
EPA	1,280.20	890	1,139,375.51
			12,268,455.02

7.2.2 Cost of Externalities

The cost of externalities was based on the European Union Emissions Trading System (EU ETS) Carbon Credits. EU ETS is one of the largest multi-country, multi-sector greenhouse gas emissions trading systems in the world. Presently, one tonne of Carbon emissions costs approximately 7.2 dollars within the EU ETS. This figure, though used in the calculations, is rather conservative given that the forecasted price, by the year 2020 is between 40 to 90€. The costing of the rest of the pollutants is in Carbon Credit equivalence per tonne. Table 7.6 shows these values together with the environmental costs of these pollutants as per ASEK[7] 4 Model on *Environmental costs for exhaust emissions from shipping 2010.*

Table 7.6 ASEK 4 Emission Environmental Costs and EU ETS Prices of Carbon Credits

Pollutant	Env.Costs-SEK/Kg	Carbon Credit Equivalence USD/Tonne(EU ETS)
PM	**3564**	**17107.20**
SO_2	**129**	**619.20**
No_x	**87**	**417.60**
CO_2	**1.5**	**7.20**

The ASEK4 environmental costs are quite attractive for a unit of a particular pollutant but these rates are reflective of the environmental harm the pollutant will have on the Swedish environment. These costs will vary from one country to another depending on the level of development and for this reason, though they are reflective of the actual cost of externalities, they may not be reflective of the environmental harm by the same pollutants in a developing nation and Mombasa in particular. The research, therefore, used the more conservative figures of the EU ETS Carbon Credit equivalence in its

[7] ASEK (Arbetsgruppen för Samhällsekonomiska Kalkylvärden) is a Swedish agency, a joint task force led by the Swedish Transport Administration dealing with the cost-benefit calculation and analysis in the transport sector.

costs analysis. The results of emissions externalities are documented in Table 7.7 for the full year of port vessel operations.

Table 7.7 Total cost of Externalities

Pollutant	Amount(Tonnes)	Cost per Tonne	Env. Cost(USD)
CO_2	64,790.11	7.20	466,488
NOx	1,319.13	417.60	550,870
SO_2	1,103.77	619.20	683,451
PM	89.74	17107.20	1,535,149
Total Environmental Costs(Year 2012)			**3,235,959.23**

7.3 OPS Power Bill for Similar Energy Consumption

OPS programs encourage the use of shore power rather than running onboard AE. This leaves the vessel operators with a power bill to pay rather than paying for bunkers. The power bill depends on the cost of shore electricity and the amount of power spent. This can be expressed as-:

The Cost of Electricity =Total kWh Consumed x Cost/kWh

Table 7.8 shows the current rates charged by the utility supplier in Kenya; Kenya Power Limited. Also included are the 8 month costs of a unit supply (kWh) for 2013 and the average of the 8 monthly charges.

The research uses this figure in computing the likely power bill had the vessels used shore power. It is important to note that apart from the unit charge cost for units spend, the utility supplier in Kenya imposes other charges to the power bill including Fuel Cost Charge (FCC), Foreign Exchange Rate Fluctuations Adjustment (FERFA) and Inflation Adjustment Levy (IA). Other charges include the Energy Regulatory Commission (ERC) Fee and Rural Electrification Program (REP) Levy. In addition, the above costs are subject to 16% VAT on the overall figure. Since some of these variables fluctuate with time, the monthly cost per unit consumption fluctuate too hence the difference in the eight monthly costs. These costs, however, consist of all charges and levies payable.

Table 7.8 Kenya Power Limited Company Energy Tariffs.

Kenya Power Limited Company Tariffs			
Tariff	Charges(KES)		
	Fixed Charge	Energy Charge/kWH	Dmd Charge /kVA
DC (Domestic, 240V)	120	First 50kWh 2.00	n/a
	120	50 to 1500kWh 8.10	n/a
	120	Thereafter 18.57	n/a
SC (Small Commercial, 415V)	120	8.96	n/a
CI1 (Commercial , 415V)	800	5.75	600
CI2 (Commercial , 11kV)	2500	4.73	400
CI3 (Commercial , 33kV)	2900	4.49	200
CI4 (Commercial , 66kV)	4200	4.25	170
CI5 (Commercial , 132kV)	**11000**	**4.10**	**170**
IT(Domestic Water Heating)	120	4.85	n/a
Period	Electricity Cost (KES/kWh)		
Jan-13	12.43		
Feb-13	12.32		
Mar-13	13.98		
Apr-13	13.70		
May-13	12.14		
Jun-13	11.86		
Jul-13	11.06		
Aug-13	12.37		
8 Month Cost Average	**12.48**		

Based on these figures, the total power bill, had the vessels used shore power, would have been as calculated in Table 7.9

Table 7.9 Cost of Power to Supply Vessels (VAT Inclusive)		
Total kWh	**Cost/kWh(KES)**	**Total Cost(USD)**
89,736,998.29	**12.48**	**13,178,142.13**

8.0 PROJECT APPRAISAL

Having determined the entire project's associated costs, determination of the viability of the project by the available appraisal techniques was the next step taken. The project appraisal was done using the three available methods; the Payback Period, Net Present Value (NPV) and the Internal Rate of Return (IRR).

All the costs were factored-in in all the appraisal methods. These costs include the cost of pollution, cost of alternative shore power bill, the OPS project costs and fuel costs. Table 8.1 gives a summary of the project costs and the figurative project cash inflow from the project undertaking. The power costs are subtracted from the sum of fuel costs and cost of externalities because it is the opportunity cost of the two.

Table 8.1 Summary of Project Costs

Project Costs Summary		
	OPS Costs	**Opportunity Costs**
Total OPS Installation Cost	14,267,895.60	
Fuel Costs		12,268,455.02
Cost of Externalities		3,235,959.23
Less Power Costs		- 13,178,142.13
Total	**14,267,895.60**	**2,326,272.12**

It can thus be concluded that investment in the project will have a net benefit of 2.33 Million USD taking into consideration the Social Cost of Carbon. This is taken as the project cash inflow per annum.

8.1 Payback period

This is one of the simplest investment appraisal techniques. The time period in which the initial cash outflow of an investment is expected to be recovered from the cash inflows generated by the investment is the Payback period.

The formula to calculate the payback period is:

$$Payback\ Period = \frac{Initial\ Investment}{Cash\ flow\ per\ period}\,(Years) \ldots\ldots\ldots \text{equation 8.1}$$

$$Payback\ Period = \frac{14{,}267{,}895.60}{2{,}326{,}272.12}\,(Years)$$

=6.13years ≈ 6years

Power transformers and cables have a life expectancy of well over 20 years if used within their rated capacity. This means a payback period of 6 years is good enough to undertake this project based on the Payback period appraisal method.

The main advantage of the payback method is that it is easy to calculate and understand. It also gives a rough indication of a project's risk and liquidity.

The method, however, has two main drawbacks; it does not take into account the time value of money and also ignores the cash-flows occurring after the payback period. For this reason, to avoid these two main flaws of the Payback period, the NPV method is also used to appraise the project.

8.2 Net Present Value (NPV).

The NPV uses discounted rather than raw cashflows. The formula for calculating NPV is given by:

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+k)^t} - CF_0 \ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 8.2}$$

Where -:

CF_t is the sum of all cash flows

K is the cashflow discounting factor

CF_0 is the initial capital outlay

This project assumes a discounting factor equivalent to the Kenyan inflation rate of 7% as per the Kenya National Bureau of Statistics. A conservative project period of 15 years has been assumed.

Based on these figures, the NPV is calculated as follows-:

$NPV = \sum_{t=0}^{n} \frac{(2.326)}{(1+7\%)^{15}} - 14.27$………Equation 8.3

$=2.326(\frac{1}{(1.07)} + \frac{1}{(1.07)^2} + \frac{1}{(1.07)^3} \ldots \ldots \frac{1}{(1.07)^{15}}) - 14.27$

=2.326(9.11) – 14.24

=21.19– 14.24

=6.95M USD

The annuity value (9.11) was obtained from annuity tables also available online.

The rationale of the NPV method is the net gain in wealth over the period of project execution/implementation. Using this method, a project is accepted if the NPV> 0 (Positive). Projects with negative NPV values are rejected.

From the calculation, it is clear that the project, with a positive NPV Value, is acceptable.

8.3 Internal Rate of Return (IRR)

IRR is the presentation of a project's success in terms of a percentage (IRR). IRR is the discount rate that forces the Present Value of the Cashflows to be equal to the cost of the project. This is the same as forcing the NPV to be zero.

Numerically,

$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+k)^t} - CF_0 = 0$…………………………...Equation 8.4

This can be rewritten as -: $\boldsymbol{CF_0 = \sum_{t=0}^{n} \frac{CF_t}{(1+k)^t}}$………………………Equation 8.5

$$14.27 = 2.326\left(\frac{1}{(1+k)} + \frac{\mathbf{1}}{(\mathbf{1}+\boldsymbol{k})^{\mathbf{2}}} + \frac{\mathbf{1}}{(\mathbf{1}+\boldsymbol{k})^{\mathbf{3}}} \ldots \ldots \frac{\mathbf{1}}{(\mathbf{1}+\boldsymbol{k})^{\mathbf{15}}}\right)$$

$$\frac{14.27}{2.326} = \left(\frac{1}{(1+k)} + \frac{1}{(1+k)^2} + \frac{1}{(1+k)^3} \ldots \ldots \frac{1}{(1+k)^{15}}\right)$$

$$6.13 = \left(\frac{1}{(1+k)} + \frac{\mathbf{1}}{(\mathbf{1}+\boldsymbol{k})^{\mathbf{2}}} + \frac{\mathbf{1}}{(\mathbf{1}+\boldsymbol{k})^{\mathbf{3}}} \ldots \ldots \frac{\mathbf{1}}{(\mathbf{1}+\boldsymbol{k})^{\mathbf{15}}}\right)$$

k=14%

From the Annuity table, annuity value 6.13 for 15 years corresponds to the rate per period of 14%. This implies-:

k=IRR=14%

This project has a IRR of 14% over a period of 15 years.

8.4 Project Appraisal Results

The Payback period method resulted in a free of initial cost operation after 6 years duration. This means that after this period, the returns from this undertaking will be net of cost except the few running costs associated with similar projects.

The results of the NPV method gave a positive wealth gain implying the project was viable for implementation.

The IRR method gave a 14% internal rate of return. Currently, a 12-year fixed coupon Infrastructure Bond issued by the Central Bank of Kenya attracts a coupon rate of 11%, 3% lower than the IRR calculated from this project. It can thus be concluded that the rate of returns is attractive enough and that, using the IRR appraisal method, the project is viable.

All three appraisal methods gave same results and agree in principle: The project is viable to undertake.

9.0 CONCLUSION AND RECOMMENDATIONS

Having done a quantitative analysis of power demand levels of the different vessels, established the fuel costs, ecological costs and the probable OPS power bill and, thereafter, carried out a project appraisal on OPS as an alternative energy source for vessels while at berth, as envisaged in the thesis objectives, the following conclusion and recommendations are made-:

9.1 Conclusion

The maritime sector has seen a proliferation of regulations, all aimed at protecting the environment. So great has been the increase in new regulation that the Secretary General of the International Chamber of Shipping (ICS) launched a scathing criticism of the process of bringing in new regulations. “There must be no more stringent environmental regulations brought in for shipping without a proper cost benefit analysis and study of the available technology”(Brown, 2013). This was in connection with the requirements for low-sulphur bunker fuel to enter into force in 2015 and the ballast water treatment equipment.

The momentum towards sustainable shipping should be a concerted effort between all players in the industry. Ports, as key interface players in the supply chain management, have a duty to fully participate in this worthy cause. In a bid to foster green operations, the World Ports Climate Initiative (WPCI) established a formal working group, in spring 2009, whose overall goal was to stimulate as many ports, terminal operators and shipping lines worldwide as possible to implement the technology of OPS, where practical and useful. The group's main objective was and still remains, to reduce local air pollutants, greenhouse gas emissions and noise by advancing OPS.

A website with a wealth of information on OPS for seagoing vessels and measures to ensure sustainable green port operations, targeted to ports, terminal operators and shipping companies was created by WPCI and made accessible through the link http://www.ops.wpci.nl/.

There has been a flurry of legal and institutional frameworks that either promotes OPS directly or indirectly. EU directive 2005/33/EC, which sets a sulphur content threshold of 0.1% in all marine fuels to be used while a vessel is staying at berth for more than 2 hours, in European ports, indirectly promotes OPS as a means to evade the high costs associated with running engines with low sulphur fuels.

Legal frameworks directly supporting OPS implementation include EU recommendation 2006/339/EC, which promotes OPS and EU recommendation 2003/96/EC, which advances subsidization of OPS for ships by waiving of electricity taxes.

On the international scene, IMO, through its circular MEPC.1/Circ.794 of October 2012 recognizes the impetus surrounding OPS and recommends industry guidance through the classification societies such as American Bureau of Shipping (ABS), Bureau Veritas (BV) and ClassNK.

July 2012 saw a landmark in seamless OPS implementation with the publishing of international standards in OPS; ISO/IEC/IEEE 80005-1:2012 (*Utility connections in port – Part 1: High Voltage Shore Connection (HVSC) Systems*) which addresses the connection between ship and shore for safety of operation.

Many surveys have been carried out in connection with OPS with different results for different ports. Many of these were carried out during the pre-standards era with different system configurations and cost considerations. The authenticity of these results should again be tested with due consideration to the standards and the environmental effects of exhaust emissions. It should also be understood that each study is unique to the concerned port as the environmental effects of emissions, even for two adjacent ports, are different and pegged on the surrounding infrastructure and habitation patterns.

This research investigated 1913 vessel visits, from very diverse vessel types and sizes, to the port of Mombasa in the year 2012 and upon due consideration of environmental impacts, came out with a positive outcome from the project appraisal results; There is a net gain to be accrued by implementing an OPS in the Port of Mombasa. This gain will not only be enjoyed by the Port Authority, but by the larger port community in general.

The domain to institute policy changes to accommodate OPS falls outside the scope of this dissertation. Most states exempt export products and sales from VAT. Nations, like Finland, exempt power supplied to vessels from VAT. This research explored the effect of exempting OPS from VAT and found a payback period of 3 years with an IRR of 30.5%, which is makes the project very attractive to all parties. Vessels will have a net savings on their power bills compared to bunker cost of 1.2M USD with the port benefiting in high investment returns.

OPS implementation not only has positive environmental impacts, it also has direct benefits to the host nation; It is a source of foreign exchange since shipping is dollar denominated, creates employment in the country’s power plants and earns the country other taxes related to power charges.

This study sets a good base for the analysis of actual impacts of emissions on port contiguous zones. Data gathered in this project can form a good database for exploration of other port related studies as a sample of operation properties of ports in developing nations. The research did not, however, consider the cost of reconfigurations that need to be carried out within vessels, which is a huge cost to the ship owners. The actual environmental impact of emissions was also not comprehensively analyzed. This leaves room for further research, taking into account the overall costs involved to the shipping sector.

Finally, with the current tidal waves of environmental regulations, OPS may come in handy in helping the shipping fraternity to keep their heads above the waters of regulation compliance.

9. 2 Recommendations

This research recommends the following to the Kenya Ports Authority management-:

Having analyzed the vessel power characteristics and cost of implementing an OPS and after carrying out an appraisal of the project, which was found to be a viable undertaking, KPA should consider offering this important service to the visiting vessels.

The OPS project need not be implemented in one go due to the financial implications involved. Phasing in the project in four parts may make the implementation process less taxing to the port authority in fiscal terms

The Port Electrical Department, through the Head of Port Electrical Engineering, should advocate and push for increase in their budgetary provisions so as to accommodate a phased in implementation of OPS. There are currently trenches running along the berths where PVG rails for the power supply to the conventional slewing gantry cranes used to be. These are found in the Bulk Carrier berths, near the SOT and the berths near the KPA Headquarters from Berth 11 to Berth 14. These trenches can be easily converted to house OPS cables by installing PVC ducts and covering them permanently with concrete to achieve a secure working environment. By doing so, a large proportion of the OPS trenching costs could be saved.

A very large amount of power, roughly 7GWh, was consumed by visiting tugs, KPA tugs and other small vessels, especially patrol crafts. Most of these vessels take long times at the berth side and can be good users of OPS. More than 90% of the average loads of these vessels' AE rating are less than 500kW and with an applicable loading factor of 22%, it is very easy to connect these vessels to OPS, even on LV systems, with relatively small sizes of cables from a distribution board located near the shore. These vessels should serve as the starting point in the OPS implementation.

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APPENDICES

PROJECT: TENDER NO. KPA/169/2010-11/EE SITE MEETING NO. 3.		DATE: 25th SEPTEMBER 2012 TIME: 10.00 am LOCATION: KPA HEADQUARTERS	
PRESENT:			
NAME	**ORGANISATION**	**TEL: No.**	**e-mail**
Joseph Birir	Kenya Ports Authority	0733839684	jkbirir@kpa.co.ke
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KENYA PORTS AUTHORITY
UP-GRADING OF INCOMING POWER SUPPLY FROM 11KV TO 132KV

GENERAL

0.1	Employer	:	**Kenya Ports Authority**
0.2	Main Contractor:	:	**Consolidated Power Projects (Pty) Ltd. (CONCO)**
0.3	Joint Venture Partner:	:	**Powergen Technologies Ltd**
0.4	Commencement date of Contract:	:	**14th August 2012**
0.5	Duration of Contract:	:	**18th Months**
0.6	Completion date of Contract:	:	**14th February 2014**
0.7	Contract Sum:	:	**US$ 6,422,477.88**

KENYA PORTS AUTHORITY
UP-GRADING OF INCOMING POWER SUPPLY FROM 11KV TO 132KV

MINUTE	ITEM	ACTION	REMARKS
3.01	**Legal issues**		
3.01.01	**Performance Bond** OK.		Valid until 1st November 2013.
3.01.02	**Insurance of works** To be activated by Contractor to run to end of contract	CONCO	Arrangement in progress.
3.01.03	**Third Party Liability** To be activated as (c) above	CONCO	Arrangement in progress.
3.02.01	**Site Inspection** Site visit preceded the meeting. i. Cable route is still being considered. A shorter route which is possible to use on the cliff is ideal. ii. KPA reported a new lane is being considered along the boundary with Kipevu (10 m. width). It might be possible to lay the 132 kV line in the island between the two carriageways. iii. It was proposed that micro-tunnelling be used in road and rail crossing, to avoid traffic disruption.		KPA (Civil)/CONCO CONCO
3.02.02	**Detailed Work plan** Schedule of works tabled by Main Contractor at meeting. Comments to be given after scrutiny.	CONCO	Done
3.02.03	Contractor has raised a Proforma Invoice, in the name of CONCO Kenya Ltd. The legal implications of this need to be sorted out before it can be processed. Invoice to be addressed to M&E.	CONCO	Issue still unresolved.

KENYA PORTS AUTHORITY
UP-GRADING OF INCOMING POWER SUPPLY FROM 11KV TO 132KV

MIN.	ITEM	ACTION	REMARKS
3.02.05	**Site Inspection:** a. Site visit made to establish area to be used, impact on road to Verification Station, and Verification Yard. The existing services information requested. KPA to provide. b. Visit also made to KPLC Substation at Kipevu to establish take-off point and 132 kV cable route to Substation M. c. Future inspections will be made on the day of site meeting from 10 am. Meeting to start after the site inspection.		
3.02.06	**Clearance of site** It was noted that containers were again placed in the area to be used for the substation. KPA advised that the sooner fencing of the site was done the sooner the containers would be cleared.	CONCO	
3.02.07	**Proposed hours of work** 8 hours daily (8am to 5pm). Additional hours may be agreed upon as and when necessary.	For info	
3.02.8	**Design approvals** Initial drawings to be sent by e-mail to Consultant, with copies to the Client and JV Partner. Final Approved drawings will be issued in hard copies. Number of copies to be issued will be advised later	CONCO	
3.02.9	**Spares required;** Contractor stated the recommended spares are needed, and offered but any spares considered unnecessary for the project would be omitted.	CONCO	
3.02.11	**Use of existing substation M:** The design and arrangement of the substation M to accommodate some of the switchgear is still being worked on for efficient use of space.	M&E CONCO	

KENYA PORTS AUTHORITY
UP-GRADING OF INCOMING POWER SUPPLY FROM 11KV TO 132KV

MIN.	ITEM	ACTION	REMARKS
3.02.13	**Safety Issues:** CONCO tabled a document outlining safety procedures for approval. It was handed over to the KPA Safety Officer.	KPA	
3.02.14	**External Approvals:** Contractor to liaise with the Consultants to acquire necessary approvals from external authorities including NEMA and the local councils.	CONCO	
3.02.15	**Training of Engineers** KPA approvals still outstanding, so arrangements for training will be made after August.	KPA	Pending.
3.02.16	**New Items**		
2.16.1	***Site Office:***		
	i. CONCO indicated site office construction will start mid-November.	CONCO	Location identified during site inspection.
	ii. Topo survey has been carried out.		
	iii. Geotechnical survey awaited.	CONCO	KPA drawing given to CONCO.
2.16.2	***Environmental Impact Assessment:*** Arrangements are being made to carry out the environmental assessment report.	M&E	
2.16.4	***Existing road to Clinic*** Contractor working out necessary alignment of the site fence.	CONCO.	

KENYA PORTS AUTHORITY
UP-GRADING OF INCOMING POWER SUPPLY FROM 11KV TO 132KV

MIN.	ITEM	ACTION	REMARKS
2.17	**Date of next meeting:** Next Site meeting will be held on Tuesday 16th October 2012 at 10 am at the same venue.		

Signed:

Kenya Ports Authority — M&E Consulting Engineers

Date …………………… — Date …………………….

BILLS OF QUANTITIES AND SPECIFICATION FOR SUB -STATION EXTENSION TO ACCOMODATE 3NO. ADDITIONAL OPS TERMINATION POINTS

ELECTRICAL BILLS OF QUANTITIES & SPECIFICATIONS FOR PORT ONSHORE POWER SUPPLY

ITEM	DESCRIPTION	UNIT	QTY	RATE (USD)	AMOUNT (USD)
1	**SUPPLY, INSTALLATION AND COMMISSIONING OF TRANSFORMERS**				
1.1	**SUPPLY OF 1600 KVA FREE BREATHING INTEGRALLY OIL FILLED TRANSFORMER FOR KPA OPS SYSTEM SPECIFICATIONS**	Nos	3	48,600.00	145,800.00
	General				
	The transformer shall be oil immersed core type and shall be				
	manufactured and tested as per IEC 76				
	It shall be provided with a conservator, an isolating valve and a dehydrating breather.				
	the oil conservator should have a Oil Level Indicator				
	The HV cable box shall be suitable for terminating three core cables upto 300 mm2 XLPE cable. The MV cable box shall be suitable for terminating up to 7No. single core PVC cables of 600 mm2 on a stud of 12 mm diameter				
	. Rating - 1600 KVA				
	. Phases - Three Phase (Double Wound)				
	. Frequency - 50Hz(1), 60Hz(2)				
	. Location - Indoor				
	. Type of cooling - ONAN				
	. Vector Group - Dyn11				
	. H.V. winding voltage - 11,000 volts				
	. L.V. winding Voltage - 6600 volts				
	. Power Frequency - 28KV(1MIN)				
	. Basic Impulse Level - 75KV				
	.Rated Voltage - 12KV				
	No Load Losses : 2300W (approx)				
	Full Load Losses : 20000W (approx)				
	.Impedance - 6% Approx.				
	. Tap changer				
	- Type: off-load				
	- 5 position tap changer				
	- Tappings: ± 2.5% ± 5.0%				
	. Padlocking Facility - Available				
	. Temperature Rise Class - winding 65°K				
	. HV Termination				
	Porcelain Bushing of Transformer Top Cover LHS				
	Cable Cover Box on Top Of Transformer Cover				
	. MV Termination				
	Flat Bar of Transformer Top Cover RHS				
	Cable Cover Box on Top Of Transformer Cover				
	Acoustic power LwA : 76 Db(A)				
	Acoustic pressure LPA at 1,00 m : 68 Db(A)				
	Flat bi-directional rollers : 4				
	Lifting lugs : 2				
	Earthing connections (M12) : 1				
	Haulage holes on base : 4				
	Draining device : 1				
	Rating plate fixed on HV side (Aluminium) : 1				
	Environment: Indoor / Outdoor				
	Each transformer shall be provided with a metal name plate giving the required particulars. In addition, the name plate shall include load and no load losses for the mediumest, lowest and nominal tap changer positions, temperature class of insulation, connection diagram and the inscription 'PROPERTY OF KENYA PORTS AUTHORITY'				
	Transformer Protection				
	The transformer protection shall include winding temperature alarm and trip as well as oil level alarm and trip.and bucholz alarm and trip				

BILLS OF QUANTITIES AND SPECIFICATION FOR SUB -STATION EXTENSION TO ACCOMODATE 3NO. ADDITIONAL OPS TERMINATION POINTS

ITEM	DESCRIPTION	UNIT	QTY	RATE (USD)	AMOUNT (USD)
	The breathing type transformers shall be fitted with a glass breather containing silica gel. The silica gel shall be changed before turning from blue to pink to protect the transformer core against the ingress of moisture				
1.2	**Transformer Installation**	**AU**	**3**	**3,600.00**	**10,800.00**
	Moving transformer from delivery point to substation premises				
	positioning transformer in the allocated area in the transformer room in the substation				
	Termination of cables on the HT and MV Side of the transformer				
	Carrying out protection cabling to the transformers instruments and relays including the Buchholz relay and the temparature gauge				
	Terminating the transformer cable on both the HT and MV switchgear panels				
1.3	**Cold commissioning comprising of:-**	**AU**	**3**	**1,800.00**	**5,400.00**
	Checking of ratios and vector group				
	Insulation resistance check				
	Reprogramming of Sepam relays in related 11kV Switchgears to accommodate the new transformer				
	Buchholz Protection Relay tripping system				
	Setting the thermometer with two electrical contacts to initiate breaker trip on fault conditions				
1.4	**Hot Commissioning comprising of:-**	**AU**	**3**	**1,800.00**	**5,400.00**
	Energisation of transformer				
	Checking of output Voltages and Phase Sequence				
	COST FOR PART 1 : SUPPLY, INSTALLATION AND COMMISSIONING OF TRANSFORMERS		**USD**		**167,400.00**

ITEM	DESCRIPTION	UNIT	QTY	RATE (USD)	AMOUNT (USD)
2	**PART 2 SUPPLY, INSTALLATION AND COMMISSIONING OF 11KV,6.6KV AND 50/60 HZ MV SWITCHGEAR PANELS**				
	General Description				
	This section covers the installation of medium voltage switchgear with vacuum or SF6 gas-filled breakers and switches including installation of medium voltage XLPE cables, protection relays and metering units				
	Adherence to specifications is mandatory. Deviations SHALL lead to disqualifications and rejection of the tender offered.				
	Only Schneider Electric,ABB OR equivalent switchgear is preferred for compatibility and integration with the existing installation.				
	Medium Voltage Switchboard Panel:				
	The switchgear shall be extensible metal clad to British Standards and IEC 62271 and IEC 694. The panels shall have separate compartments for the bus bars, cable box, fixed isolator contacts, currents and or voltage transformers and the instrument panels (low voltage section). The complete switchboard shall be of flush-front design.				
	The low voltage section shall be completely separate from the medium voltage section and have terminal box that has space for relays, instruments and termination.				
	The switchgear shall be designed for free standing erection.				
	The top of the cubicle shall be provided with separate overpressure vent, directed upwards and not sideways.				
	Doors shall be provided at the front of respective circuit breaker/switch compartment and cable connection. The cubicle door shall be provided with a window through which the position of the circuit breaker/switch can be checked.				
	The switchgear equipment shall be constructed so that it corresponds to IP43 for enclosures according to IEC 62271 and the degree of protection in accordance with IEC 529.				
	Anti-condensation heaters shall be provided inside each cubicle. They shall be located so as not to cause injury to personnel or damage to equipment. The heaters shall be controlled from a two position control switch with positions "ON – OFF" in each cubicle. The heaters shall operate from a single a.c. supply.				
	The panels should have restricted dimensions suitable for installation in limited spaces. In particular and without compromising the insulation level, bus - bar current rating and short circuit current performances the width of the panels should not exceed 600mm.				
	The switchgear shall be built up of individual metal clad cubicles or modules with earthed metal partitions. The circuit breakers shall be mounted on an in built carriage and preferably be of the horizontal isolation and horizontal draw-out type.				
	Bus bars, connections and their support shall be rated 1250Amps continuously under ambient conditions and capable of carrying the short-time current associated with the short circuit ratings of the circuit breakers, for 3 Seconds.				
	Auxiliary 24V DC 48V DC, 110V AC and 240V AC supplies for Circuit Breaker control, Alarm circuits, Protection relays, Metering and Motor supply for each Panel, shall be controlled by suitably rated Miniature Circuit Breakers.				

ITEM	DESCRIPTION	UNIT	QTY	RATE (USD)	AMOUNT (USD)
	The cubicle shall be tropical vermin proof. The plates shall be of mild steel thoroughly cleaned by shot blasting or other approved methods. They shall then be given a primary coat and two coats of contrasting colour of durable and weather resisting paint. The final coat shall be gloss and of Admiralty Grey (Shade 632) as specified in BS 381C.				
	Standards and switchgear Design Specifications				
	IEC 60694 Common specifications for high-voltage switchgear and control gear standards				
	IEC 60298-200 AC metal-enclosed switchgear				
	IEC 62271-100 -High-voltage alternating-current circuit-breakers				
	IEC 62271-102 -AC disconnections and earthing switches				
	IEC 60044-1 -Current transformers				
	IEC 60044-8 -Low power current transformers				
	IEC 60255 -Protection Relays				
	IEC 60044-2 -Voltage transformers				
	IEC 60801 -Control-Monitoring				
	IEC 61958 -Voltage presence indicating systems				
	IEC 60529 -Degrees of protection provided by enclosures (IP code)				
	Circuit Breakers and Switches:				
	Circuit breakers shall be three poles operated, indoor type, with Sulphur Hex fluoride (SF6),or vacuum, insulation and interrupter and shall comply with the requirements of IEC56. The Switchgear shall be withdraw-able type. The withdraw-able Circuit breakers shall be of the horizontal type and the withdraw-able position clearly visible. Vertical withdraw-able type shall not be accepted. The circuit breakers shall be of the mechanical and electrical trip-free type. Built-in interlocks shall be incorporated to prevent any mishandling and provision for key locking and padlocking shall be made.				
	Technical Specifications and Ratings for Circuit Breakers				
	Circuit Breaker Current rating - 200A – 800A				
	Number of poles - 3				
	Rated voltage - 12kV				
	Frequency - 50Hz				
	Rated Short Time Current - 25kA				
	Duration of Short Circuit - 3s				
	First Pole to clear Factor - 1.5				
	Operating sequence - 0-0.35-Co-3min-Co				
	Impulse withstand voltage - 95kV				
	One minute power frequency				
	Withstand voltage - 28kV				
	Rated Short Time Making				
	Current (peak) - 63kA				
	Auxiliary d.c. voltage for closing				
	and tripping coils - 24 or 48V				
	Auxiliary a.c. voltage - 110 or 250V, 50Hz single Phase				
	Current Transformers:				
	The current transformers shall be in accordance with the requirements of IEC 60044-1 and shall have the specified accuracy under load conditions and shall be able to withstand the effect of short circuit fault current rating of the switchgear for three seconds.				
	Technical specifications of current transformers:				
	Short Time Current (STC) - 25kA for 3s				
	Maximum Continuous Thermal Rating - 600A				
	Impulse withstand voltage - 95kV				
	One Minute Power Frequency				
	withstand voltage - 28kV				
	CT Burden - 30VA				

ITEM	DESCRIPTION	UNIT	QTY	RATE (USD)	AMOUNT (USD)
	Voltage Transformers:				
	Voltage transformers shall be suitable for operation of the protective gear, metering and tap-changing sensing and shall be in accordance with the requirement of IEC 60044 – 2.				
	The voltage transformers shall be three phase, five limb, star/star connected and complete with fuses and links.				
	Voltage Transformers: On or in the Transformer Incomers.				
	Ratio : 11000/√3 :110/√3V				
	VA : 200 VA				
	Class : 0.5				
	Impulse withstand voltage: 95 kV				
	One minute power frequency withstand voltage: 28 kV				
	Relays:				
	The protective relays shall include a test device, which enables the tripping, measuring and signal circuits of the protective relays to be connected to separate testing equipment.				
	The relays shall be of SEPAM series Numeric Design OR equivalent, and shall be in accordance with IEC 255.				
	The relays shall have the following functions				
	50,51,50N,51N,50BF,46,27,27S,59,59N,47,81,67N,27D,27R,37,32P,66,38/ 49T,48/51LR,32Q/40,				
	49RMS, KW, KVA, KVAR, KWH, KVAH, and KVARH (see attached drawing CEME-E001/1):				
	Relay contacts shall be suitable for making and breaking the maximum currents, which they are required to control in normal service.				
	The LV compartment Terminal Block shall include a test switch (block), which enables the CTs circuits to be Isolated from the Relay and shorted, to facilitate relay testing in situ and to allow Isolation of VT circuits , Alarm and Trip Circuits				
	The relay Thermal rating should be such that the fault clearance times on any combination of current and time multiplier settings shall not exceed the thermal withstand capability of the relay. (Max. fault current = 31.5kA)				
	The relays must conform to IEC 60255 and be EMC 89/336/EEC compliant				
	Instruments:				
	All indicating instruments shall be flush mounted and shall be in accordance to the requirement of IEC 51.				
	Each cubicle shall have the following indications:				
	One indicating lamp complete with push button switch to provide trip circuit healthy indication which must function for both circuit breaker open and close positions with inscription ―TRIP CIRCUIT HEALTHY in black letters on white background.				
	One mechanical ON/OFF indicator, with inscription "ON" white letters on red background and inscription "OFF" white letters on green background. This should be an integral part of the circuit breaker				
	One mechanical indication of the state of the spring inscription - SPRINGS CHARGED (white letters on red background); SPRINGS FREE, (white letters on green background).This should be an integral part of the Circuit Breaker.				
	One indicator lamp to show the breaker in closed position - RED colour				

ITEM	DESCRIPTION	UNIT	QTY	RATE (USD)	AMOUNT (USD)
	Medium Voltage Earthing				
	Switchgear may include cubicle type metal clad circuit breakers. For earthing purposes the metallic body of the equipment must be earthed. This should be done by running an earthing lead to 2 meter copper earth rods driven into the ground at spots diametrically opposite the side of low voltage earthing. The cross section of the earthing lead should be of the same size as the current carrying conductors. The spots where the earthing rods are placed should be clearly marked. The medium voltage earthing resistance should not exceed 10 ohms.				
	For 11kV distribution transformers ,the vector group is Dyn 11. This means that the medium voltage windings are delta connected while the low voltage windings are y or star connected. The neutral point „n" is brought out and is earthed.				
	Power Cable Termination:				
	The cable box shall be suitable for up to 12 No. 150mm² single core (4 per phase) XLPE insulated cables.				
	The cable box shall be suitable for heat shrinkable termination.				
	Three core single gland fabricated sheet steel cable boxes complete with gland and armour clamp suitable for receiving three core 11kV cables up to 400 mm2 11kV XLPE cable. (For feeder type panels).				
	The cable box design shall be suitable to facilitate easy modification in future, to receive three single core (1 per phase) 11kV cables of size up to 400 mm².				
2.1	**11KV SWITCHGEAR SUPPLY**	**Nos**	**4**	**41,310.00**	**165,240.00**
	Supply only of 11Kv, **4 panel** extensible SF6 insulated indoor/outdoor metal clad switchgear as shown on attached Drawing complete with the following:				
	· 11kV 1250A 3 pole copper bus bars				
	· 630A TP motorised draw-out type circuit breakers.				
	· Sepam Protection relays Series 40				
2.2	**11 KV BUSBAR VOLTAGE SUPPLY**	**Nos**	**1**	**20,655.00**	**20,655.00**
	Supply only of 11 Kv, 1 **panel** extensible indoor/outdoor metal clad switchgear as shown on attached Drawing complete with The Voltage transformer and protective fuses asper the given specifications				
2.3	**INSTALLATION SITE WORKS**				
	Assembly and cold commissioning comprising of:-	**AU**	**1**	**4,050.00**	**4,050.00**
	Assembly of switchgear in Substation T and electrically linking it with the existing 11kV panel including busbar, supply and control cables				
	Checking of torques on coupling links				
	Mechanical and Electrical operational checks.				
	Programming of the Sepam Relay				
2.4	**Hot Commissioning comprising of:-**	**AU**	**1**	**2,025.00**	**2,025.00**
	Energisation of switchboard				
	Checking and confirmation of phase sequence				
	carrying out all tests on the Relay, Voltage and Current transformers				
2.5	**6.6 KV SWITCHGEAR SUPPLY**	**Nos**	**5**	**41,310.00**	**206,550.00**
	Supply only of 6.6 Kv, 5 **panel extensible** SF6 insulated indoor/outdoor metal clad switchgear as shown on attached Drawing complete with the following:				
	· 6.6 kV 1250A 3 pole copper bus bars				
	· 630A TP motorised draw-out type circuit breakers.				
	· Sepam Protection relays Series 40				

ITEM	DESCRIPTION	UNIT	QTY	RATE (USD)	AMOUNT (USD)
2.6	**6.6 KV BUSBAR VOLTAGE SUPPLY**	Nos	1	20,655.00	20,655.00
	Supply only of 6.6 Kv, 1 **panel** extensible indoor/outdoor metal clad switchgear as shown on attached Drawing complete with The Voltage transformer and protective fuses asper the given specifications				
2.7	**INSTALLATION SITE WORKS**				
	Assembly and cold commissioning comprising of:-	AU	1	4,050.00	4,050.00
	Assembly of the switchgear including the 6.6kV Panels,the busbar voltage and the busraiser in Substation T and electrically linking them with the existing 6.6kV panels including busbars, supply and control cables as per diagram				
	Checking of torques on coupling links				
	Mechanical and Electrical operational checks.				
	Programming of the respective Sepam Relay to correspond with crane settings				
2.8	**Hot Commissioning comprising of:-**	AU	1	2,025.00	2,025.00
	Energisation of the complete 6.6kV switchboard				
	Checking and confirmation of phase sequence in all panels				
	Carrying out all tests on the Relays, Voltage and Current transformers				
2.9	**6.6 KV DOUBLE BUSBAR SWITCHGEAR SUPPLY**	Nos	7	57,800.00	404,600.00
	Supply only of 6.6 Kv, 7 **panel extensible** SF6 insulated indoor/outdoor metal clad switchgear as shown on attached Drawing complete with the following:				
	· 6.6 kV 1250A double busbar 3 pole copper bus bars				
	· 630A TP motorised draw-out type circuit breakers.				
	· Sepam Protection relays Series 40				
2.1	**6.6 KV BUSBAR VOLTAGE SUPPLY**	Nos	1	28,900.00	28,900.00
	Supply only of 6.6 Kv,double busbar, 1 **panel** extensible indoor/outdoor metal clad switchgear as shown on attached Drawing complete with The Voltage transformer and protective fuses asper the given specifications				
2.11	**INSTALLATION SITE WORKS**	AU	1	4,500.00	4,500.00
	Assembly and cold commissioning comprising of:-				
	Assembly of the switchgear including the 6.6kV Panels,the busbar voltage and the busraiser in Substation T and electrically linking them with the existing 6.6kV panels including busbars, supply and control cables as per diagram				
	Checking of torques on coupling links				
	Mechanical and Electrical operational checks.				
	Programming of the respective Sepam Relay to correspond with crane settings				
2.12	**Hot Commissioning comprising of:-**	AU	1	2,500.00	2,500.00
	Energisation of the complete 6.6kV double busbar switchboard				
	Checking and confirmation of phase sequence in all panels				
	Carrying out all tests on the Relays, Voltage and Current transformers				
	HIGH VOLTAGE FREQUENCY CONVERTERS				
2.13	**SUPPLY OF 1250 KVA FORCED VENTILATION 50/60 HZ FREQUENCY CONVERTER SPECIFICATIONS**	Nos	3	487,500.00	1,462,500.00
	General				
	Supply of 1000kW, 50/60Hz ABB frequency converters with 11kV input and output Voltage level rating .The Converter shall be made using the latest high performance Insulated Gate Bipolar Transistor (IGBT) power switching devices controlled by a micro controller.				
	The converter should be capablle of remote operation with				

ITEM	DESCRIPTION	UNIT	QTY	RATE (USD)	AMOUNT (USD)
	Ethernet, Modbus-TCP, dry contacts control protocols. The user interface should include a graphic display touch panel module and an advanced redundancy feature should form one of the panel features.				
	Electrical characteristics				
	Input				
	Typical grid voltage 11kV				
	Frequency 50 / 60 Hz				
	Input section IGBT voltage source converter				
	Converter voltage 200 -480 VAC				
	Total harmonics distorsion < 3 %				
	Output				
	Typical ship voltage 480 V / 11 kV				
	Frequency 60 / 50 Hz				
	Output section IGBT voltage source converter				
	Converter voltage 400 .. 480 VAC				
	Total harmonics distorsion < 3 %				
	Efficiency 95% typical				
	Max overload capacity 30 seconds 150%				
	Short circuit limit 0.5 seconds 200%				
	Mechanical				
	Enclosure IP 20 or IP 23				
	Cooling Forced ventilation				
	Standard color RAL 7035				
	Applicable Standards				
	ISO/IEC/IEEE FDIS 80005-1, IEC 61400-21, IEC 60146-2, IEC 61800-3,				
	IEC 60721, IEC 61071-1, IEC 60871, IEC 60439, IEC 62271-1, IEC				
	60071, IEC 60664, IEC 60204, IEC 60529, IEEE519, IEC/TR 61000-3-6				
	Designed to CE mark requirement				
2.14	**Assembly and cold commissioning comprising of:-**	**AU**	**1**	**3,375.00**	**3,375.00**
	Termination of the frequency converter to the6.6KV breakers				
	Checking of torques on coupling links				
	Mechanical and Electrical operational checks.				
	Programming of the respective Relays to correspond with the rectifier load demands				
2.15	**Hot Commissioning comprising of:-**	**AU**	**1**	**2,700.00**	**2,700.00**
	Energisation of the frequency converter bank				
	Checking and confirmation of auto operation of the bank as per load demand				
	COST FOR PART 2 : SUPPLY, INSTALLATION AND COMMISSIONING OF 11KV,6.6KV AND FREQUENCY CONVERTER SWITCHGEAR		**USD**		**2,334,325.00**

BILLS OF QUANTITIES AND SPECIFICATION FOR SUB -STATION EXTENSION TO ACCOMODATE 3NO. ADDITIONAL OPS TERMINATION POINTS

ITEM	DESCRIPTION	UNIT	QTY	RATE (USD)	AMOUNT (USD)
3	PART 3. SWITCHROOMS, CABLES,CABLE DUCTS AND ASSOCIATED ACCESSORIES				
3.1	SWITCH ROOM	Lot	1	94,500.00	94,500.00
	Civil works including provison of construction materials,all construction works,provision of indoor ducts ,earthing and provision of lightining arrestors on the substation roof.This includes all grill doors, airtight doors for switchgear rooms and windows as per Figure 5.11				
3.2	Cable Cost	lm	2250	53.00	119,250.00
	Supply of 95 mm² CU-XLPE-SWA-PVC, 6.6kV ,3 core copper cable.The Cable should have a Max. continuous current rating of 259A at1.2 °C m/w Soil thermal resistivity & at 0.8 m depth in ground at 30°C				
3.3	CABLE DUCTING	lm	2250	38.00	85,500.00
	Construction of 4 no 150mm duct from substation Q to the berth termination points including excavate bituminous layer to the required depths and carting away unwanted materials from port premises. The ducts should be PVC class E pipes 150mm Dia including connection fittings				
3.3	CABLE DRAWING	AU	3	9,450.00	28,350.00
	Draw the 95 mm² CU-XLPE-SWA-PVC, 6.6kV ,3 core copper cables for OPS from substation to shore connection points and connect to the Shore connection points.				
3.6	SERVICE MANHOLES	EA	24	4,800.00	115,200.00
	Cable service pit/manholes construction complete with a spring assist high density steel cover				
3.7	SHORE CONNECTION BOXES				
	Supply of three connection boxes for shore-Vessel Interface	EA	3	34,425.00	103,275.00
	COST FOR PART 3: CABLE DUCT AND ASSOCIATED ACCESSORIES		USD		426,825.00
	SUMMARY				
	COST FOR PART 1 : SUPPLY, INSTALLATION AND COMMISSIONING OF TRANSFORMER3		USD		167,400.00
	COST FOR PART 2 : SUPPLY, INSTALLATION AND COMMISSIONING OF 11KV,6.6KV AND FREQUENCY CONVERTER SWITCHGEAR		USD		2,334,325.00
	COST FOR PART 3 : SWITCHROOMS, CABLES,CABLE DUCTS AND ASSOCIATED ACCESSORIES		USD		426,825.00
	SUB TOTALS		USD		2,928,550.00
	5% CONTIGENCIES		USD		146,427.50
	TOTAL		USD		3,074,977.50
	ADD 16% VAT		USD		491,996.40
	TOTAL INCLUSIVE OF VAT		USD		3,566,973.90
	COST FOR FOUR SIMILAR INSTALLATIONS		USD		14,267,895.60

APPENDIX III

IEEE EXTRACT OF CABLE CARRYING CAPACITIES

COPPER		
MULTICORE ARMOURED CABLES WITH THERMOSETTING INSULATIONS		
Conductor Crossectional Area	1 two core cables single phase ac.dc	1 three or four core cable three phase ac
mm2	A	A
1.5	27	23
2.5	36	31
4	49	42
6	62	53
10	85	73
16	110	94
25	146	124
35	180	154
50	219	187
70	279	238
95	338	289
120	392	335
150	451	386
185	515	441
240	607	520
300	698	599
400	787	673

Aluminium		
MULTICORE ARMOURED CABLES WITH THERMOSETTING INSULATIONS		
Conductor Crossectional Area	1 two core cables single phase ac.dc	1 three or four core cable three phase ac
mm2	A	A
16	82	71
25	108	92
35	132	113
50	159	137
70	201	174
95	242	214
120		249
150		284
185		328
240		386
300		441

APPENDIX IV

Our Ref.: HV12K8.065 OPS

5th September, 2012

Kenya Port Authority,
P. o. Box95009-80104,
Mombasa.

<u>For The Attention Of MR. DENIS MULWA</u>

<u>REF: BUDGETARY QUOTATION FOR SUPPLY OF 11KV AND 6.6 KV SM6 SWITCHGEAR</u>

We thank you for your enquiry for the above and are pleased to quote budgetary prices as follows:-

<u>ITEM 1: - 11KV SM6 SWITCHGEAR.</u>

One 3 panel, indoor type 11kV SM6 metalclad switchboard comprising of: -

3 x 630A 11kV Transformer Feeder Panels

<u>Budgetary Price:</u> - Euro 107,000.00 plus 16% VAT Ex-Works, Nairobi

<u>ITEM 2: - 6.6 KV SM6 SWITCHGEAR.</u>

One 4 panel, indoor type 6.6kV SM6 metalclad switchboard comprising of: -

1 x 630A 6.6kV Incomer Panel with VTs
1 x 630A 6.6kV Bus-Coupler Panel (without protection)
1 x 630A 6.6kV Riser Panel
1 x 630A 6.6kV Feeder Panel

<u>Budgetary Price:</u> - Euro 133,000.00 plus 16% VAT Ex-Works, Nairobi

We trust you will find our quotation in line with your requirements and should you require any further information, please do not hesitate to contact the undersigned.

Yours faithfully,
POWER TECHNICS LIMITED

Mayur Shah
CONTRACTS MANAGER
<u>LV/HV SWITCHGEAR.</u>

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