Implementing modern maintenance management at KivuWatt-Rwanda: Part-1

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The KivuWatt Power Plant, an integrated offshore-onshore facility at lake Kivu, that generates electricity into the Rwandan national grid utilising the lean-burn internal combustion processes in the Wärtsilä 20V34SG gas engines is probably one of its kind in design and technological innovation on planet earth. Its uniqueness therefore ultimately requires sophisticated but technologically simplified modern maintenance management tools to ensure an optimum upkeep of assets' healthcare. This paper introduces the salient aspects of the maintenance management approach implemented at site bringing out the perceived and observed benefits. The approach reported in the paper is expected to have broad applications in the growing field of energy production management in which sustainability is an essential requirement for success of a business venture.

Keywords: KivuWatt, Wärtsilä, technological innovation, assets' healthcare, maintenance management, power generation, sustainability, lean-burn IC process

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1. INTRODUCTION

1.1. General

Modern scientific technology and tools combined with research result in advancement in Plant Engineering, a field which is key to sustainable development. Plant Engineers and managers typically need modern scientific technology and tools to run their plants smarter, safer, faster, and better for the sustenance of both social and economic benefits.

1.2. Background

The existence of Lake Kivu, dangers posed by huge amount of biogas reserves trapped and highly pressurized in the resource zone, 260 to around 480 meters below water surface under a layer of heavy water containing minerals washed out of the nearby volcanos made it known as the "killer lake" (Wärtsilä, 2016). According to research records prior to the innovation and inception of KivuWatt project, it has been scientifically proved and reported that when the gas concentration gets too high, or the lake is hit by one of the regular earthquakes in the region, the gas can be released, posing a threat to lives of the people living in the vicinity.

By tapping these gas resources, ContourGlobal is making Lake Kivu a safer place, while at the same time utilizing the trapped methane gas for much needed electric power generation (ContourGlobal, 2017).

In addition to gas extraction and power generation business activities, to show corporate social responsibility (CSR) as part of the global corporate citizenry, Contour-Global-KivuWatt is also engaging with the local communities, training and developing local workers and funding charitable projects such as providing libraries and computers at Kibuye schools in the district of Karongi.

The 2009 twenty-five (25) year Power Purchase Agreement (PPA) and Concession agreement (CA) signing between ContourGlobal and Rwandan government for a 100MW power generation project gave way for construction of the KivuWatt biogas power plant under the build-own-operate-transfer (BOOT) model. The innovative ground-breaking technology project development took seven years, from concept in 2008 to completion of first phase, a 25 MW project portion, in November 2015. First phase plant entered commercial operation on 31 December 2015 to sell the power to the National Utility and commenced fullscale operation after official launch thenceforth in January 2016.

Successful completion of the first phase gave second phase of the project which will produce 75 MW and transfer to the national grid.

2. AIMS AND OBJECTIVES

The project aimed at providing an engineering solution for maximization of application of modern technology in managing operations and maintenance of systems and processes ensuring their reliability without compromising the per design required output and service delivery in a sustainable as well as economically benefiting manner.

The objectives of the project have been as follows:

- Work together with ContourGlobal-KivuWatt Engineering Management team to investigate the business as usual regime in Operations and Maintenance Management of the systems at the Power Plant and identify gaps for improvement
- Conduct a Requirement Survey and analyse work process flow (WPF) in order that problems associated with the systems are investigated
- Perform master data coding for key enterprise process assets
- Perform data collection, compilation and quality manage primary asset data listing
- Analyse existing checklists and schedules for preventive maintenance (PM) as well as reorganise collected and compiled data in readiness for deployment into a central database
- Perform program Installation, test and commission the integration process
- Perform Implementation Training
- Evaluate the results of the project (challenges and benefit)
- Identify appropriate and applicable measures and standards for mitigation of potential adverse effects and then promote responsible and professional practice for economic benefit but in respect of life, law and public good.

3. FACILITY DESCRIPTION

A representative block diagram of the integrated Offshore Barge-Link-Onshore Plant facilities listing different sections of the constituent facilities has is shown in Figure 1 and subsequently briefly explained in sections 3.1 through to 3.8.

3.1. The offshore gas extraction facility (GEF)

The Gas Extraction Facility (GEF), a special 3000-tonne barge, located 13km from the shore and tethered to the bottom of the lake, extracts gas by bringing gas-laden waters (water is drawn from 350 metres below the surface) from 35 bars to 2 bars of pressure via a gas separator where gas bubbles are extracted from the water. Raw gas is then washed in four wash towers, ultimately producing clean methane gas. The raw gas composition is about 70% carbon dioxide (CO_2) and 30% methane (CH_4). The GEF is designed to remove the CO_2 and provide 9,500 m3/hr of dry gas with 90% CH_4. To the knowledge of the author, KivuWatt GEF is the only one of its kind in the world.

3.2. The link and the moorings

The methane extracted gas is transported to the power plant through a HDPE pipelines, technically called Export Lines which link the GEF (offshore) and the PP (onshore) gas reservoir from which the power generating engines are fed. Export lines run for 13 km, are balanced and supported from the lake base as well as with moorings on sides for the length between the two integrated facilities.

3.3. The onshore power plant (PP)

The PP constitutes Electricity generating engine hall and the aggregate of Wärtsilä intelligent power engines, ancillary equipment, and the human-machine-interface (HMI) control system. At the power plant (PP), combustion engines generate electricity to be supplied to the Rwanda energy grid.

3.4. Marine landing site (MLS)

By operational activities carried out at the MLS, it briefly could be described as a constructed site for the landing, holding of utility boats, boat fuel filling as well as refueling and storage of boat accessories, and marine rescue and life-saving equipment.

3.5. The boats and the utility vehicles

The on-water and on-land transport modalities are considered as key peripheral assets for mobility of the personnel and goods within, around and between the integrated facilities that form KivuWatt Power plant and systems.

3.6. Administrative block

The mezzanine block adjacent to the Power Engines Hall is for KivuWatt management staff and power plant operations staff which includes offices, executive boardroom, server-room, plant control room, kitchen, changerooms and ablution rooms below which lies the main store on the ground floor.

3.7. Conference centre and canteen block

This is a stand-alone block comprising conference hall, training centre/open plan offices for Maintenance planning engineers, technicians, Safety, Health, Environmental, Risk & Quality (SHERQ) staff, operations staff, canteen and ablution rooms and the canteen.

3.8. Perimeter fence and security gate-office

This include outbound facility safety and security physical structure for security personnel.

The primary focus of this modern Asset Management project has been to provide an efficient, on demand and

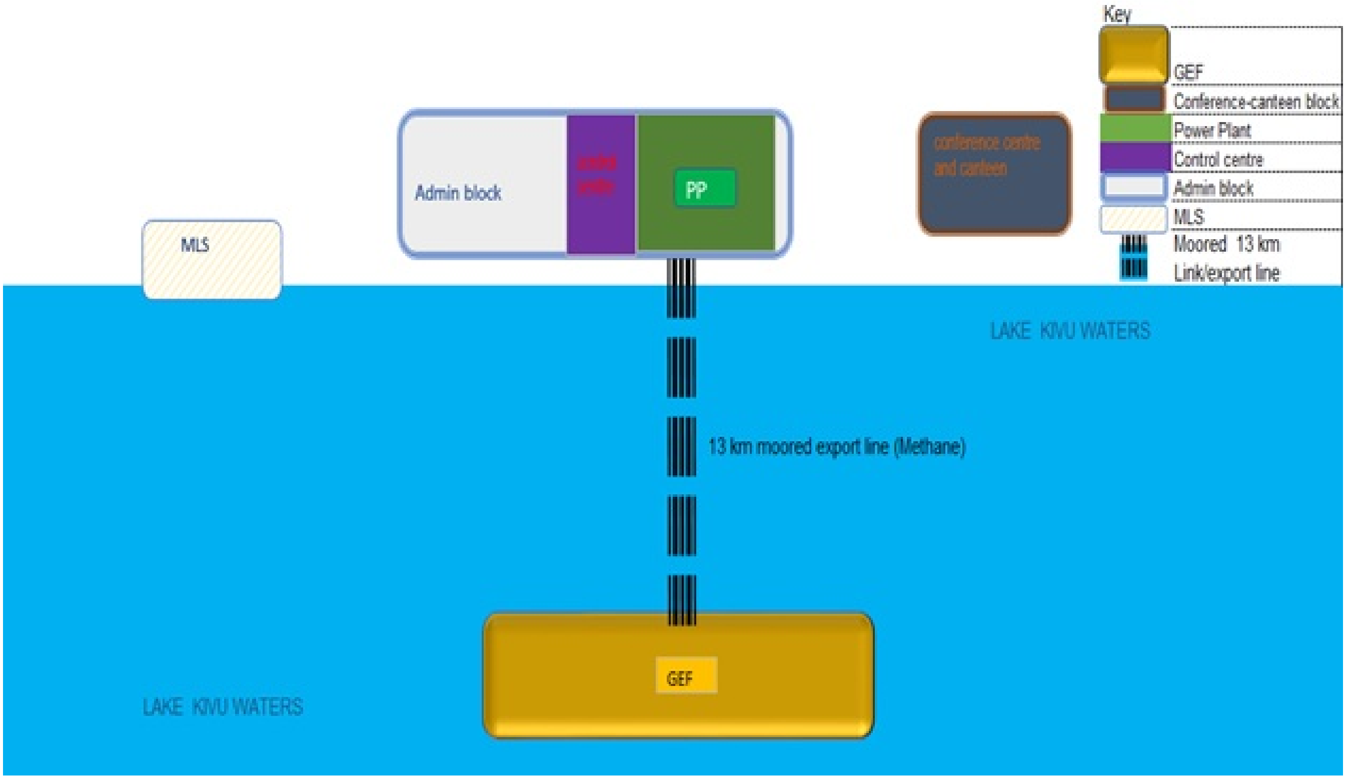

FIGURE 1. Block layout diagram of KivuWatt Electricity Power Plant

systematic solution to problems in systems' operation and maintenance management activities at the newly inaugurated (in 2016) ground-breaking innovation of KivuWatt bio-gas power plant to meet demand for asset reliability, economic and sustainability issues that affect the livelihood and development of the African continent, more specifically applicable to Rwanda.

4. REVIEW OF RELEVANT LITERATURE

Relevant literature searched in respect of implementation of this project focused on areas of sustainability in Rwanda, Methane gas power plants and Methane gas/fuel flow, Wärtsilä technology, engineering management solutions, Operations and Maintenance (O&M) management, and systems integration as follows.

4.1. Sustainability

United Nations Industrial Development (UNIDO) on Inclusive Sustainable Industrial Development (ISID) in its 2014 ISID brochure no. 12-03.0 (UNIDO-ISID, 2014, pp. 6-12), states that,

> *Any progress on poverty eradication will be short-lived if we do not succeed in achieving the necessary economic growth within an environmentally sustainable framework. Also states that, successfully implementing ISID in our current era of globalization requires new approaches that harness globally available knowledge, technology and innovation. Knowledge exchange and technology transfer will therefore significantly contribute to realizing ISID.*

According to Environmental Sustainability in Rwanda's Economic Development and Poverty Eradication Strategies (EDPRS): Towards Mainstreaming Environment, it is stated that,

> *Poverty in Rwanda is intimately related to a series of interlocking issues, in particular land, demography, environmental degradation, as well as low and limited sources for growth. It is evidently clear that for progress in poverty reduction to be made, the issues of land, demography and environmental degradation must be immediately dealt with failing which, deteriorating environmental situation and tardy and prone to disruptions inclusive sustainable industrial development will be prevalent...*

To further understand sustainability from a perspective of micro-macro-economics, an approach model has been devised which shows the link between the determinant factors against the impacts and the outcome indicators shown in the Figure 2, a PESTLE based sustainability indicators approach (PESTLE, 2015).

4.2. Methane gas power plants

The common sources of methane gas are from landfills and bio-digester tanks for which the extraction

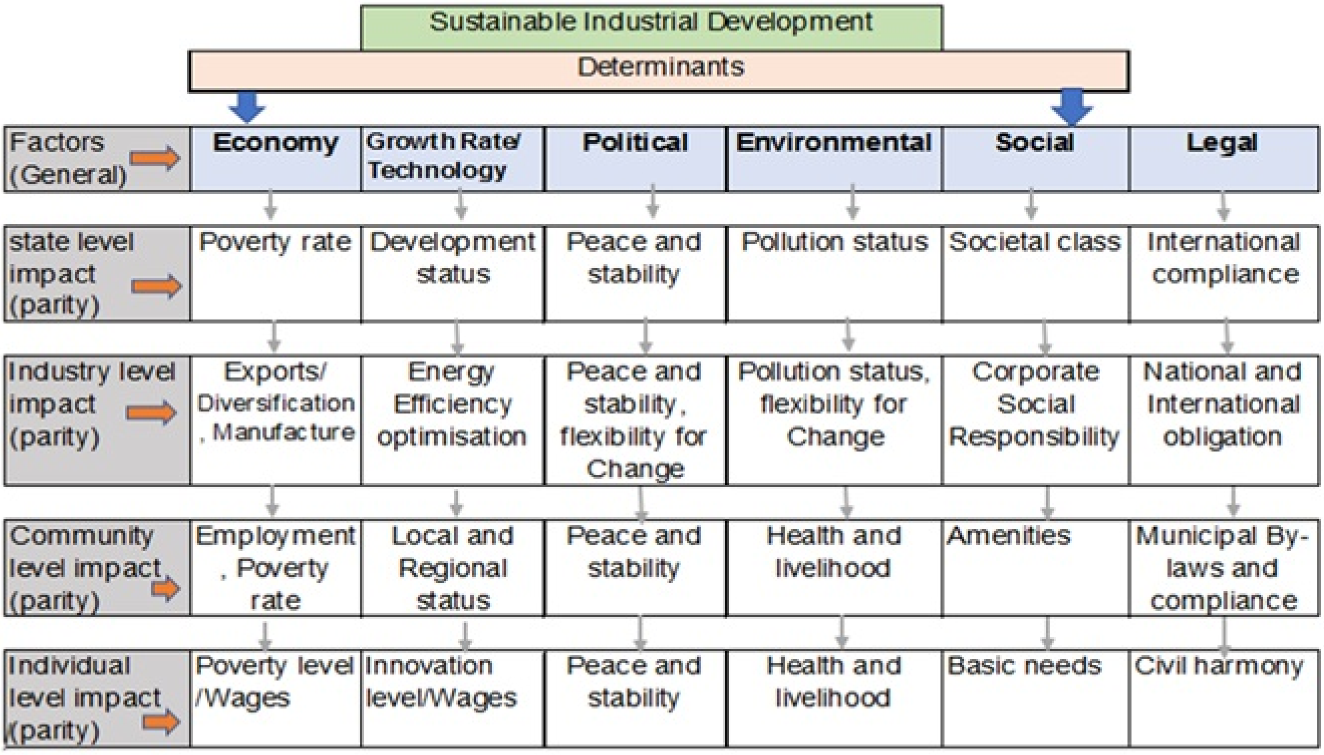

FIGURE 2. Relationship of indicators for assessment of industrial sustainability

technology and design is not complex. In contrast, the gas extraction technology and design which was introduced by the innovative KivuWatt barge Gas Extraction Facility (GEF) was a product of deep engineering research and innovation which took seven years to be concluded.

The methane powered power plants (heavy duty 20-cylinder by Wärtsilä coded 20V34SG engine) are the type installed at KivuWatt power generation facility. Wärtsilä's quality and environmental management systems fulfil and are certified according to ISO 9001 and ISO 14000.

4.3. Wärtsilä Technology

According to Wärtsilä OEM technical guide (Wärtsilä Corporation, 2015), Wärtsilä started the development of lean-burn, spark-ignited Otto gas engines in 1992. The first WÄRTSILÄ 34SG engine was released in 1995 and now the product range of lean-burn gas engines has been expanded by introducing the new Wärtsilä 34SG.

These engines take the power output of the Wärtsilä 34SG series up to 9 MW. The Wärtsilä 34SG is a four-stroke, spark-ignited gas engine that works according to the Otto process and the lean-burn principle. The engine has ported gas admission and a pre-chamber with a spark plug for ignition. The engine runs at 720 or 750 rpm for 60 or 50 Hz applications and produces 8700kW and 9000 kW of mechanical power, respectively. The efficiency of the Wärtsilä 34SG is the highest of any spark-ignited gas engines today. The natural gas fuelled, lean-burn, medium-speed engine is a reliable, high-efficiency and low-pollution power source for baseload, intermediate peaking and cogeneration plants.

A typical composition of Methane in natural gas is presented in Table 1 (Demirbas, 2010).

The stoichiometric combustion of methane is typically

$$CH4 + 2O2 + 2(3.76)N2 \rightarrow CO2 + 2H2O + 7.52N2$$

With lean-burn, i.e. oxidisation with excess air of around 5%, the lean combustion becomes

$$CH4 + 2.1O2 + 7.9N2 \rightarrow CO2 + 2H2O + 7.9N2 + 0.1O2$$

The excess air in the combustion products denotes complete combustion. This is the basis for considering the Wärtsilä 34SG series biogas lean-burn power engines as exceptionally designed for sustainability of the environment as there is almost insignificant or trace emission factor from the combustion process, making this technology fall within the band of green renewable energies.

4.4. Methane flow in pipes & reactivity properties

The KivuWatt methane flow includes in the risers to the barge that run 0.3 km deep as well as linear to the power plant, 13 km away. Piping in use is high density polyethylene (HDPE) material which according

Component	Typical % Volume Analysis	% Volume Range
Methane	94.9	87.0 to 96.0
Ethane	2.5	1.8 to 5.1
Propane	0.2	0.1 to 1.5
Isobutane	0.03	0.01 to 0.3
η-Butane	0.03	0.01 to 0.3
Isopentane	0.01	Trace to 0.14
η-Pentane	0.01	Trace to 0.14
Hexane	0.01	Trace to 0.06
Nitrogen	1.6	1.3 to 5.6
Carbon dioxide	0.7	0.1 to 1.0
Oxygen	0.02	0.01 to 0.1
Hydrogen	Trace	Trace to 0.02

TABLE 1. Natural Gas composition – courtesy of (Demirbas, 2010)

to Plastic Piping Institute (Plastic Piping Institute, 2012), has properties of: long-term service life, highly-resistant to corrosion, abrasion and chemicals, strong, durable, flexible, ductile and lightweight, longer-length pipe capability with leak-proof joints, lower labour requirements for installations and Significant overall cost savings.

4.5. Engineering Management solutions

Migration from the prior management system of Excel only processing of maintenance activities (because of the time consuming and intensity of workload that it posed), to a database programmed modern technology maintenance management system (MTMMS) was the best option to simplifying maintenance management activities.

4.6. Description of O&M Management

According to DOE-US (Sullivan et al., 2013), best practice in industry, Operations and Maintenance (O&M) management integration program is a critical component of the overall industrial processes. The management function should bind the distinct parts of the program into a cohesive entity. Based on experience, the overall program should contain five very distinct functions making up the organization: Operations, Maintenance, Engineering, Training, and Administration—OMETA. Beyond establishing and facilitating the OMETA links, O&M managers have the responsibility of interfacing with other departmental managers and making their case for ever-shrinking budgets. Their roles also include project implementation functions as well as the need to maintain persistence of the program and its goals.

4.7. Systems Integration

Just as Integration is, in calculus, used in the calculation of complex areas and volumes of irregular shapes and solids, so is the solution to complexity in engineering systems management if the systems are linked or networked to have any entered data be centrally configured but updated from any of the link points normally referred to as workstations.

According to 4C Systems and EMaintE Consulting (EMaintE Consulting, 2012), systems integration is done based on a variety of platforms including local area network (LAN), wide area network (WAN) and a hosted service termed software as a service (SaaS). Different platforms are suited for different data analytics.

5. PROJECT FEASIBILITY CONSIDERATIONS

The project feasibility was assessed based on compliance with ethical issues and professional code of conduct followed by project feasibility analysis based on TELOS Model (Hall, 2011).

5.1. Ethical and Professional Code of Conduct

The project feasibility study checked potential for compliance with the codes of conduct of two relevant societies in the U.K. Society of Operations Engineers-IPlantE (Society of Operations Engineers, 2016), states that,

> *All members of the Society of Operations Engineers shall, by their conduct, uphold the reputation of the profession in applying the specialist discipline of operations engineering in the specification, evaluation, acquisition, commissioning, operation, management, inspection, testing, maintenance, repair, refurbishment, development and disposal of vehicles and fixed, mobile and removable machinery, plant, equipment and systems and all activities related or incidental to any of them.*

Engineering Council and Royal Academy of Engineering Statement of Ethical Principles, (Engineering Council UK, 2018) states that,

> *Engineers invent the future and their work affects the lives of millions of people, for better or worse. That raises enormous ethical issues in every branch of engineering, from computing through biotechnology and energy to civil and aeronautical.*

The academy also lists the statement's underpinning principles as: (i) Honesty and integrity (ii) Respect for life, law, the environment and public good (iii) Accuracy and rigour (iv) Leadership and communication.

Affiliated to both these cited organisations, the consultant ensured compliance with the obligation that at all times professional practice can be followed, adhering to their codes of conduct. Implementation of modern maintenance management at the KivuWatt plant was assessed as feasible to be executed in conformance with the requirements as agreed in the due diligence documents which were generated based on prescripts of Ethics and Professional Code of Conduct.

5.2. Project Feasibility Approach

Hall (Hall, 2011) first wrote the acronym "TELOS" in respect of cost-benefit-analysis by considering attainability, coordination, effective operability and organisation of a proposed system to produce profitable economic benefits. The TELOS Model was utilised in analysis of the feasibility of this project. The structure of the model is as per Figure 3.

FIGURE 3. TELOS Feasibility model (Hall, 2011)

The TELOS Feasibility model was applied to the KivuWatt Modernised Maintenance Management project as explained in Table 2.

The evaluation of the effectiveness of the existing O&M management paradigm for the operability of the plant, including considering the aspects of risk, safety and life cycle was approached using asset reliability and management standard.

Modern Facilities Management requires that owners and managers of Assets understand the applications of the concepts of total life cycle cost (TLCC) of assets and optimisation of the assets and facilities so that their assets are always economically profitable, sustainable, compliant with legislation and environmentally friendly.

ISO 55000:2014 explains the approach by a model framework that links and integrates operational excellence in Asset Management. This fits well with the Facilities Management standard, ISO 41011:2017 stipulating that Facilities Management is an Organisational function which integrates people, places and processes within the built environment with the purpose of improving the quality of life of people and the productivity of the core business.

The ISO 55000 model framework as depicted in Figure 4 was followed during feasibility assessment.

TELOS Parameter	How it was applied to KivuWatt Project
Technological	Most modern scientific technology of database programming was used to develop the implemented product
Economic	A fit-for-purpose LAN CMMS with lowest initial and running costs was negotiated for implementation by project sponsor Ethane
Legal	The project implementation ensured meeting requirements for applicable legislation
Organisational	The project implementation has resulted in effective coordination, operability and management of activities at the establishment
Scheduling	Once off schedule for automated planned preventive maintenance (PM) activities has eradicated the time intensive and tiresome manual preparation and processing of PM Work Orders

TABLE 2. Description of TELOS application

FIGURE 4. Asset Management Model based on ISO 55001:2014 and PAS 55 IBM, 2009

6. METHODOLOGY AND APPROACH

The overreaching objective of this project implementation was to ensure that simplification in complexity of achieving maximum uptime of all assets and operating in a healthy state gets maintained with the aid of an easy to use, developed for purpose computerized Maintenance Management system (CMMS).

A dual prong model framework (design model framework and implementation model framework) for the system approach was employed as follows.

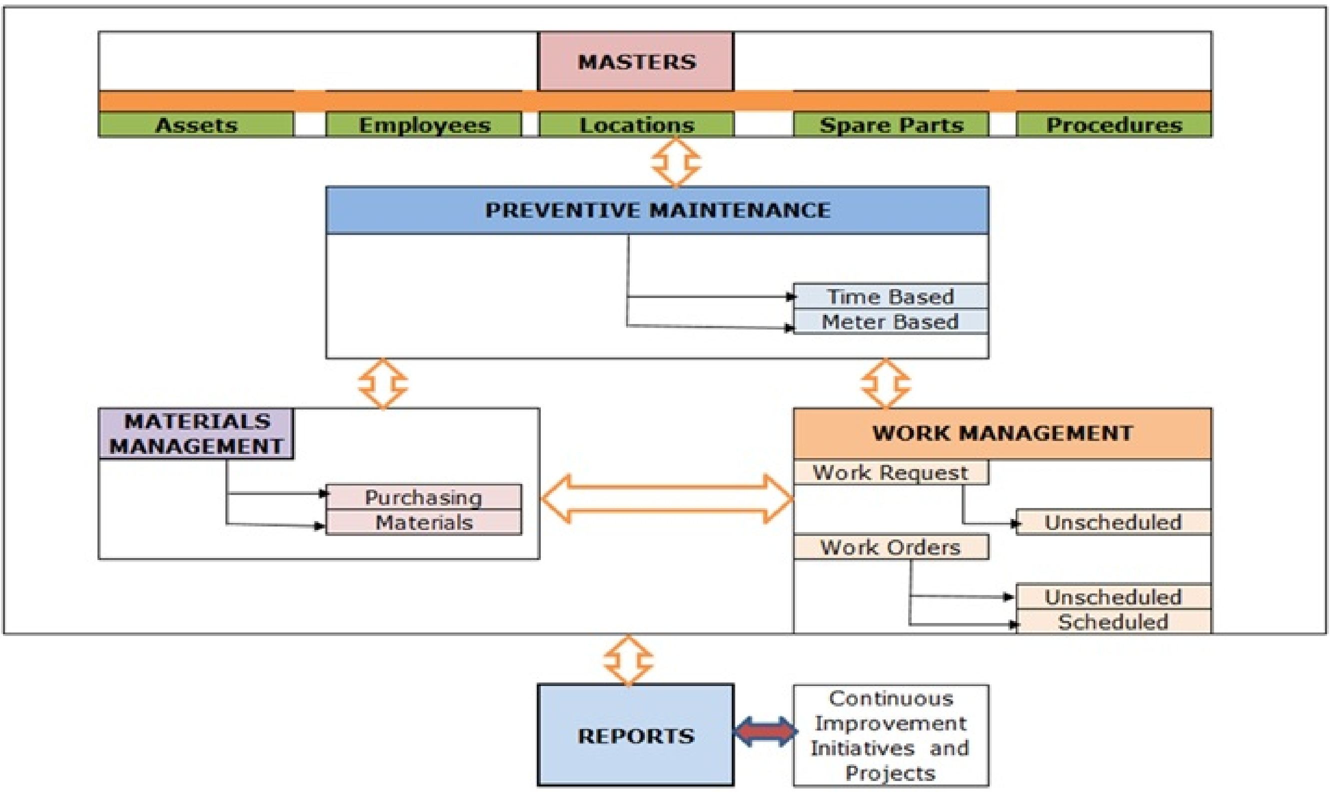

FIGURE 5. CMMS Design Model Framework (courtesy of EMaintE Consulting and 4C Systems)

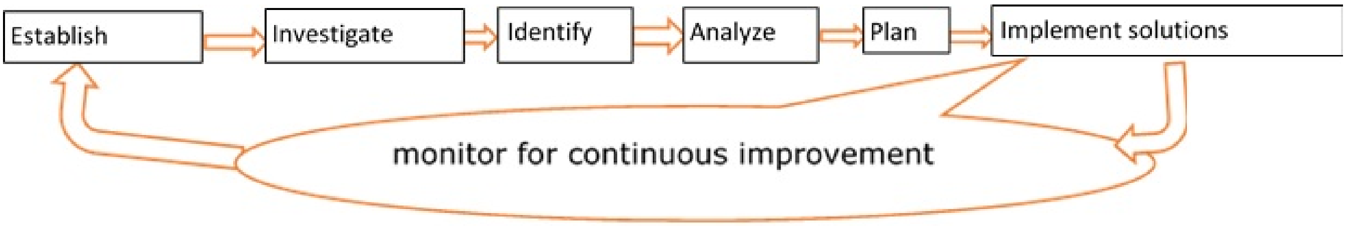

FIGURE 6. Engineering management optimisation (EMO) model

6.1. The design model framework

The design and development of a model framework for a computerised maintenance management database is what determines the hierarchy in structure of the fields for recording various parameters of the enterprise process assets (EPAs), resources and their associated activities in order that there is simplification of the patterns via which the various processes flow.

Five levels of main data tables are used in the design model framework for the CMMS that is used at the KivuWatt facilities and are Masters, Preventive Maintenance, Materials Management, Work Management, Reports, as shown in the Figure 5.

A tabulated functional description of main data tables is depicted in Table 3.

6.2. The implementation model framework

The United Nations Industrial Organisation (2012) based iterative systems engineering management optimisation (EMO) model shown in Figure 6 was significantly utilised in this project.

6.3. Project execution plan

Planning entailed pre-site visit and onsite visit activities as follows.

6.3.1. Pre-site visit plans

The core areas of preparations prior to consultant's arrival at the ContourGlobal-KivuWatt site were generally split into due diligence activities and software training material where:

(i) Due diligence activities included exchange of communication and agreements on the ContourGlobal standing policies on; Supplier code of conduct, Vendor card and registration, anticorruption policy, anticorruption compliance, service providers tax compliance, banking details as well as confirmation of partial prepayment for consultancy service as

Database Parameter	Key Function
Masters	Provides for the main structure for Primary data entry on which different tasks, activities and processes depend
Preventive Maintenance	Provides for scheduling of predetermined automatic trigger of Time-based or Meter-based maintenance tasks
Materials Management	Provides for inventory and procurement management
Work Management	Provides for both planned and unplanned work process and management
Reports	Provides for pre-set standard reports for instant on-demand generation

TABLE 3. Implemented CMMS Main Levels of data management

an indication of commitment to conditions on approved quotation and subsequent purchase agreement.

(ii) Software training material included preparation of: software and training workshop data, design CD labels, write and label CDs, design and prepare certificates as well as communication with KivuWatt plant and facilities management on the prerequisite platform software and hardware required by the program and a list of prospective workshop attendees to enhance offsite generation of certificates.

(iii) Pre-site visit confirmation of project take-off entailed communication and proposing of initial schedule of activities.

6.3.2. Onsite planning of project activities

In line with the pre-site visit schedule of activities, the onsite plan entailed discussing all the scheduled implementation activities during the project kick-off meeting held in the Plant Manager's office. These included discussion of the systems' approach, the requirement survey to identify of all existing gaps and shortfalls in the existing methods of operations and maintenance (O&M) management, identify the facilities setup using the P&ID (process and instrumentation diagrams/layout design drawings), identify, organise and allocate time and resources for all the activities in sequence of: Plant walkthrough, physical verification of all parent and child assets listed on the facility register, installation, integration and setting auto-backup of the CMMS program, review collected data, perform master data coding, capture primary data into the program, review and reorganise all data required for planned maintenance including Preventive Maintenance (PM) task lists, PM Schedules, quality checking data, import data into the database, perform program test, training workshop according to scheduled groups and hand-over certificates of participation, launch the program, close-out workshop and handover project, monitor operation by visiting all workstations using the program or its add-ons, site visit and project implementation report (an offsite activity).

7. CONCLUSIONS

This paper elucidated some of the salient aspects of an important offshore-onshore facility at Lake Kivu that generates electricity and transmits the same into the Rwandan national grid utilising the lean-burn internal combustion processes. As Part-1 of the two part paper, the areas covered were background of the project, aims, objectives, facility description, review of relevant literature, project feasibility considerations, methodology and approach. The second part will highlight more detailed description of scope of works, implementation steps, setting up of the modern O&M management system, Data Quality Control issues, Training considerations, implementation challenges, and benefits along with proposed future work. The project management presented in this paper is a case study that can help other projects in the African as well as other regions across the globe to improve planning, and execution of large magnitude projects in general, energy oriented projects in particular integrating several mainstream as well as consequential issues that affect the society and environmental sustainability.

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