DESIGNING THE SPECIFICATIONS AND IMPLEMENTATION OF A PV-MFC HYBRID SYSTEM PROJECT BASED ON A PUBLIC-PRIVATE PARTNERSHIP (PPP) AND SOUTH AFRICA'S PROCUREMENT POLICIES: CASE STUDY UMHLATHUZE

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ABSTRACT

Electricity supply shortages in South Africa cause insecurity of supply, which subsequently negatively affects economic growth and increases electricity prices for energy consumers, making energy unaffordable for the effective execution of day-to-day activities. Discussions at a national level indicate that tariff increases are likely, further burdening energy consumers (business owners and citizens). Indications are that there could also be a surcharge to consumers that use the national conventional fossil fuel-based energy grid but supplement supply from other sources, and additional surcharges for users of 100% renewable. Considering the potential unrest and concerns from end-users of electricity, this paper proposes guidelines for the procurement of a photovoltaic-microbial fuel cell (PV-MFC) hybrid system as a means of implementing decentralized energy generation for municipalities, with the uMhlathuze municipality used as a case study. Public-private partnership (PPP) procurement is proposed as an effective vehicle for the safe acquisition of renewable technology that offers stable yet sustainable investment capital, distributed and manageable risks associated with project implementation, and profitable long-term payback strategies. The details of such specifications framework are accurately outlined after a feasibility study has been concluded that indicates the precise design of the PV-MFC technology required and the amount of capital financing for the implementation of the hybrid renewable energy system (HRES) has been established.

KEYWORDS: *Public-Private Partnership, Renewable Project Specification, PV-MFC Hybrid Technology, Photovoltaics & Microbial Fuel Cells*

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1. INTRODUCTION

Ending energy poverty and achieving sustainable energy for all by 2030 are global challenges for humanity that require innovative trends in the renewable energy sector that favour and benefit future installations of up-scaled power plants [1]. The author further indicates that hybrid renewable energy systems (HRES) consist of two or more energy sources (with at least one of them renewable) integrated with power control equipment and an optional storage system. HRES can either be a standalone hybrid energy (or power) system, or off-grid, or remote, or island, or hybrid energy (or power) system, or microgrid, or mini-grid, or an autonomous power system. Musvoto et al. [2] state that the electricity shortages in South Africa in 2008 exposed the risk to both water and wastewater treatment operations posed by an unreliable power supply and continuous increases in electricity prices. This has stimulated interest in technologies such as HRES that can be used by municipalities for the purpose of

recovering energy from wastewater sludge. Thus, to curb the adverse effects of electricity shortages, HRES installations should be fast-tracked with seriousness and commitment.

The majority of government-initiated energy or hybrid energy system (HES) projects in South Africa are technically driven by economic feasibility analysis focused on energy cost and return on investment; this paper attempts to cover the multiple key design aspects of HRES, in particular, that of the photovoltaic microbial fuel cell (PV-MFC) hybrid system for the uMhlathuze municipality. This PV-MFC hybrid system is the main focus in this design overview to enable procurement purposes using the type of load, energy sources, storage, availability of meteorological data, etc. Procuring and undertaking detailed feasibility projects takes a year and a half to two years, and the general construction of giant power plants takes between seven and eleven years. Modise and Mahota [7] indicate that the South African government established from electricity demand projections that an additional energy target of 40 000MW capacity is required by 2025. This can be achieved if municipalities are given the autonomy to generate energy using HRES. In the past sludge has been viewed as a nuisance in the wastewater industry yet forms a large part of wastewater operations. The consensus is that sludge and solar energy are economically feasible for energy generation [2].

2. BACKGROUND

The City of uMhlathuze (also known as Richards Bay, referred to as uMhlathuze municipality in this paper), is situated on the northeast coast of the KwaZulu-Natal province of South Africa, about 180 kilometres north-east of the City of Durban. Emanating from the Statistician General report [8] that South Africa is rich with renewable sources and is imbued with heavy sunshine. Fig. 1 shows the meteorological report [9] indicating data for solar energy at the uMhlathuze area.

Figure 1: 10-Year Meteorological Data of Average Sun Hours

and Sunny Days at the Umhlathuze Area

Figure 1 reflects the trend of sunlight averaging over 270 sun hours per year for the past 10 years. This reveals that uMhlathuze municipality has ample sun hours which can support the procurement and use of photovoltaic technology for the generation of electricity.

Figure 2: The 2020 Annual Meteorological Data on Average Sunny Days and Sun Hours for the uMhlathuze Area.

Figure 2 reflects the 2020 month-to-month meteorological data [9] with an annual average of 300 sun hours is per year. The least average sunny days occur during the rainy months from October to March with an average of 278 sun hours per the 6 months. The least number of sunny days according to the [9] is 4 that occur in November and December 2020. Since a day has 12 hours and the number of days considered in this paper is 30 per month, the number of hours in a day per month is 360. With the above information and the conversion efficiencies of solar energy to electricity using photovoltaics, the potential amount of energy that can be generated can be determined, however, the intended energy required and allocated budget are major determinants. Further, [9] indicates that the average temperatures in the Richards Bay area for the past 10 years are between 26.5°C during summer months and 20°C during winter months.

The above data attests that the uMhlathuze municipality is a good contender for the implementation of photovoltaic technology to generate electricity. In alignment with the aim of implementing a PV-MFC hybrid system for generation purposes, the average quantities of sustainable quality sewerage discharge (consisting of mainly organic solids) through the municipal sewer pipeline system needs to be ascertained to work out the amount of biomass that can reliably be collected and available for generation, and by how much contribution this can make towards electricity generation. In other words, apart from determining the electricity required to power the wastewater treatment plant and the minimum energies required to start up and keep the PV-MFC system operational, the amount of energy that the municipality can reduce consumption from the national grid through the implementation of the PV-MFC hybrid system must be

determined in order to define energy savings and the margins by which energy bills can be reduced.

Investigations have revealed that the municipality contributes on average a total sum of about 25 000 m³ raw domestic (residential) and commercial sewerage per day to the effluent pipeline that discharges final effluent (raw sewerage treated by dilution processes using seawater) to the Indian ocean. A study conducted by Enzani Engineers in 2014 [3] confirmed the above and indicated that municipal sewerage containing human fecal (waste), fats, oils, and greases must be processed using separation and other treatment processes in order to ensure that the residual biomass is in the required form for generations. The exact processing of collecting municipal sewerage (waste) is important in establishing if the required energy can be satisfied, however, the details can only be accurately learned once a comprehensive feasibility study has been conducted.

There are 824 municipal wastewater treatment plants in South Africa, and 55 % of the total energy consumed in the country is accounted for by municipal wastewater treatment processes [CSIR, 10]. The amount of water supplied to both commercial institutions and residential households at the City of uMhlathuze yields a proportional sewer discharge in the absence of pipe bursts and/or pipe leaks. According to [2], unprocessed sludge has the same energy content as low-grade coal, at approximately 19 MJ/kg (5.2 kWh/kg) on a dry weight basis, although the energy content varies depending on the level of sludge treatment, with untreated primary sludge having the highest energy content. The authors cite Marx et al. (2004) who state that the capital costs of sludge management can be up to 50 % of the overall investment at a wastewater treatment plant (WWTP), thus energy recovery is essential for the long-term sustainability of wastewater operations, with treated municipal waste such as waste activated sludge yielding slightly less energy content of about 14 MJ/kg (3.8 kWh/kg).

Fats, oils, and greases (FOG) discharged from commercial and domestic kitchens are clean and contain higher volumes of volatile solids (organic content) and energy potential than sewage sludge [4]. FOG has a high caloric value suitable for energy recovery or generation, but treatment and handling is necessary since waste materials produced by FOG have a negative impact because of the accumulation and blockage of sewer systems at different points in the sewer system from the kitchen to pumping stations and wastewater (sewage) treatment works. Processing of FOG together with concentrated activated sludge and normal sewer discharge from sewer pipelines must be modelled in order to obtain the required feed quality (concentration) and quantity (flow rate). Details of FOG treatment together with that of influent can be determined through feasibility studies.

Waste from kitchens is generally composed of FOG and food material and waste from toilets is composed of human waste; both are collected and discharged through the sewer pipeline to pumping stations and subsequently collected at a wastewater treatment plant or macerator station. Macerators are also used at uMhlathuze municipality, and these stations consume less energy compared to conventional wastewater treatment plants because not all the processes of treating sewage in macerator stations are highly energy consuming or require energy. Processes are screening for foreign objects, separation of sewage by directing sludge to dry beds, and dilution processes whereby seawater is used to dilute residual sewerage before being finally disposed of through an effluent pipeline that disposes it to the ocean. Thus, to holistically account for energy consumption and energy bills, the baseline is drawn from energy consumed and billed from a water scheme that comprises a water abstraction plant, water treatment plant, and pumping stations. In respect to

this paper, the total energy bills of the water scheme supplying the area under investigation at the municipal area were compared with the sum of energy bills resulting from 68 small to medium and main sewer pumping stations and were found to be more-or-less the same value.

The initial costs associated with implementing renewable technology such as PV-MFC technology mainly comprise land costs, acquisition costs of procuring PV and MFC technologies, PV module and MFC structural costs, civil and general works costs, power conditioning unit costs, energy storage unit costs, legal compliance costs, etc. uMhlathuze municipality owns the identified potential sites for the implementation of the PV-MFC hybrid system project and this reduces the initial costs of implementing the HRES project by up to 20 %. [1] indicates that the cost of implementing an HRES project depends on internal and external factors and whether the technology is locally produced or not, for internationally produced renewable technology, other associated costs are incurred and are influenced by the country's financial status and rating (borrowing power) to pay interest on loans used as capital investment and for import costs, transportation costs, customs (tax) costs, and the country's socio-economic and political stability. The country's economic status plays a role in the willingness to procure renewable energy technologies. Burton et al. (2006, cited by [2]) state that the challenge of certain internationally established technologies is that they have not been demonstrated in the South African market, and due to being unproven, scalability and reliability of these technologies are hampered when attempting large scale implementation.

Since there is an urgent call for radical and affordable solutions in the Republic of South Africa to improve the persisting energy crises, this paper provides a guide to using legislation already in place in the Republic to fast-track procurement of technology and to fund HRES projects. Two procurement processes must be undertaken: firstly, procurement of a transactional advisor (TA) to conduct a comprehensive feasibility study, advice stakeholders on the feasibility of the project using a detailed report, and prepare tender documents in preparedness for the implementation of the project. Secondly, if the project is found to be affordable and viable, the TA arranges the procurement of service providers to construct, install and commission the HRES project in line with approved specifications and budget indicated by the feasibility report. The design specification of the PV-MFC hybrid system is outlined together with procurement specifications using the municipal finance management act (MFMA) and the National Treasury (NT) guidelines on supply chain management (SCM) in Nhleko and Inambao [5].

The NT guidelines [6] under section 16.1 define affordability as meaning that the financial commitments to be incurred by an institution in terms of the public-private partnership (PPP) agreement can be met by funds designated within the institution's existing budget for the institutional function to which the agreement relates, and/or funds destined for the institution in accordance with the relevant treasury's future budgetary projections for the institution. Further, the guidelines define a private party to a PPP agreement as being, among others, a municipality. The NT guidelines view a PPP agreement as a vehicle (written contract) for the government and the private sector to join efforts in acquiring services that have mutual benefit. Thus the guidelines define a PPP as a commercial transaction between an institution and a private party where the private party performs an institutional function on behalf of the institution and/or acquires the use of state property for its own commercial purposes and assumes substantial financial, technical and operational

risks in connection with the performance of the institutional function and/or use of state property from which the private party receives a benefit for performing the institutional function or from utilizing the state property. This can occur either by way of consideration to be paid by the institution which derives from a revenue fund or, where the institution is a national government business enterprise or a provincial government business enterprise, from the revenues of such institution, or the collection of charges or fees by the private party from users or customers of a service provided to them, or a combination of such consideration and such charges or fees.

3. METHODOLOGY

3.1 PV-MFC Design Specifications for an HRES Project Using a PPP Agreement

Nhleko and Inambao [5] conducted a measurement of energy consumption at the water treatment plant and pump station, all located at $-28^{\circ}76'07.58''$ S $32^{\circ}07'74.81''$ E, responsible for the supply of water to the main reservoirs. This municipal land is one of the identified potential sites where the PV-MFC hybrid system can be implemented. The other identified potential municipal site identified for the same HRES project of implementing the PV-MFC hybrid system is the Arboretum macerator station located at $-28^{\circ}77'98.56''$ S $32^{\circ}06'79.74''$ E.

The arboretum municipal sewer system at the City of uMhlathuze discharging from both commercial and residential households, comprises pump stations, pipelines, and a macerator station, and is designed to discharge wastewater only. This system is not connected to stormwater drains (pipelines). Since macerator stations consume less energy compared to conventional wastewater treatment plants due to the fact that the separation and dilution processes happening at the macerator station require very little electricity, and that the water supplied to and consumed by residential households and commercial institutions is the same quantity as the wastewater received at the macerator station in the absence of pipe bursts and water or wastewater leaks and the introduction of unsolicited connections from unregistered (illegal) dwellings, this paper reflects energy consumptions based on Table 1 from [5]. The sum of energy consumption of the treatment plant and pump station was calculated as 75 681.98 kWhrs per day, with the monthly energy demand of the water treatment plant and pump station reflected in Table 9 of [5]. The design or scope for the PV-MFC hybrid system is as follows:

- Abd El-Aal (2005) observes that when an MFC is used as a backup system to PV generation, during disruptions MFCs take longer than diesel generators to restore electricity. In order to mitigate this fact, a blended approach is proposed whereby the MFC continuously generates the minimum required electricity equivalent to night load or energy required during peak times, assuming that PV generation normally satisfies energy demand equivalent to the sum of that of water treatment plant, pump station and energy storage unit.
- Various researchers and authors have indicated that connecting PV modules in series yields higher electricity, which is the case for MFCs as well. Upon determination of the required energy to power the treatment plant and pump station (all located in one site) by means of a feasibility study, the best-suited configuration of PV modules and MFCs in achieving the required energy must be designed, taking into account affordability and the

- Determine the most viable and affordable software to be used for the hybrid system as determined by the feasibility study, even if it is unproven.

Based on findings of the feasibility study, determine the best and most affordable design for the continuous abstraction, piping, and incorporation of seawater to the MFC plant. Planners must bear in mind the existing infrastructure of the 10 mega litre desalination plant at Alkantstrand (location -28°79'80.62" S 32°09'56.55" E) that is not being operated at the moment due to the cost implications of operating it.

3.2 Procurement Specification for TA to Design and Plan HRES Project Based on Findings and Recommendations of the Feasibility Report

Phase 1 of a PPP project cycle (the project inception stage) requires that the HRES project be registered with the relevant treasury at the NT, and a project officer and a transaction advisor (TA) be appointed by the accounting officer or accounting authority of an institution. These two appointments require a competent person(s) with skills and experience; however, the process of appointing the two persons is different. For a project officer, the accounting officer may appoint anyone within his/her personnel to oversee the whole PPP project that he/she deems trustworthy. Regarding the appointment of a TA, specifications are drafted and a tender process is followed to procure the services of a TA who then is officially appointed by the accounting officer. A TA is defined by the NT guidelines as a person or persons appointed in writing by an accounting officer or accounting authority of an institution, which has or have appropriate skills and experience to assist and advise the institution in connection with a PPP, including the preparation and conclusion of a PPP agreement.

Since the TA must be a person or service provider equipped with extensive technical, legal, and financial skills and experience, the NT guideline provides that the TA must conduct a feasibility study of the proposed HRES (PV-MFC hybrid system) that fully satisfies the needs analysis, options analysis, project due diligence, value assessment, economic valuation, and procurement plan in accordance with supply chain management and other applicable legislation.

The functions of the TA together with the specifications for the TA are directed towards the development of a comprehensive and detailed feasibility study as follows:

- Conduct an environmental impact assessment (EIA) for the project and undertake all required processes such as registration of the project with the various necessary departments, mainly the Department of Environmental Affairs and the Department of Water and Sanitation.
- Conduct options analysis of recently developed PV module technology that uses materials that render the PV modules affordable with better conversion efficiency. Further, an options analysis of proton exchange membrane fuel cell (PEMFC) technology must be conducted with other technologies such as the phosphoric acid fuel cell

(PAFC) that can be implemented or have been implemented in the South African market, considering the availability of phosphoric acid from the parastatal company FOSKOR. However, the use of PAFC means dependency on FOSKOR's production of phosphoric acid, so the trends of the level of production of phosphoric acid by FOSKOR must be examined for the last 10-years.

- Design and cost for the entire project, indicating costs and activities for each project phase. The TA must document and report designs, activities, and costs in a report and a GANTT chart, a project management tool that indicates all project-related items for purposes of gaining approval from the municipality and interested potential funders.
- Look for funding from various interested private local and international institutions and evaluate the conditions of each institution and recommend an institution with affordable rates and legally conducive conditions for the successful procurement and implementation of the project. The TA must be able to negotiate payback and any other related terms or items.
- Produce a report on all technical, legal, and financial aspects of implementing the PV-MFC hybrid system project using credible needs and financial test tools such as cost-benefit analysis (CBA), net present value (NPV) analysis, payback, etc., and recommend affordable, compatible and yet easy to operate and maintain PV and MFC technologies that can operate as a hybrid unit. This report must include the feasibility of maximum power point tracking (MPPT) technology and programming of the same for maximum harvesting of solar energy and technology that will be used to manage and monitor the flow of substrate into the MFC for optimum performance and conversion efficiency of biochemical energy to electrical energy.
- The TA must get all required approvals from all parties involved in the procurement of the right technology and implementation of the PV-MFC hybrid system and report on comments and approvals received in report form to all stakeholders.

An impact assessment study must be conducted by the TA in relation to the municipality's business model and aim or initial purpose in undertaking the project.

3.3 Procurement Specification for a Service Provider for the Supply, Delivery, Construction, Installation, and Commissioning of PV-MFC Hybrid System

- Upon all required approvals, the TA must prepare procurement (tender) documents for bidding purposes (either for open or closed bidding) depending on conditions agreed upon by all stakeholders. The procurement documents must be prepared in line with the municipal finance management act (MFMA); municipal systems act (MSA), NT guidelines with PPP processes, public sector, and municipal supply chain management processes and policies.
- The TA must conduct independent evaluations on all aspects of received bids, make recommendations to the municipality and appear at the municipal bid evaluation committee (BEC) in respect to evaluations. Due diligence shall be conducted by TA in conjunction with appointed municipal BEC members and project officers

in line with all NT guidelines and supply chain management (SCM) policies.

- The TA must perform project manager functions in line with project management body of knowledge (PMBOK) standards and SCM policies to completion and commissioning of the project. This includes reporting on progress, milestones, financials (include payment certificates), and any other project-related matters through various communication media such as meetings that have been agreed upon at the planning stage of the project.
- The TA must negotiate on prices with the potentially successful bidder where needs are, as directed by stakeholders before the final award. Also, the TA must negotiate for the training of municipal personnel with regards to operating and maintaining the hybrid system.
- The TA must oversee contingency works and any additional works after necessary approvals have been obtained. Also, the TA must oversee payments and payment of guarantee upon completion of the period indicated by the municipal SCM policy.

4. RECOMMENDATIONS

The appointment of a TA for the above functions is necessary to avoid the need for municipal personnel to cover all the required specialties to perform functions of the project which could result in such personnel multi-tasking which would not be very efficient. Appointing a TA also avoids the consequences of municipal staff turn-over and loss of information due to loss of staff. In terms of new staff, records and progress reports and other documented items can be made available from a single point of contact, the TA.

In view of the nature of the project, the anticipated financial commitment by the municipality for this project is R42 million for conducting the feasibility study (at the time of the writing of this paper). In pursuit of these funds, the municipality can approach the NT and request assistance in finding funds in this financial year from the three-year budget cycle to enable the start of the project or request full or part funding for a two-year financial period, due to the anticipated duration of the feasibility study which is between one and a half years and two years.

5. CONCLUSIONS

The appointment of a TA as soon as possible is necessary for the municipality to achieve its set goals and those of the national government of all citizens having access to electricity by the year 2030. The implementation of this HRES based project would reduce the trend and consequences of non-expenditure on allocated budgets. The location of the City of uMhlathuze in relation to the above indicated available renewable sources, together with available municipal land, makes the municipality a good candidate for improved energy bills, improved delivery of essential services to the surrounding communities, and reduced greenhouse emissions, based on energy generation using renewable sources.

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