International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 / https://doi.org/10.14445/22315381/IJETT-V70I10P209
Volume 70 Issue 10, 67-78, October 2022

Original Article

High Voltage & Short Circuit Testing Laboratories in Economic Growth of African Region: A Prospect for Prosperity

Saad Saleem Khan[1], Mohsin Amjad[1], Imtiaz Hussain Gilani[1], Stephen Larkin[2], Hussain Shareef[3], Waqar Ali Sher[1]
[1]*National Transmission & Despatch Company, Lahore, Pakistan*
[2]*Africa New Energies, United Kingdom*
[3]*United Arab Emirates University, United Arab Emirates*

[3]*Corresponding Author : shareef@uaeu.ac.ae*

Received: 17 June 2022 Revised: 05 September 2022 Accepted: 27 September 2022 Published: 19 October 2022

Abstract *- Several countries promote national innovation alongside indigenous manufacturing through institutional structures, ultimately supporting their economic growth. Changes in the international economic environment warrant using contemporary technologies to facilitate local manufacturers. The contributions of labs to indigenous technological capacities have different impacts on economic sectors. In the overall economic scenario, the energy sector is the backbone of the country's growth and is fed through high-power equipment. For an uninterrupted power supply, the reliability and innovation of high-voltage (HV) equipment are essential, accomplished by electrical testing laboratories (labs). Presently, the available labs in the African region do not sufficiently meet international standards and the commitment of local manufacturers. These labs are crucial for economic growth and raising living standards. We have studied the existing labs in the African region and are acquainted with various tests as per IEC requirements. A strategic assessment is considered using SWOT analysis, wherein opportunities are compared with threats and strengths with weaknesses. The financial analysis presents the revenue level for a given investment, which indicates the addition of multiple testing portfolios for the lab and demands government involvement for collaboration and sustainability in the initial development period.*

Keywords *- Economic growth, Financial Analysis, HV and SC Lab, Novel approaches, Strategic Assessment, SWOT Analysis.*

1. Introduction

This paper presents the role of an indigenous high-voltage (HV) electrical laboratory that meets the current technological and economic aspects. The process of economic development involves acquiring capabilities in the local manufacturing sector and supporting the industry with the resources required to meet international standards. Further, indigenous facilities are now more important to compete with other countries. Following those mentioned above, modern societies' industrial and economic growth is highly dependent on an uninterrupted energy supply, which is possible only with a reliable transmission and distribution network fed by robust grid stations. A grid station comprises different components, and the reliability of the equipment is ensured by pre-installation quality assurance testing and post-installation maintenance testing. Specialized electrical engineering labs duly equipped with the latest testing equipment and novel testing methodologies, these testing facilities are offered. Labs are responsible for maintaining the testing and standards that adhere to international quality requirements and enable the equipment to compete in global markets. Moreover, from conventional operations, labs also enhance economic security through localized industrial competitiveness and innovation with advanced technology in the electrical and electronics industry, leading to increased exports, and ultimately raising the quality of life [1].

Laboratories are essential in ensuring compliance within the regulatory framework and conforming to market requirements. These laboratories provide important data and information for trustworthy and transparent decision-making. Their major services include inspection and certification while ensuring financial, social, and environmental considerations. Therefore, most developed and developing economies enhance their laboratory capacities through extension and augmentation for sustainable industrial and economic development. It also helps the United Nations Industrial Development Organization (UNIDO) provide sustainable development goals (SDGs), such as people and prosperity. This, as a whole, is called quality infrastructure because it combines institutions, public and private organizations, financial resources, and people [2].

A modern laboratory grounds the technical foundation for sustainable economic growth through the following objectives [3]:

- localization and industrial development
- technological advancement

- domestic and global market access and compatibility
- employment opportunities and efficient use of human resources

Following quality compliance, all electrical equipment at different voltage levels must be appropriately insulated, separating the circuits from grounded connections to protect operations. The insulation materials consist of liquid, gas, air, vacuum, or a solid base. Many standards governing equipment characteristics and electrical insulation are the responsibility of manufacturers. However, low- and high-voltage level profiles are subject to testing to ensure the functionality and protection of the equipment. However, the HV level for various regions varies; as per IEC, a voltage level above 1 kV is defined as an HV. The numerous benefits offered by the HV system have led to the development of power systems with voltages up to 1200 kV. It also demands the corresponding progression of HV engineering, an experimental science requiring various HV tests for equipment validation and calculation verification [4].

Every HV electrical equipment has a standard operating/withstanding HV level, up to which the equipment can withstand various overvoltages and abnormal conditions without degrading its performance. All electrical equipment, ranging from low to ultra-high voltage levels, requires electrical insulation to isolate circuits from each other and the ground. Therefore, HV testing is performed to measure the performance of these insulations under abnormal conditions/overvoltages [5]. High-power or short-circuit (SC) tests validate the switching capacity, thermal stresses, and dynamic performance of the HV electrical equipment. The various components that constitute an HV system (generation, transmission, substations, etc.) must be subjected to various tests (routine, type, and special tests) to ensure their reliable performance at the requisite voltage level and ability to withstand surges in voltage as a result of events such as lightning strikes or SC.

HV and SC labs provide a platform to conduct these tests independently to ensure the reliability of the manufactured HV electrical equipment. Following ISO/IEC-17025, a modern HV and SC laboratory should be equipped with testing facilities capable of determining the design, configuration, and materials of various HV equipment, such as generators, circuit breakers, transformers, transmission line materials, switchgear, insulators, cables, and motors, to ensure reliability, anticipated performance, and safety. Newly manufactured equipment can be tested to guarantee conformity to design specifications with national and international standards. The equipment in operation can be reassessed after certain modifications, and the damaged equipment can be investigated to determine the root cause.

There are many standardized HV and SC labs worldwide where HV electrical equipment is subjected to various quality acceptance tests according to applicable IEC standards. However, the HV and SC testing facilities in Africa have not yet been established to the extent they should have been, as very few internationally recognized and accredited labs provide services. This state of affairs enables researchers to investigate the potential of HV and SC labs, the type of tests required to be performed, and the identification of the requisite testing facilities required in such labs in the African region. These labs will help local manufacturers of HV switchgear equipment test their products in compliance with national and international standards within the region.

This research article focuses on the existing HV and SC labs in Africa and recommends a comprehensive HV and SC lab conforming to the acceptable standards required for such labs to contribute to the economy based on the details and elaborations of existing labs. It will also encourage R&D in the field of HV and SC testing and equipment for future requirements and help potential investors make proper decisions for adapting newly developed R&D products.

An HV Laboratory must conform to ISO/IEC-17025 for the following purposes:

- Electrical equipment manufacturers to validate their products.
- Electrical utilities (generation, transmission, and distribution) to check equipment during or after modifications.
- Service providers to provide testing services to electrical equipment manufacturers.
- R&D and calibration of new HV equipment and testing methods.
- Educational purposes of institutes/universities and professional training of employees.

In addition to economic opportunities and technical applicability, assessing business sustainability in an economic ecosystem is essential. Business sustainability depends on several factors. First, reaping the desirable benefits as perceived at the macroeconomic level. Second, the evolution of anticipated threats and weaknesses mitigates them with opportunities and strengths. Therefore, SWOT analysis, which helped determine the key success factor, was also performed in this study. Following this assessment, the investment appraisal is presented to ascertain the net present value (NPV), payback period, and internal rate of return (IRR). These parameters support business decisions by providing insights into return on investment (ROI) [6].

This paper is structured as follows, as shown in (Fig. 1). The first section describes economic opportunities and contributions. The second section explains the technical aspects, such as the region's classification of HV test labs, focusing on electrical power equipment testing and discussing innovations in the testing, and compares the current labs in the African region. The third section elaborates on the strategic business analysis and investment appraisal that will help decide and set up a standardized lab in the African region. The fourth section elucidates the financial analysis of investment appraisals to identify financial parameters.

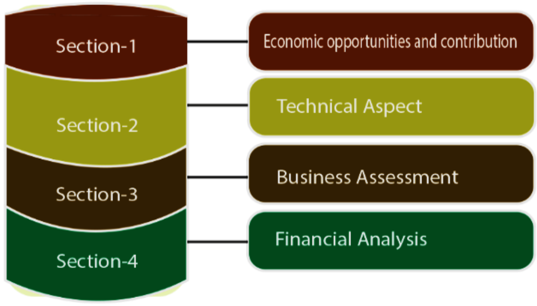

Fig. 1 Formation of the paper

2. Economic Opportunities and Contribution

The African economy is undergoing an industrial revolution and moving swiftly towards a developed nation wherein the energy sector plays a vital role, leading to solid financial health in the economy. The electricity demand is mainly driven by an increased population and other additional dynamics, including industrialization, growing metropolises, and changing weather. This situation warrants the expansion and augmentation of the power system network. Other regional countries will also undergo the same situation in the present and near future. Considering the local and regional growth in the power sector, the need for locally manufactured electrical equipment in the African region to fulfill domestic and international requirements provides a strong base for establishing an HV and SC testing lab [7].

The traits of economic analysis include [8]:

- The economic perspective of the society
- Applicable prices
- Exclusion of taxes and subsidies to identify the value to the society
- External positive and negative factors are considered and quantified in monetary terms, such as reducing employment, reducing carbon emissions, and promoting human development.

An economic analysis provides the expected present and future states with and without the project and alternatives. However, external factors attributed to the project were also considered in this study. Thus, the economic contribution of a project to society can be described by Equation (1).

$$E_C = B_E - C_E - CAPEX + OEPEX, \quad (1)$$

where E_C is the economic contribution, B_E are external benefits, C_E is external cost, $CAPEX$ capital expenditure, and $OPEX$ operating expenditure.
The economic contribution indicates the benefits and financial analysis discussed in the succeeding section of this paper.

The primary objective of economic analysis is to identify the net gains from a project for society. This analysis is compulsory when public financing is involved and, most importantly, when the project is important at the national level to boost the local electrical equipment manufacturing industry. Furthermore, economic analysis is frequently applied to recognize the private investment as a socioeconomic contribution. The analysis types vary according to the project size; small projects, such as microgrid stations, have local economic impacts, whereas large-scale projects, such as labs, are important nationally. Therefore, it has significant economic and social impacts. Thus, the lab creates a beneficial economic and social nexus vital for balanced economic growth.

2.1. Impact of Foreign Direct Investment

These circumstances will attract foreign direct investment (FDI) in the electrical equipment manufacturing industry and partners in establishing the laboratory [9]. The new investment positively impacts economic growth in the following dynamic ways:

- FDI attracts or invites new technologies and provides comparatively more growth than local investments.
- Indicates a direct relationship between FDI and human capital.
- Indicates the firm policy of a country for import and export management.
- Increases the foreign exchange reserves and provides a regular addition by generating export revenues.
- Provides an extended range of employment opportunities.
- Supports the local industries in decreasing the production cost.
- Promotes knowledge capacity building in the sector.

Overall, economic growth can be observed at the macro and micro levels, which provide direct and indirect benefits [9].

The broad indicator includes the gross domestic product (GDP), which encompasses the total market value of all finished goods and services generated within the geographical boundary of a country in a certain period and provides an overview of economic health. Therefore, to analyze the impact of the addition of labs on the African economy, it would be necessary to include all the anticipated production of electrical equipment, allied jobs, and services resulting from the lab's establishment. The GDP can be calculated using Equation (2), and growth can be measured by subtracting it from the anticipated GDP.

$$GDP_P = G_m + S_m + I + G_X, \quad (2)$$

where GDP_P represents the present volume of GDP, G_m are goods produced at market value, S_m is services at market value, I is investments, and G_X is government expenditure [8].

2.2. Employment Opportunities

With the induction of electrical labor in the African region, significant employment opportunities will be created. It can be segregated into two segments and induced. The direct impact can be apparently measured from the jobs created in the lab during its development phase from onsite labor and operations phase from testing crews.

The induced impact can be categorized as the development of allied industries, in which a considerable number of jobs will be offered, improving locals' living standards and reducing the unemployment ratio. Due to the overall impact of employment, household spending will increase, and it will support local restaurants, retailers, and other service providers. However, this hinders the migration of human capital to other countries [10].

2.3. Localization

African countries are striving for competitiveness not only in Africa but also in Europe. To compete with developed countries, focusing on promoting and installing high-tech technologies is necessary. The significant benefits to be added are low-cost human capital and raw materials. The addition of labs in a country will advance innovation and boost R&D culture, which is necessary for industrialization, leading to the localization and integration of regional resources with utilization at the national level and exports for foreign exchange generation [11].

3. Technical Considerations

HV tests are performed to assess the dielectric withstand performances. High-power (i.e., SC) tests verify the interruption and switching performance of the HV equipment under test. In general, various tests can be classified as follows [12]:

- **Type Tests:** These tests are conducted on one or more prototype unit(s) and not all manufactured products to validate the design details and consumer specifications.
- **Routine Tests:** These tests are performed on each manufactured-product unit to verify the operational performance.
- **Special Tests:** These tests are performed to execute the agency requirements to assess characteristics. These tests are required to assess the newly introduced designs in HV electrical equipment.
- **Demonstration Tests:** When a new technology is introduced, demonstration tests are conducted to demonstrate the advantages and disadvantages of the new technology.
- **Field/Onsite Tests:** After installing HV equipment at the site, when there is a major overhaul, repair work, or augmentation, field or onsite tests are performed on the equipment. These are the same tests carried out in the laboratory but at reduced stress levels to avoid irreparable damage to the equipment.
- **Commissioning Tests:** These tests are performed when HV equipment is installed in the system and becomes a part of the utility after these tests. Commissioning tests to ensure that the installed equipment, mainly its insulation system, can withstand the system voltage after becoming part of the power system.

Type tests are conducted at independent, duly accredited test laboratories. The accepted lab must be a short circuit testing liaison (STL) member, an organization aimed at harmonizing the application of relevant IEC and regional standards [13]. STL verifies the following categories of tests:

- SC making and braking performance
- Switching performance, normally the capacitive-current switching performance
- Dielectric performance
- Temperature rise performance and measurement of the main-circuit resistance
- Mechanical performance

3.1. Typical HV Tests Performed at a Lab

Table 1 outlines the common HV tests conducted in HV laboratories using various electrical equipment [14].

HV Test Equipment:

HV test equipment comprises the following major components/apparatus/devices necessary to conduct requisite HV testing, as depicted in (Fig. 2) [15]:

1. HV/Impulse Voltage Generator: The HVG/IVG is to convert the feed voltage of low or medium level to the desired level of HV required for testing. The HVG type depends on the nature of the required test voltage.
2. Test object helps in generating HVAC using resonant circuits.
3. Power to the HVG/IVG is supplied from the power grid. This unit consists of switching and regulation modules that generate the desired voltage commanded by the control system.
4. Capacitive voltage dividers are employed to measure the standard lightning impulse (LI) and switching impulse (SI).
5. Resistive Voltage dividers are used for measuring very fast front LI and DC
6. Control and Measuring System: Voltage is adjusted through programmable logic control. The voltage measurement of the test object, partial discharge, dielectric measurement, and other measurements was performed using the measuring system following IEC-60060-2.

3.2. Typical SC/High Power Tests Performed at a Lab

High-power tests are performed to assess the switching capacity, capability to bear thermal stresses, and dynamic performance under short-circuit failures (3-Ø, Ø-Ø, Ø-Ø-G, Ø-G faults, etc.) of HV electrical equipment. Table 2 summarizes the common SC tests performed at the SC/high-power lab.

3.3. Short Circuit/High Power Tests Equipment

The major equipment in a short-circuit/high-power lab comprises the following [16].

- SC power generator generates the current required for various high-power tests per standards.
- Protection Circuit breakers for the protection of testing set up.

- Making Switch with appropriate making current.
- Medium-voltage SC transformer for attaining the desired SC current at a medium-voltage level.
- Low-voltage SC transformer to obtain the desired SC current at the low-voltage level.
- Low-voltage test capacity of network facility for SC making and breaking test at network facility voltage level.

(Fig. 3) shows the simplified layout of the SC/high-power laboratory [17].

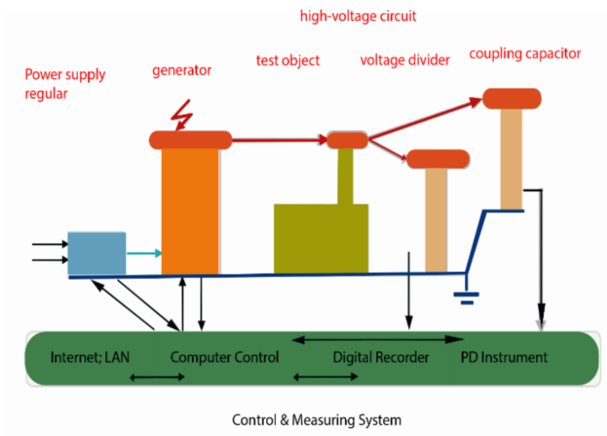

Fig. 2 Typical HV Test System

3.4. High Voltage & High Power Labs in African Region

This section describes the African region's testing facilities and the tests conducted in the laboratories. African laboratories will be compared with some globally top laboratories. Based on the comparison, a standardized lab equipped with requisite testing facilities is suggested, acknowledging the highest ratings of equipment manufactured in Africa.

3.4.1. Statistical Data of Labs and Maximum HV Transmission Level in African Continent

Table 3 describes the presence of HV laboratories, tests performed in those HV labs, and the maximum HV transmission level in these African countries.
Continent.

The data show that only two countries, Egypt and South Africa, have appropriate HV labs. The rest of the African continent lacks a HV lab facility, which highlights the need for such a facility to cover the testing requirements of the local manufacturers of the region. Furthermore, all African countries have a maximum HV transmission level of 400 kV except for Egypt and South Africa, which have 500 kV and 765 kV DC transmission levels, respectively.

Thus, HV labs, capable of conducting tests on AC equipment up to a 500 kV voltage level and DC equipment up to 765 kV, can evidently cover the market needs of the African continent.

Table 1. HV Tests at Lab

Test Objects/Equipment	Applicable Standards	HV Tests
Gas-insulated Metal enclosed Switchgear	IEC 62271-203	• Lightning Impulse Voltage tests (Withstand & Flashover), • Switching Impulse Voltage tests (Withstand & Flashover), • AC Withstand Voltage tests, • AC Power Frequency tests (Dry & Wet), • DC Dielectric tests (Withstand & Flashover), • Combined voltage tests (BIAS), • Chopped Wave tests, • Partial Discharge Tests, • RIV (Radio Interference Voltage) Tests, • Long-term Electrical Aging tests, • Mechanical Endurance tests, • Dielectric tests on insulators, • Power Frequency Sparkover Test on Surge Arrestors, • Hundred percent Standard Impulse Sparkover Test on Surge Arrestors, • Front of Wave Sparkover Test on Surge Arrestors
Metal-enclosed Switchgear and control gear	IEC 62271-200	
High Voltage Circuit-Breakers	IEC 62271-100, IEC 62271-101 IEEE Std C37.09	
Automatic Circuit Reclosers	IEEE Std C37.60, IEC 62271-111	
Disconnectors and Earthing Switches	IEC 62271-102	
High Voltage Switches	IEC 62271-103, IEEE Std C37.71	
Switch-Fuse Combinations	IEC 62271-105	
Auto Sectionalizers	IEEE Std C37.63	
High Voltage Fuses	IEC 60282-1 IEEE Std C37.41	
Power Transformers, Instrument Transformers	IEC 60076-5, IEC 60076-11 IEEE Std C57.12.00, IEC 61869	
Reactors	IEC 60289	
Insulators	IEC 60383, IEC 60137	
Power Cable and Accessories	IEC60502-2	
Surge Arrestors	IEC 60099-6	

Table 2. High Power Tests at SC Lab

Test Objects	Applicable Standards	High Power Tests
Gas-insulated metal-enclosed switchgear	IEC 62271-203	• Short-circuit Making & Breaking tests for AC and DC • Short-line fault tests • Out-of-phase making and braking tests • Short-time withstand current and peak withstand current tests • Capacitive-current switching tests • Magnetising and small inductive current switching tests • Making & Breaking tests • Temperature Rise Tests • Mainly active load current switching tests • Shunt reactor current switching tests • Internal arc tests, etc.
Metal-enclosed Switchgear	IEC 62271-200	
High Voltage Circuit Breakers	IEC 62271-100, IEC 62271-101 IEEE Std C37.09	
Auto Reclosers	IEEE Std C37.60, IEC 62271-111	
Disconnectors and Earthing Switches	IEC 62271-102	
High Voltage Switches	IEC 62271-103, IEEE Std C37.71	
Switches-Fuse Combinations	IEC 62271-105	
Auto Sectionalizers	IEEE Std C37.63	
High Voltage Fuses	IEC 60282-1 IEEE Std C37.41	
Power Transformers, Shunt Reactors	IEC 60076-5, IEC 60076-11 IEEE Std C57.12.00	

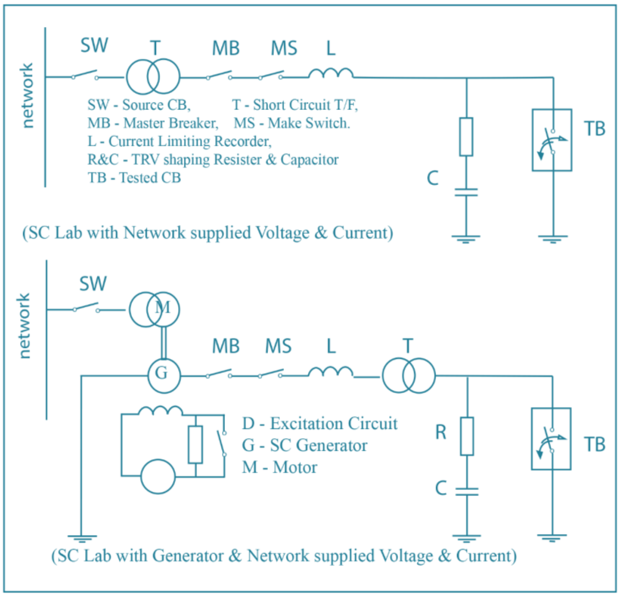

Fig. 3 High Power/SC Lab Layout

3.4.2. Modern HV Labs for Africa Region

After the comparison mentioned above and acknowledgement of the highest voltage level in the African region, a lab equipped with the HV & SC equipment listed in Table 4 can cover the testing needs of the region [12].

It provides the footprints of a standardized, comprehensive HV and SC lab, where all possible HV equipment testing may be conducted, and an environment of continuous R&D can be fostered. It will also motivate local electrical equipment manufacturers to expand their potential beyond their current manufacturing abilities, as their products can obtain quality certification within the region.

The testing requirements for each type may vary according to the application, importance, and requirements of the customer, but testing must fulfill the following purposes [18]:

- Checking the loading capability
- Verifying dielectric withstand capability
- Validating operating characteristics and guaranteed performance
- Internal quality and design assurance by the manufacturer
- Fulfilling customer requirements
- Complying with the national and international standards
- Obtaining reference values for future testing

Innovative testing methods may relieve the utility/manufacturer/customer economic constraints. The methods' feasibility may be reviewed regarding limitations, effectiveness, and cost-benefit analysis for implementation.

3.5. Field Testing and Commissioning of HV Systems

In addition to conventional laboratory testing, conducting field testing services is necessary to make it convenient for power system operators and manufacturers. It will also substantially increase the revenue. Current electrical equipment and installations include electrical testing as a standard feature, which has become a vital instrument in all types of electrical installations and equipment over the years, owing to the increasing prevalence of industrial accidents and human error.

In addition to testing individual electrical equipment components, installed electrical systems must be ensured to fit the design documentation, construction submittals, and owner project requirements (OPR). Furthermore, functional performance testing tracking is also important [19].

Newly installed or retrofitted electrical power equipment and systems are subjected to acceptance testing under the acceptance testing specifications for electrical power systems during the commissioning phase. Whether a project is brand new or a retrofit, it must be commissioned to ensure the intended performance of the electrical system in terms of safety and reliability [26,27,28]. Field testing verifies that the equipment is ready for use and operates under the manufacturer's standards, thus ensuring its dependability. An effective HV system is based on proper testing and commissioning, which, in turn, depends on sound financial support. Hence, government collaboration and funding from organizations tend to be fruitful in this field [29].

Table 3. Tests performed in different regional labs

Country	Name of HV Lab	Test Performed	Max H.V level
Egypt	• Pyramid High Voltage Research Center [20] • Faculty of Engineering Cairo University [21]	AC Equipment Partial Discharge, Impulse, Mobile and other tests	500 kV
Kenya	• Kenya Bureau of Standards Electrical Testing Laboratory {22]	No	400 kV
South Africa	• Center of Excellence in High Voltage Engineering (CEHVE) [23], • H.V. TEST (PTY) LTD (S.A) [24], • NETFA SABS [25]	AC Equipment Partial Discharge, Impulse, Mobile and other tests	400 kV, 765 kV DC

Table 4. Components of HV &SC equipment

SN.	Name of Equipment	Ratings/ Technical Details
1	HV Transformer	2800 kVA
2	Impulse Generator	2.4 MVA
3	Short Ckt Generator	2800 MVA
4	HV AC Kit / AC Test Transformer	400 kV, 500 mA
5	HV DC Kit	200 KV DC
6	Partial Discharge System	800 KV
7	Capacitance and Tan Delta Bridge	2-Channel, up to 400 Hz, 400 kV Capacitor System
8	Partial Discharge Unit	3 PC at 800 kVA
9	Coupling Capacitor System	100 kV, 1 pC
10	HV Surge Tester	800 kV, 1000 A
11	High Frequency Generator	Up to 200 Hz, 1000 kVA
12	Motor Generator Set	Three Phase Induction Motor of 1 MW
13	Oil Testing Kit	Up to 100 kV RMS
14	HV Resonant Test System	30–300 Hz, up to 220 kV
15	Transformer Turn Ratio Tester	Range 0.9–100000
16	H.V Hi Pot Tester	100–200 kV
17	Current Injector	Up to 150 kA, 500 kV,
18	Temperature Rise Test Kit	• Tests in AC: Single-Phase (50/60 Hz): up to 50 kA, • Tests in AC: Single-Phase (50/60 Hz): up to 10 kA, • Tests in DC: up to 4 kA
19	Measuring Device	Fast digital transient recorders with optic fiber isolated digitizers located in test cells High-speed digital video recording system
20	Measuring Device	Automated data processing system, by IEC and STL guidelines Fully-automated control systems for short-circuit generators and synthetic

4. Strategic Business Assessment

A new lab will offer innovative methodologies for electrical engineering throughout the African region and serve a large geographical area that will create value, commercialization, and innovation. As discussed in the preceding sections, only two African countries have five electrical labs running commercially; however, these labs offer comparatively fewer services than other international labs. The newly established lab will leverage its geographical importance, enter into long-term contracts with manufacturers, and achieve cost-effectiveness by employing lab services. The lab will perform exceptionally well because of the latest testing equipment and novel testing approaches. Manufacturers can obtain services from the same region instead of hiring services from other countries [30, 31].

The lab cliental portfolio will consist of existing local manufacturers, new manufacturers looking for ease of business, and international companies, which suffer owing to the busy schedule of existing European labs. Moreover, the electrical engineering manufacturing industry is growing by 7% annually [32], and companies range from local manufacturers to international corporations. By focusing on improved services, goodwill and a large amount of revenue can be gained, which will serve as a strategic asset. Thus, there are numerous opportunities to establish a lab and grow the business, especially in a monopolistic environment, to serve potential manufacturers since the manufacturing of transformers is considerably less technical; consequently, the investment would flourish in anticipation of the testing facility. Moreover, this would help save foreign exchange and follow sustainable development growth (SDG) by creating employment opportunities [33].

4.1. Potential Benefits

The potential benefits are divided into two categories: laboratory and innovative services, elucidated as follows [34]:

4.1.1. Laboratory Services

- Quality improvement
- Reduction in time consumption
- Manufacturing of new and advanced products
- Testing and analysis processes simplification
- Efficiency enhancement
- Attaining optimization

4.1.2. Innovative Services

- Support for local business development and innovation
- Assistance in modern manufacturing techniques
- Promotion of the exports
- Patent applications
- Training and participation in public-private partnership programs
- Global markets require the adoption

4.2. SWOT Analysis

The SWOT Analysis of the proposed Lab is elaborated in Table 5.

Table 5. SWOT Analysis [34]

Strength	**Weakness**
• Modern equipment and establishment of a new building as per global requirements • Advantage geographical location • International accreditation provides a competitive advantage • Equipment range with professional personnel efficiently responds to market demand • Presently no competitive equivalent lab, so there is limited competition • The institutional structure offers an advantage over privately-owned competitors • Aiming for least profit operation comforts clients • Financial support from international funding agencies • Collaboration with the Chamber of Commerce & Industry • Opportunity to serve all around Africa and regional countries.	• High operating expenses • Dependency on local and regional electrical manufacturing industry • High employee turnover rate because of offers from other competitors and low wage rate in the region • No distinguishing services compared to competitor labs • The reluctance of funding agencies at the time of inception • Limited equipment listed by the lab • Innovative services are necessary for a healthy income base • No free limit to set pricing because of competition • Lack of anticipated demand in a specific segment of testing services
Opportunity	**Threat**
• Sizable customer base • First internationally accredited lab in the region • A geographical advantage to serve the large area • Potential to perform as a research and development center for innovation and to increase the income • First-mover advantage can be gained by studying the competitors	• Competition may arise from other Government-sponsored institutions • Deterioration in free competition by setting baseline prices by the government • Economic recession directly affects the energy sector, so the demand for services will be reduced • Reduction in standard services prices by privately-owned labs • Competitors have achieved breakeven, so they may drastically reduce the prices

4.3. Institutional Structure

A new lab can be established with the three shareholding alternatives:

i. Sole ownership of the beneficiary
ii. Public ownership (through major institutions, e.g., chambers, public institutions, associations, etc.)
iii. Public-private partnership (PPP) (private companies with controlling shares of public organizations)

Various researchers and experiences have suggested that the PPP structure successfully implements the anticipated project. This arrangement helps pitch dynamism from the private sector's viewpoint and simultaneously provides transparency owing to the participatory structure. Sole public ownership is relatively less flexible because of the slow decision-making process and dramatic changes in strategies. Full ownership of the private sector is not preferred, considering the impact of cartelization.

4.4. Benefits of International Accreditation

The lab will be established by adopting ISO, IEC, and IEEE standards to benefit from standardization as a powerful strategic tool [35]. The following main benefits will be addressed:

- Independent evaluation and recognition for high-level performance
- International recognition in terms of quality, reliability, and commitment
- Exchange of valuable information globally
- Acknowledgement of technical competencies
- Setting distinctions among the competitors
- Help in promoting the business

4.5. Key Success Factors

The lab will not be regarded as a conventional testing center where the services will be offered in terms of laboratory and innovation. The success of a lab depends on different factors that must be incorporated into the business model to ensure sustainability in the long run. First, long-term contracts may be secured with large-scale manufacturers for a constant revenue stream. Second, a well-conversant marketing setup can attract new clients and establish strong relationships with industry contributors. Furthermore, a comprehensive service experience can be developed, including lab work, design services, analysis, consultations, training, and follow-up supervision [36].

5. Financial Analysis

Following the economic contribution and technical and strategic assessments, financial analysis is imperative to identify the project's feasibility. Financial analysis broadly comprises the various financial parameters that are present. It estimates project profitability from the investor perspective by comparing the project against the expected revenue stream over the useful life of assets, as shown in Equation (3):

$$NV = R - CAPEX - K_f - OEPEX, \quad (3)$$

where NV Net Value, R revenue, $CAPEX$ capital expenditure, K_f Cost of finance, and $OPEX$ operating expenditure.

The prime objective of financial analysis is to examine the revenue generation capability of the project, which is sufficient to gain the desired ROI to create attractions for investors. Financial analysis results generally demonstrate the IRR, NPV, payback period, and profitability index (PI). Some investors, especially those where lending agencies are involved, are also interested in understanding the financial risk of the project; therefore, the debt service coverage ratio is also assessed.

The IRR is calculated through the trial-and-error method, as expressed by Equation (4), and the discounting rate equals the discounted future cash inflow with the CAPEX. It is the point of return where investors have neither loss nor profit, and NPV=0. It is calculated using the trial-and-error method.

$$IRR = r_a + \frac{NPV_a}{NPV_a - NPV_b}(r_b - r_a), \quad (4)$$

where r_a is the chosen lower discount rate, r_b is the higher discount rate, NPV_a is the NPV at r_a, and NPV_b is the NPV at r_b.

NPV represents the net of discounted cash inflows and outflows of the future stream over the project life, as shown in Equation (5). The NPV is calculated as the weighted average cost of capital (WACC), which comprises debt and equity costs. Projects with a positive NPV are acceptable for investment.

$$NPV = P_f - P_{OPEX} - P_{CAPEX}, \quad (5)$$

where NPV is the net present value, P_f represents the value of future cash inflows, P_{OPEX} is the present value of operating expenses, and P_{CAPEX} is the present value of capital expenditure.

The payback period indicates the period required to cover the amount invested in the initial CAPEX, as expressed in Equation (6). It is only possible with sufficient and stable net cash inflows over the useful life of the assets.

$$Payback\ priod = \frac{CAPEX}{Average\ annual\ revnue} \quad (6)$$

The PI indicates the earnings per dollar of the investment for the operation life of the assets. It is calculated using (7). The present value net of revenue and the OPEX of future cash flows are divided by CAPEX, which provides project PI. This tool is useful when multiple investment options are available, so a project with a higher PI will be attractive.

$$PI = \frac{\sum Present\ value\ of\ cash\ flows}{CAPEX} \quad (7)$$

The debt service coverage ratio (DSCR), also called the debt coverage ratio (DCR), is used to measure the debt capacity of the project to serve loan liabilities and can be calculated using Equation (8). EBITD indicates earnings before interest, taxes, and depreciation. However, this can be used with the entire lending amount, markup rate, and principal repayment scenario.

$$DSCR = \frac{EBITD}{Interst + Principal} \quad (8)$$

As discussed in the preceding paragraphs, CAPEX and OPEX are important components for cost estimation; therefore, it is necessary to identify the prime elements as follows [37]:

CAPEX – Equipment, erection, installation, land, civil works, interest during construction (IDC), and

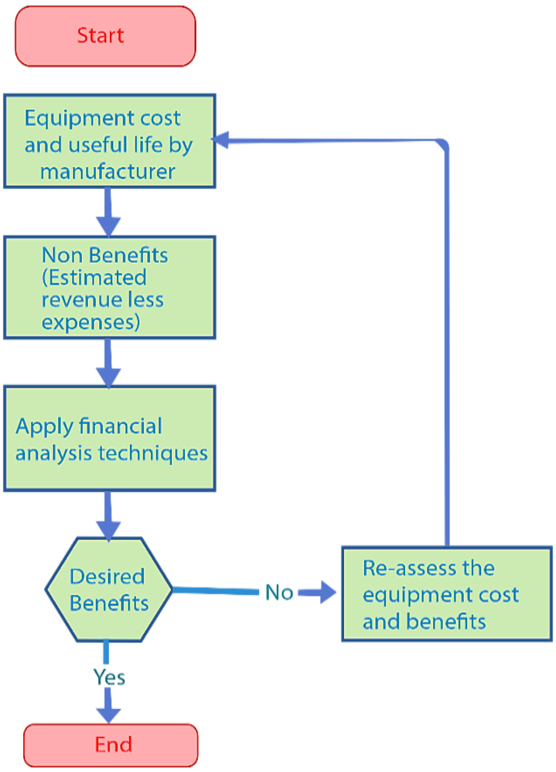

Fig. 4 Pseudocode flowchart for financial analysis

administrative expenses during the project implementation phase.

OPEX: personnel cost, stores and spares, maintenance expenses, office, and miscellaneous expenses.

The financial analysis can be carried out using the stated equations and flow chart, as shown in (Fig. 4).

The financial analysis stated in this study was based on tentative amounts from different consultants. The equipment selected for the financial analysis is the 2500 MVA Short Circuit generator (SCG) with tentative assumptions, as tabulated in Table 6.

Table 6. Assumptions for financial analysis

Description	Parameters
Cost of 2500 MVA SCG*	$26 million
Administrative and misc; expenses	3% of the total cost
Construction period	2 years
The useful life of the asset	25 years
WACC	13.9%
Operating expenses	30% of the revenue
Expected annual revenue stream**	$5.1 million

**Includes allied equipment and installation costs*
*** Revenue level to obtain the positive financial results*

The revenue stream is anticipated by accounting for the high testing frequency in collaboration with local and internal manufacturers. To achieve the desired quantum of revenue, it is necessary to onboard equipment manufacturers in the African region. This matter should also be considered while preparing a detailed feasibility analysis and raising matters at the government level [38]. Administrative and misc expenses are estimated as per the general practice used in different project evaluations. The useful life is taken from the manufacturer's defined operative life of the equipment. The WACC comprises two components–debt and equity–and is taken from the average return on the S&P 500. Using the aforementioned financial appraisal tools in MS Excel, the results were generated and are depicted in Table 7.

Table 7. Results of financial analysis

Description	Results
Internal Rate of Return (IRR)	14.2%
Net Present Value (NPV)	$398,896
Payback Period (PP)	7.28 years
Profitability Index (PI)	6.14

The results show an IRR of 14.2%, slightly below the market-rated WACC. The payback period and PI were remarkable. Although the NPV was positive, it is worth mentioning that this NPV can only be achieved with annual revenue of $5.1 million, which is very ambitious. Still, it can be attained by collaborating with local manufacturers, as discussed in the preceding sections.

5.1. Sensitivity Analysis

The sensitivity analysis played a supportive role in the analysis. It assesses the uncertainty and risk impacts of project implementation and operations. One or more factors can influence projects at a certain time [39]. The variations identified through a sensitive analysis provide insight into the sources of greater risk. In a project sensitivity analysis, under financial and economic conditions, the typical parameters are as follows:

- Investment amount
- Financing cost
- Expected revenue
- Operating expenses

6. Conclusion

This study indicates the importance of indigenous manufacturing, supported by a new state-of-the-art electrical testing laboratory in the African region. The new lab can serve a large region by employing in-lab, on-field, and innovative approaches. The is considered an essential asset for economic growth to enhance the GDP and create employment opportunities. This lab will primarily support the lab testing of different equipment at different voltage levels, which will later be enhanced in on-field facilities. The strategic assessment uses SWOT analysis, which shows reasonable strength and huge opportunity vis-a-vis weakness and threats. Therefore, an internationally accredited laboratory can promote local manufacturing and establish a sustainable business model. This situation was augmented in the financial analysis to identify the financial viability, which shows that a sizable annual revenue quantum is required to maintain the return on investment. Hence, while making detailed feasibility, it is equally necessary to raise matters at the national level to collaborate with the government and bring investors on board.

Funding Statement

The research is funded by Africa New Energies Limited (www.ane.na).

Acknowledgement

All the authors thank the United Arab Emirates University for their support. Special thanks to Mr. Muhammad Usama for his assistance.

References

[1] Abarca, Roberto Maldonado et al., “Labor Productivity Growth and Industrialization in Africa,” *New Communication and Information Systems*, 2021, 2013–2015.

[2] Amory B. Lovins, E. Kyle Datta, Thomas Feiler, Karl R. Rábago, Joel N. Swisher, André Lehmann, Ken Wicker et al., “*The Hidden Economic Benefits of Making Electrical Resources the Right Size*,” 1st Edition, London, 2002. https://doi.org/https://doi.org/10.4324/9781315073804.

[3] Amrin, Aslanbek K, and Nailya K, Nurlanova et al., "Innovation Activity: Localization, New Trends and Assessment Methods," *Engineering Economics,* vol. 31, no. 2, pp. 134-144, 2020. https://doi.org/10.5755/j01.ee.31.2.21501.

[4] Bekun, Festus Victor, Fırat Emir, and Samuel Asumadu Sarkodie et al., "Another Look at the Relationship between Energy Consumption, Carbon Dioxide Emissions, and Economic Growth in South Africa," *Science of the Total Environment,* vol. 655, pp. 759-765, 2019. https://doi.org/10.1016/j.scitotenv.2018.11.271.

[5] Belkhir, Mohamed, Narjess Boubakri, and Jocelyn Grira et al., “Political Risk and the Cost of Capital in the MENA Region,” *Emerging Markets Review*, Elsevier B.V, vol. 33, 2017. https://doi.org/10.1016/j.ememar.2017.08.002.

[6] Gochero, Plaxedes, and Seetanah Boopen et al., "The Effect of Mining Foreign Direct Investment Inflow on the Economic Growth of Zimbabwe," *Journal of Economic Structures*, vol. 9, no. 1, 2020. https://doi.org/10.1186/s40008-020-00230-4.

[7] Doğan, Buhari, Daniel Balsalobre-Lorente, and Muhammad Ali Nasir et al., "European Commitment to COP21 and the Role of Energy Consumption, FDI, Trade and Economic Complexity in Sustaining Economic Growth," *Journal of Environmental Management,* vol. 273, pp. 111146, 2020. https://doi.org/10.1016/j.jenvman.2020.111146.

[8] Govender, Inban, George Alex Thopil, and Roula Inglesi-Lotz et al., “Financial and Economic Appraisal of a Biogas to Electricity Project,” *Journal of Cleaner Production*, vol. 214, pp. 154-165, 2019. https://doi.org/10.1016/j.jclepro.2018.12.290.

[9] Kousky, Carolyn, Liesel Ritchie, Kathleen Tierney, and Brett Lingle et al., "Return on Investment Analysis and Its Applicability to Community Disaster Preparedness Activities: Calculating Costs and Returns," *International Journal of Disaster Risk Reduction*, vol. 41, pp. 101296, 2019. https://doi.org/10.1016/j.ijdrr.2019.101296.

[10] Lamjahdi, Aicha, Hafida Bouloiz, and Maryam Gallab et al., “Toward a Model to Apprehend the Complexity of Manufacturing Firm’s Overall Performance,” *International Journal of Engineering Business Management,* vol. 12, pp. 1-20, 2020. https://doi.org/10.1177/1847979020901982.

[11] Kang, Jiangjiang, Wei Xu, Li Yu, and Yueming Ning et al., "Localization, Urbanization and Globalization: Dynamic Manufacturing Specialization in the YRD Mega-City Conglomeration," *Cities,* vol. 99, pp. 102641, 2020. https://doi.org/10.1016/j.cities.2020.102641.

[12] Luo, Xiaoxiao, Qianbo Xiao, Qian Wang, and Zhiping Sheng et al., "A Novel Method for Distribution Transformer Short-Circuit Test," *Journal of Physics: Conference Series,* vol. 1885, no. 4, 2021. https://doi.org/10.1088/1742-6596/1885/4/042055.

[13] SV. Kulkarni, et al., “Transformer Engineering, Design, Engineering and Diagnostic,” *Edited by CRC Press, Taylor & Francis Group*, 2014.

[14] Korea Electric Research Institute, Technical Brochure, "Testing & Certification Services," [Online]. Available: https://www.keri.re.kr. Accessed on 04.04.2022.

[15] HV Technologies Inc. Technical Brochure, "HV Test Equipment," [Online]. Available: https://www.hvtechnologies.com. Accessed on 04.04.2022.

[16] Power Testing & Technology Institute Korea, Technical Brochure, [Online]. Available: https://www.ls-electric.com. Accessed on 04.04.2022.

[17] Al, R. Smeets et al., “*Short-Circuit Performance Tests*,” In: Ito H. (Eds) Switching Equipment, Edited by CIGRE Green Books, Springer, 2019.

[18] International Electrotechnical Commission, 2003. "International Standard International Standard," © IEC:2001, vol. 13, pp. 61010-1, 2003.

[19] Mandolfo, Marco, Shan Chen, and Giuliano Noci et al., "Co-Creation in New Product Development: Which Drivers of Consumer Participation?" *International Journal of Engineering Business Management,* vol. 12, pp. 1-14, 2020. https://doi.org/10.1177/1847979020913764.

[20] Al, KERI et. n.d.,"Testing and Certification Services," 2022. [Online]. Available: https://www.keri.re.kr/.Accessed on 10.04.2022.

[21] Day, Jerod et al., "High-Voltage Laboratory Testing of New Electrical Products," 2019.

[22] Carlson, et al., n.d. "Testing of Power Transformers," *ABB, Business Area Power Transformers*.

[23] Hauschild, Wolfgang, and Eberhard Lemke et al., "High-Voltage Test and Measuring Techniques," *High-Voltage Test and Measuring Techniques*, 2018. https://doi.org/10.1007/978-3-319-97460-6.

[24] Nielsen, Peter Bode, Morten Hørmann, Jakob Nymann Rud, and Frederik Møller Lauge et al., "Guide Report 3: Economic and Financial Analysis 2 Guide Report 3: Economic and Financial Analysis," 2016.

[25] Rizk, F. A., & Trinh, G. N et al., "High Voltage Engineerin," *CRC Press*, 2014.

[26] IEC60076-3. "Power Transformers, Part-3 Insulation Levels, Dielectric Tests and External Clearances in Air," In, Edition-3, 2013.

[27] IEC60076-1, "Power Transformers, Part-1 General," In, Edition-3, 2011.

[28] IEC60076-5, "Power Transformers, Part-5, Ability to Withstand Short Circuit," In, Edition-3, 2006.

[29] Tenbohlen, S., M. Beltle, and Martin Siegel et al., "PD Monitoring of Power Transformers by UHF Sensors," *Proceedings of the International Symposium on Electrical Insulating Materials*, vol. 1, pp. 303-306, 2017. https://doi.org/10.23919/iseim.2017.8088747.

[30] McKendry P et al., "Overview of Anaerobic Digestion and Power and Gas to Grid Plant CAPEX and OPEX Costs," *International Journal of Bioprocessing and Biotechniques Review Article McKendry P*, vol. 2, pp. 109, 2019. https://doi.org/10.20911/IJBBT-109.100009.

[31] US Bureau of Statistics, "Growth Rate in Electrical Field," *Electrical and Electronics Engineers*, 2021. [Online]. Available: https://www.bls.gov/. Accessed on 18.04.2022.

[32] Mo, John P.T., and Anthony Caporaso et al., "Simulation Analysis of Engineering Business Process in Asset Sustainment Activities Based on Total Cost of Ownership," *International Journal of Engineering Business Management*, vol. 13, pp. 1-19, 2021. https://doi.org/10.1177/18479790211010125.

[33] United Nations Industrial Development Organization (UNIDO), "Laboratory Policy: A Guide to Development and Implementation," 2021.

[34] "Business Plan for the Laboratory," no. 6, 2016. [Online]. Available: https://rekabetcisektorler.sanayi.gov.tr/ Date accessed: 04.04.2022.

[35] Singh, Manohar, Vishnuvarddhan Telukanta, and K. S. Meera et al., "An Innovative Solution for Type Testing of Power Transformers," *International Journal of Emerging Electric Power Systems,* vol. 20, no. 1, pp. 1-14, 2019. https://doi.org/10.1515/ijeeps-2018-0234.

[36] Sukathong, Sakonphot, Poonpong Suksawang, and Thanakron Naenna et al., "Analyzing the Importance of Critical Success Factors for the Adoption of Advanced Manufacturing Technologies," *International Journal of Engineering Business Management*, vol. 13, pp. 1-16, 2021. https://doi.org/10.1177/18479790211055057.

[37] Young, John H, and Allison P. Legister et al., "Project-Based Learning in International Financial Management," *Journal of Teaching in International Business*, vol. 29, no. 1, pp. 76-87, 2018. https://doi.org/10.1080/08975930.2018.145594

[38] S.M. Gubanski, P. Boss, Der Houhanessian, G. Csépes V., J. Filippini, P. Guuinic, U. Gäfvert, et al., n.d. "Dielectric Response Methods for Diagnostics of Power Equipment," Report of the TF D1.01.09 33 (0). [Online]. Available: https://e-cigre.org/publication/254-dielectric-response-methods-for-diagnostics-of-power-transformers, Date accessed: 22.04.2022.

[39] Wang, Dongyang, Lijun Zhou, Zhi Xin Yang, Yi Cui, Lujia Wang, Junfei Jiang, and Lei Guo et al., "A New Testing Method for the Dielectric Response of Oil-Immersed Transformer," *IEEE Transactions on Industrial Electronics*, vol. 67, no. 12, pp. 10833–10843, 2020. https://doi.org/10.1109/TIE.2019.2959500.