Journal of Engineering and Technology for Industrial Applications

ISSN 2447-0228

February 2022 Volume 08 / No 33

Editor-in-Chief: J. C. Leite

www.itegam-jetia.org

ITEGAM - JETIA ISSN 2447-0228 Online
Journal of Engineering and Technology for Industrial Applications (JETIA)

O **ITEGAM-JETIA: Journal of Engineering and Technology for Industrial Applications** is a publication of the Galileo Institute of Technology and Education of the Amazon (ITEGAM), located in the city of Manaus since 2008. JETIA publishes original scientific articles covering all aspects of engineering. Our goal is the dissemination of research original, useful and relevant presenting new knowledge on theoretical or practical aspects of methodologies and methods used in engineering or leading to improvements in professional practice. All the conclusions presented in the articles It should be state-of-the-art and supported by current rigorous analysis and balanced assessment. Public magazine scientific and technological research articles, review articles and case studies.
JETIA will address topics from the following areas of knowledge: Mechanical Engineering, Civil Engineering, Materials and Mineralogy, Geosciences, Environment, Information and Decision Systems, Processes and Energy, Electrical and Automation, Mechatronics, Biotechnology and other Engineering related areas.

Publication Information:
ITEGAM-JETIA (ISSN 2447-0228), (online) is published by Galileo Institute of Technology and Education of the Amazon on a every two months (February, April, June, August, October and December).

Contact information:

Web page: www.itegam-jetia.org
Email: editor@itegam-jetia.org
Galileo Institute of Technology and Education of the Amazon (ITEGAM).

Joaquim Nabuco Avenue, No. 1950. Center. Manaus, Amazonas. Brazil.
Zip Code: 69020-031. Phone: (92) 3584-6145.

ITEGAM - JETIA ISSN 2447-0228 Online
Journal of Engineering and Technology for Industrial Applications (JETIA)

ITEGAM-JETIA. v.8, n.33. February of 2022. Manaus - Amazonas, Brazil. ISSN 2447-0228 (ONLINE)
https://www.itegam-jetia.org

SUMMARY

Journal of Engineering and Technology for Industrial Applications

ISSN ONLINE: 2447-0228

ITEGAM-JETIA

Manaus, v.8 n.33, p. 4-12. Jan/Feb, 2022

DOI: https://doi.org/10.5935/jetia.v8i33.803

RESEARCH ARTICLE OPEN ACCESS

DESIGN OF A MULTI-LEVEL INVERTER FOR APPLICATIONS IN DISTRIBUTED GENERATION

Francisco Eneldo López Monteagudo*[1], Jorge de la Torre y Ramos[2], Erick Bernal Guerrero[3], Francisco Bañuelos Ruedas[4], Rafael Villela Varela[5], Claudia Reyes Rivas[6], Carlos Alberto Olvera Olvera[7], Santiago Villagrana Barraza[8] and Luis Octavio Solís Sánchez[9]

[1, 2, 3, 4, 5, 6, 7, 8, 9] Autonomous University of Zacatecas, Av. López Velarde No. 801 CP 98060 Zacatecas, Mexico.

[1] http://orcid.org/0000-0001-6082-1546, [2] http://orcid.org/0000-0002-6601-2050, [3] http://orcid.org/0000-0003-0263-3058, [4] http://orcid.org/0000-0003-3198-9715, [5] http://orcid.org/0000-0003-0088-4718, [6] http://orcid.org/0000-0001-9028-2096, [7] http://orcid.org/0000-0003-1519-7718, [8] http://orcid.org/0000-0002-8810-0801, [9] http://orcid.org/0000-0003-2545-4116

Email: *eneldolm@yahoo.com, jorgetorre@uaz.edu.mx, ericbguerrero@uaz.edu.mx, fbanuelosrs@hotmail.com, wrwrmx@yahoo.com.mx, clausy_17@yahoo.com, olveraca@gmail.com, svillagrana@uaz.edu.mx, lsolis@uaz.edu.mx

ARTICLE INFO

Article History
Received: December 15th, 2021
Accepted: February 21th, 2022
Published: February 28th, 2022

Keywords:
Selective harmonic elimination,
Multi-level inverter,
Cascading H bridges.

ABSTRACT

At present, the use of electricity generation systems through alternative sources of energy is continuously increasing, due to the increase in global energy demand, and a trend in which CO2 emissions are being reduced. As a result of these trends, the implementation of these energy sources has increased steadily in the last quarter of a century. For the integration of these alternative forms of electricity generation to be adequate, especially in the use of solar energy and wind energy, because it is necessary to condition them, it has become latent the need to implement electronic power devices such as inverters (continuous current - alternating current), which currently seek to have small, medium and high power sources of electricity, which meet the requirements of efficiency, quality and safety established by the Commission Federal de Electrician (CFE). In the present work, the design and the implementation of a DC/AC converter (direct current - alternating current) using a topology for the inverter of cascaded H - bridges with independent DC sources in a multilevel configuration of 11 voltage levels of control. Applying the technique of the Selective Harmonic Elimination modulation, technique that allows it by Fourier series analysis appropriately chooses the switching angles for the elimination of harmonics of the most significant low frequency.

I. INTRODUCTION

At present, the use of electricity generation systems through alternative sources or renewable sources of energy (FRE) increases continuously, due to the increase in world energy demand. With the increase in alternative sources of energy interconnected to the electricity system, it is necessary to use new distributed generation strategies with a significant impact on the reduction of CO2 emissions and other pollutants to the environment, which makes the implementation of the FRE, such as geothermal, hydroelectric, tidal, wind or solar plants [1].

With the increase in alternative sources of energy interconnected to the electricity system, it is necessary to use new distributed generation strategies with a significant impact on the reduction of CO2 emissions and other pollutants to the environment, which makes the implementation of the FRE. In the Mexican electricity sector, a growth of alternative energy sources is projected in distributed generation systems interconnected to the RED [2].

The secretary of energy (SENER), projects an average annual growth of 3.5% for the next 15 years. To place the gross consumption at the end of 2029 at 471.59 TWh, while in 2014 the gross consumption was 280.1 TWh. For interconnection in Mexico, standards are established that contribute to increasing the efficiency of alternative energy systems [3].

New technologies based on multilevel converters have been developed mainly in the field of photovoltaic and wind applications with connection to the grid [4].

In the search for a better quality of electrical energy, different inverters have been developed with multilevel technology with a low percentage of total harmonic distortion (DAT) [5]. Among multilevel inverters, three topologies stand out: floating capacitor, anchored diode and cascade H bridges, which have applications in medium and high power, the development of this research is focused on the cascade H bridges topology using a single power source. DC. The main advantage of this structure is the reduced number of semiconductors and firing control circuits, as well as better quality and voltage efficiency, which makes the cascade H-bridge inverter a perfect candidate for photovoltaic applications [6] .

Different modulation techniques can be applied to control a multilevel inverter, some based on high frequency Pulse Width Modulation (MAP), and others with fundamental switching frequency. But there is one that stands out due to its characteristics is the modulation technique known as selective harmonic elimination (ESA). This modulation approach reduces the number of carriers reducing switching losses, total harmonic distortion (DAT) and thus increases the power quality (CP) [7]. There are different algorithms for the application of the ESA, one of them is the genetic algorithm which allows to minimize the selective harmonics and therefore the DAT, this algorithm allows to determine optimal switching angles to eliminate some lower order harmonics, minimizing the distortion of total harmonics, while maintaining the required fundamental voltage [8]. This technique can be applied to multi-level investors with any number of levels.

II. TOPOLOGIES OF MULTILEVEL INVERTERS

Several multilevel converter topologies have been developed, the most common being the H-bridge cascade converters, the anchored diode converter, and the floating capacitor converter, source [9].

II.1 ANCHORED DIODE MULTI-LEVEL INVERTERS

The anchored diode multilevel inverter (IMDA) is characterized by dividing the continuous supply voltage into a certain amount of levels by means of series connected capacitors, the topology for a three-level IMDA is shown in figure 1.

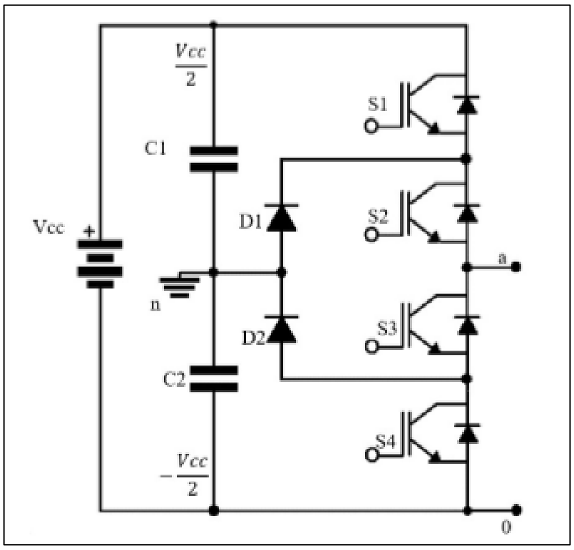

Figure 1: Three Level Anchored Diode Topology.
Source: [9].

In the IMDA topology the number of necessary capacitors is considered (m − 1), in which "m" represents the number of levels of the inverter. In addition, (m − 1) (m − 2) / 2 interlocking diodes are also required, which must be able to block the voltage coming from the capacitor and thus limit the voltage stress of the power devices. As the number of control levels increases, the quality of the output voltage improves and the waveform resembles a sine wave [9].

II.2 MULTILEVEL INVERTERS WITH FLOATING CAPACITORS

The structure of the multilevel floating capacitor (IMCF) inverter is similar to that of IMDA but uses capacitors instead of diodes to set voltage levels. Figure 2 shows the electronic diagram of a three-level single-phase inverter.

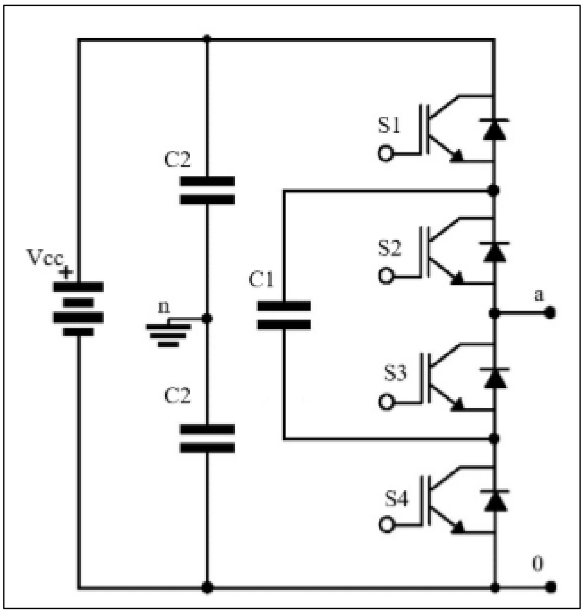

Figure 2: Inverter Topology with Three-Level Floating Capacitors.
Source: [9].

The IMCF of figure 2, for its construction requires (m − 1) capacitors, 2 (m − 1) switches for m desired voltage levels at the output and (m − 1) (m − 2) / 2 auxiliary capacitors per phase. Each capacitor must maintain a fixed voltage; however, because the capacitors are not always charged, the converter has great problems keeping voltage levels balanced. In this case, the modulation technique implemented must correct said problem by implementing a very complex control; furthermore, in this topology it is necessary to previously charge the capacitors before starting to operate as an inverter, therefore, the start-up becomes slow [9].

II.3 MULTILEVEL INVERTERS WITH CASCADE CONNECTED H-BRIDGES

The cascade connected H-bridge multilevel inverter topology (IMPHC) is based on the series connection (or cascade) of several three-level inverters, which are constituted as cells and each of them is powered by a power source independent direct current (DC), which avoids the use of interlocking diodes [9]. Figure 3a shows the topology of a cascade inverter with asymmetric sources and figure 3b shows the waveform for 7 levels.

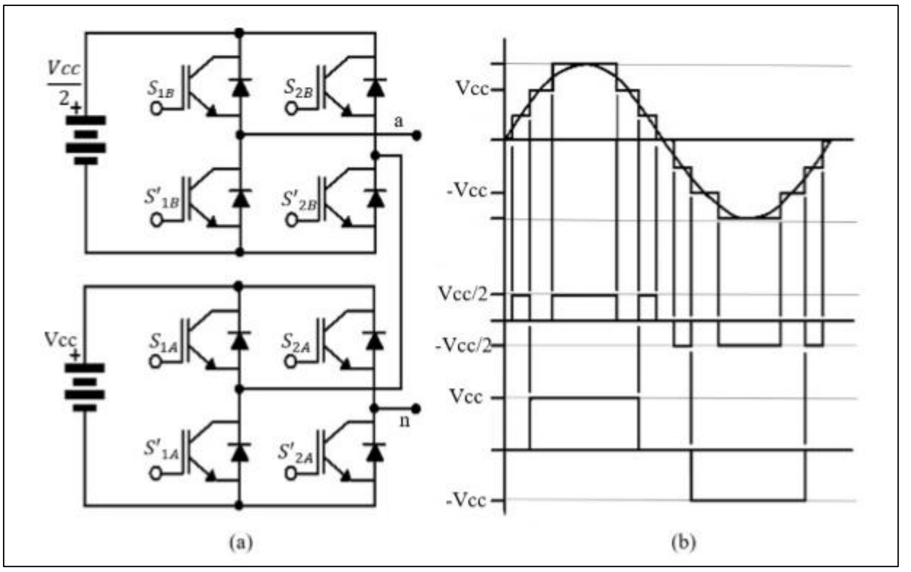

Figure 3: (a) Inverter topology in cascade with asymmetric sources, (b) Waveform for 7 levels.
Source: [9].

As seen in figure 3 (a), the output wave voltage is the sum of the voltages that are generated in each cell, these voltage sums make up a quasi-sinusoidal output wave through different switching arrangements of the semiconductor power devices (DSP), with the option of being controlled by the different existing switching techniques.

Due to its characteristic of having independent DC sources, one of the main advantages of topologies of this type is the possibility of easily increasing the number of levels by adding cells in cascade without having to redesign the power stage. Within the IMPHC, two classifications arise, those that have symmetrical and asymmetric sources, the difference between them lies in the magnitude of the power supply of each inverter. Symmetric inverters require that the power supplies have the same magnitude, while asymmetric ones have voltage sources of different values [9]. This is reflected in the number of levels that can be generated based on the same power-up sequence. Resulting in asymmetric inverters they can generate more voltage levels than symmetric ones.

For an IMPHC of symmetric sources, in this the number of voltage levels at the output is given by m = (2n + 1). Where "m" represents the number of levels, and "n" the number of cells of the inverter. In this inverter the number of voltage levels that can be obtained are 2Vcc, Vcc, 0, -Vcc and -2Vcc. For this type of inverter, in a con figuration with two cells and symmetrical sources, up to five levels can be obtained [9].

In the same way, for a configuration of two cells in cascade, where the second power supply is scaled to twice the first source, there is an IMPHC of asymmetric sources, as can be seen in Figure 3 (a). The generalized waveform for an inverter with 7 voltage levels can be seen in Figure 3 (b), which can be generated from different DSP switching sequences. Table 1 shows the most common sequence used in the literature consulted.

Table 1: Switching sequences for a 7-level IMPHC.

Voltage	S_{1A}	$S´_{1A}$	S_{2A}	$S´_{2A}$	S_{1B}	$S´_{1B}$	S_{2B}	$S´_{2B}$
1.5 Vcc	1	0	0	1	1	0	0	1
Vcc	1	0	0	1	0	1	1	0
0.5 Vcc	0	1	0	1	1	0	0	1
0	0	1	0	1	0	1	0	1
-0.5 Vcc	0	1	0	1	0	1	1	0
- Vcc	0	1	1	0	1	0	0	1
-1.5 Vcc	0	1	1	0	0	1	1	0

Source: Authors, (2021).

The switching sequence most commonly used in IMPHCs of asymmetric sources to obtain 7 voltage levels is indicated in table 1, where “0” represents that the DSP is off and “1” that the DSP is on.

In the IMPHC of asymmetric sources, up to nine voltage levels can be obtained, a scaling three times greater than the other, this being the maximum number of levels to control as established in equation 1:

$$m = 3^n \tag{1}$$

Where:

“m” represents the number of levels of the inverter, and “n” represents the number of cells of the IMPHC of asymmetric sources.

In the same way, more H bridge cells can be added, each one with its independent DC source and in this way increase the number of levels, being that in an inverter with 3 H bridge cells according to Equation 1 the number of voltage levels will be 27, this configuration being sufficient to meet the objective of this project to degenerate 11 voltage levels.

III. MODULATION TECHNIQUES

The modulation techniques for multilevel algorithms are programs or electronic circuits that manage the DSPs, so that certain levels of the inverter are turned on or off, at the same time they are in charge of regulating the amplitude, frequency and minimizing the harmonic content of the voltages and Inverter output currents, and depending on the topology, it must be in charge of maintaining the balance of the capacitors in the DC bus. The main modulation techniques for multilevel inverters are shown in figure 4.

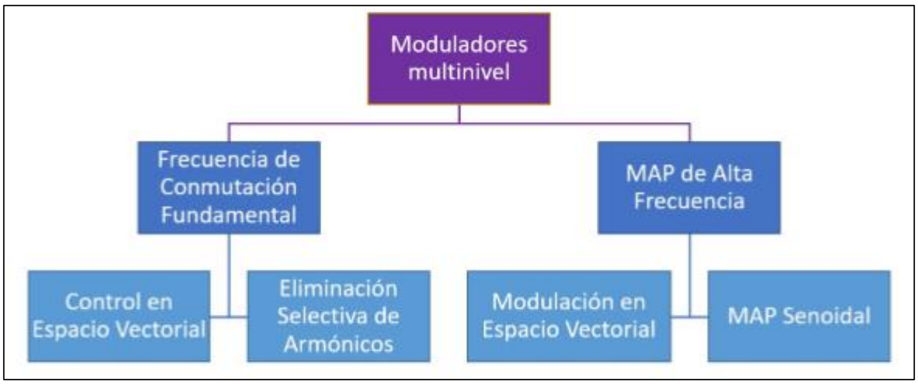

Figure 4: Classification of multilevel modulation methods.
Source: [9].

Figure 4 shows the scheme of the main modulation techniques, which are derived in two main aspects. In the first aspect are those that work at a High Frequency MAP in which there are Modulation in Vector Space and those of multilevel sinusoidal MAP and in the second there are those that work at a Fundamental Switching Frequency, that is, that They work at the frequency of oscillation of the electrical network, within these there are the Control in Vector Space (CEV), and the Selective Elimination of Harmonics (ESA). The importance of modulation techniques is due to the fact that they define the performance of multilevel inverters.

IV. MULTILEVEL INVERTER DESIGN

A prototype of an 11-level multilevel inverter was designed and built using the selective harmonic elimination (SHE) technique, which works autonomously, adjusting to the frequency changes that exist in the electrical grid.

IV.1 MULTILEVEL INVERTER POWER STAGE

The multilevel inverter topology of H bridges connected in cascade with asymmetric sources (IMPHC-FA), is the topology that is best adapted for the development of the multilevel inverter with 11 voltage levels. The IMPHC-FA topology developed for the 11-level inverter design is shown in Figure 5.

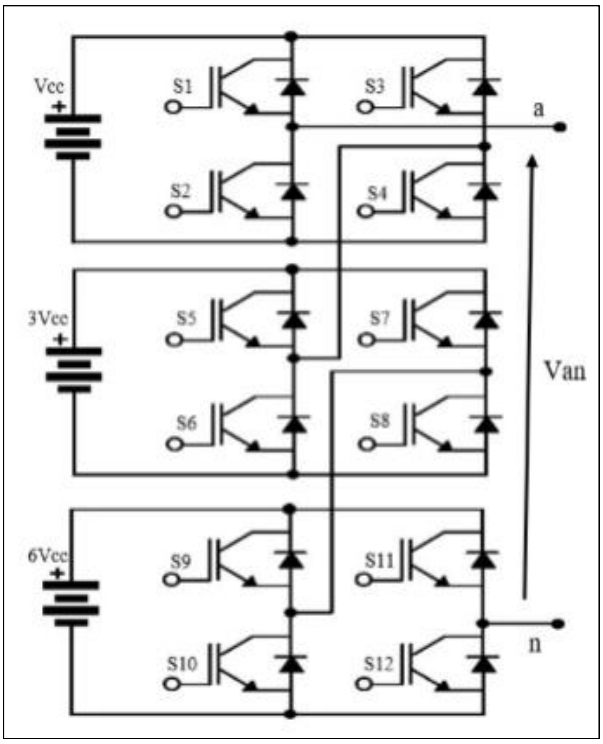

Figure 5: Multilevel inverter with three H-bridges and asymmetric sources.
Source: [9].

From equation 1 it is verified that the proposed topology for the multilevel inverter will be able to provide the 11 voltage levels and thus obtain a quasi-sinusoidal output signal. Digital Signal Processors (DSP) are used to control the IMPHC-FA inverter.

V. MODULATION AND CONTROL STAGE OF THE MULTILEVEL INVERTER

For an adequate selection of DSPs for the control of the IMPHC-FA, it is necessary to know the maximum power, voltages and currents that the power supplies are capable of supplying, which must be independent for each of the H-bridges of the multilevel inverter.

The multilevel inverter developed is powered by a 320W photovoltaic panel, with a maximum voltage and current of 37.4V and 8.56A, which has DC sources designed to operate with the parameters indicated in table 2.

Table 2: Parameters of independent DC sources.

Source	Voltage source (V)	Rated current (A)	Maximum current (A)
Vcc	31.1	0.255	0.856
3 Vcc	93.3	0.755	2.568
6 Vcc	186.6	1.53	5.136

Source: [9].

From table 2 it is observed that the maximum input current is 1.53A, but added to the two smaller bridges, the maximum current for the DSPs is 8.56A, in the same way the blocking voltages have to be considered, which is given by VCC/2. Therefore, an IGBT IRGB4062D transistor was selected as DSP for switching in the multilevel inverter, its main characteristics are shown in table 3.

Table 3: Characteristics IRGB4062D.

V_{CE} (collector emitter voltage)	600V
I_C (collector current)	24A
I_C pulsed (pulsed collector current)	72A
PD (dissipated power)	125W → 200W
Tj (junction temperature)	55◦C → +175◦C
Rθjc (joint thermal resistance)	0.60◦C/W
Rθcd (thermal resistance of sink)	0.50◦C/W

Source: [9].

The selected IGBT IRGB4062D transistor has internally a soft recovery diode in parallel with the transistor which is responsible for protecting the IGBT transistors from reverse currents. Figure 6 shows the power stage for an H-bridge.

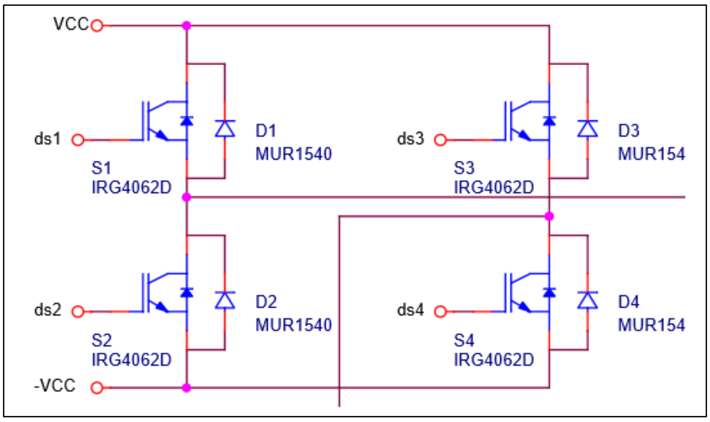

Figure 6: Power stage for an H-bridge.
Source: [9].

The design of the control stage is developed simultaneously with the design of the power stage, given its importance for an adequate switching of the DSPs, as well as to be able to control the voltage and current levels, keeping them at constant levels to allow an adequate interconnection of the multilevel inverter to the electricity grid.

The control strategy used is based on Selective Harmonic Elimination (ESA), which, in addition to maintaining constant voltage and current levels, has the characteristic of being able to selectively eliminate low-frequency harmonics, reducing the percentage of harmonic distortion total (DAT), also only filters are used to eliminate high frequency harmonics.

For the use of the ESA, it is necessary to consider the output waveform of the multilevel inverter, for the above, the generalized waveform for 11 voltage levels is proposed, which can be seen in figure 7.

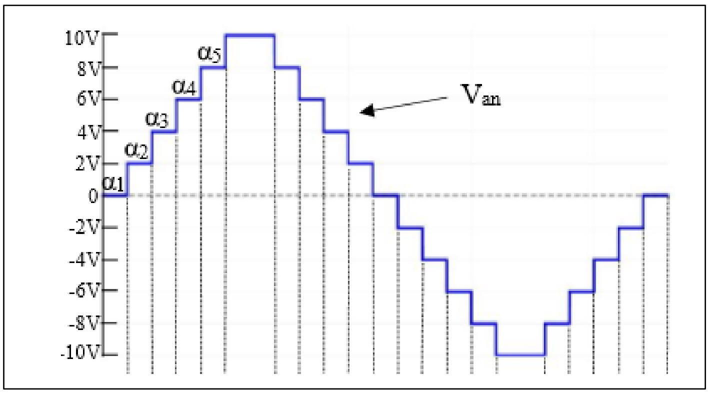

Figure 7: Generalized waveform for an inverter with 11 voltage levels.
Source: [9].

From the generalized waveform of Figure 7, the waveforms that each of the H-bridge cells of the multilevel inverter will have can be determined. Figure 8 shows the waveforms for each H-bridge of the 11-level inverter.

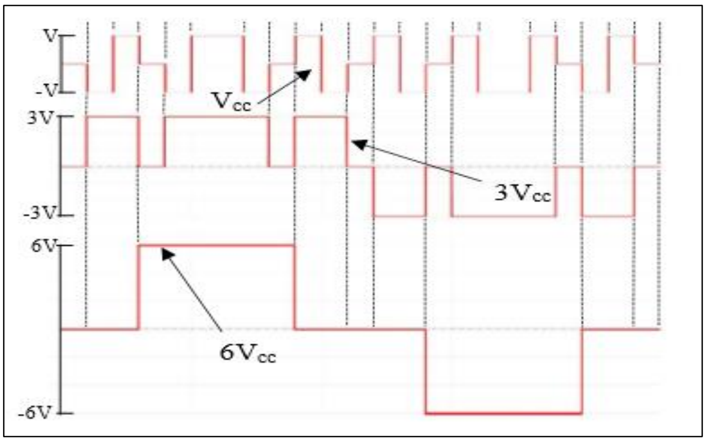

Figure 8: Waveform determined for each H-bridge of the 11-level multilevel inverter.
Source: [9].

Figure 8 shows the output waveform that was determined for each of the H bridge cells, where each one represents the inverter cell with the same name of the desired power supplies for the 11 inverter levels that is Vcc, 3Vcc and 6Vcc.

From the waveforms that were determined in figure 8, it is possible to obtain the switching sequences for each of the IGBT transistors. Table 4 shows the switching sequences for the 11-level multilevel inverter.

Table 4: Switching sequences for the 11-level multilevel inverter.

Volts	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
0	0	1	0	1	1	0	1	0	1	0	1	0
2	0	1	1	0	1	0	0	1	1	0	1	0
4	1	0	0	1	1	0	0	1	1	0	1	0
6	1	0	1	0	1	0	1	0	1	0	0	1
8	0	1	1	0	1	0	0	1	1	0	0	1
10	1	0	0	1	1	0	0	1	1	0	0	1
8	0	1	1	0	1	0	0	1	1	0	0	1
6	1	0	1	0	1	0	1	0	1	0	0	1
4	1	0	0	1	1	0	0	1	1	0	1	0
2	0	1	1	0	1	0	0	1	1	0	1	0
0	0	1	0	1	1	0	1	0	1	0	1	0
-2	1	0	0	1	0	1	1	0	1	0	1	0
-4	0	1	1	0	0	1	1	0	1	0	1	0
-6	1	0	1	0	1	0	1	0	0	1	1	0
-8	1	0	0	1	0	1	1	0	0	1	1	0
-10	0	1	1	0	0	1	1	0	0	1	1	0
-8	1	0	0	1	0	1	1	0	0	1	1	0
-6	1	0	1	0	1	0	1	0	0	1	1	0
-4	0	1	1	0	0	1	1	0	1	0	1	0
-2	1	0	0	1	0	1	1	0	1	0	1	0
0	0	1	0	1	1	0	1	0	1	0	1	0

Source: Authors, (2021).

These switching sequences for each of the IGBT transistors, which are observed in table 4, where "1" indicates that the IGBT is on and "0" that it is off, are complemented by the switching or tripping times that They will be obtained through the ESA application, thus allowing them to be obtained at the inverter output.

The control stage was implemented with an ATMEGA 2560 micro-controller, found in Arduino boards which uses the open source programming language, the schematic diagram is shown in figure 9, [10].

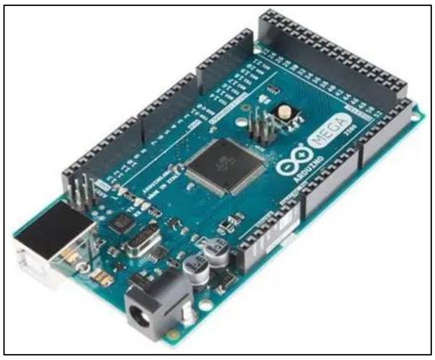

Figure 9: Arduino MEGA 2560.
Source: [10].

Said control stage based on the ATMEGA 2560 micro-controller in Figure 9, focuses on the processing of the switching sequences for the inverter transistors, taking the zero-crossing reference signal from the grid for its start, as well as real-time monitoring of voltage and current signals, which will allow knowing the frequency, power factor and harmonic spectrum values.

The control stage must be completely isolated from the power stage of the multilevel inverter and from the reference signals of the grid, so it is necessary to implement opto-couplers and a conditioning stage for the switching sequences. According to the characteristics of the Arduino MEGA, it can only provide outputs of maximum 5V and 50mA and according to the requirements of the IGBT IRGB4062D transistor it needs an input in its gate of 20V and 200nA.

For the design of the trigger conditioning stage of the IGBT transistors, the 4n26 opto-coupler was selected for the isolation of the control stage and the IR2101 driver for conditioning the trigger signals, which is capable of conditioning voltage and current at constant levels for use in IGBT transistors.

The conditioning circuit for the trigger signals was con fi gured to obtain at the output of the IR2101 driver the 20V output required by the IGBT transistor, this circuit that is observed in Figure 10, that is, opto-coupler, driver, and transistor is useful for half a bridge so it will be necessary to implement 6 similar circuits.

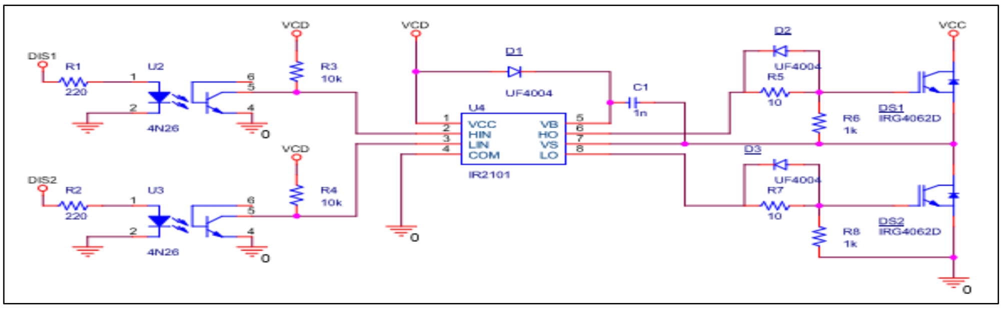

Figure 10: Conditioning circuit for trigger signals.
Source: Authors, (2021).

The switching signals are processed in the micro-controller and directed through the outputs of the digital pins towards the opto-couplers, in order to isolate the control stage, the signal that comes out of the opto-coupler, will be the input of the driver which will be injected into the gate of the IGBT transistor to turn it on and off.

VI. TESTS AND RESULTS

Different tests were carried out on the developed prototype, in the same way the results obtained by means of a commercial network analyzer system (Fluke 43BPowerQualityAnalyzer) are shown, which allows, among other functions, to obtain the values calculated in the prototype.

To carry out the initial tests of the system, a purely resistive load was implemented.

Figure 11 shows the voltage, current and power waveforms obtained by the prototype for a purely resistive load fed by the multilevel inverter and figure 12 shows the voltage and current waveforms for the Fluke 43B system.

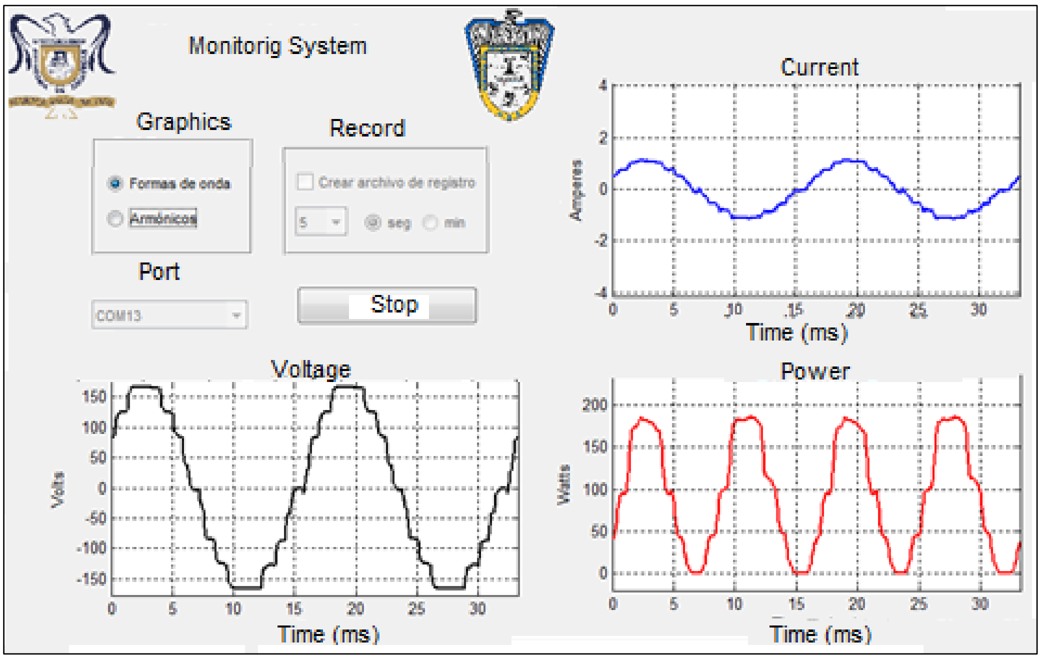

Figure 11: Waveforms obtained in the prototype with the multilevel inverter and resistive load.
Source: Authors, (2021).

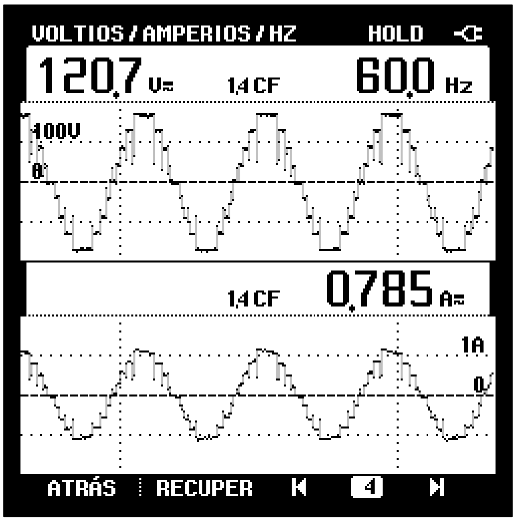

Figure 12: Waveforms Obtained by Fluke 43B Analyzer with Multilevel Inverter and Resistive Load.
Source: Authors, (2021).

Figure 13 shows the graphs of voltage, current and power harmonic components obtained by means of the prototype for a purely resistive load fed by the multilevel inverter, and figure 14 shows the voltage, current and power harmonic components corresponding to the Fluke 43B system.

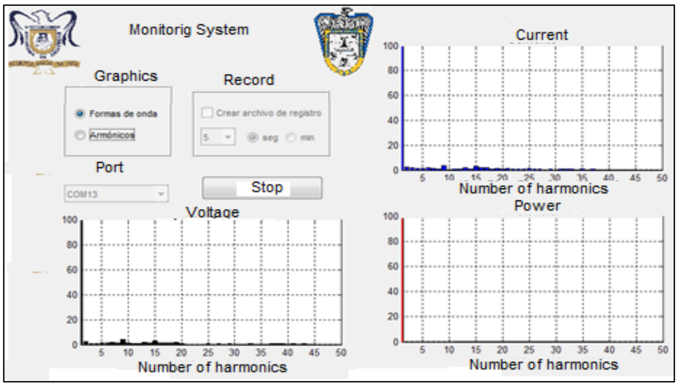

Figure 13: Harmonic components obtained through the prototype with the multilevel inverter and resistive load.
Source: Authors, (2021).

Figure 14: Harmonic components obtained by Fluke 43B analyzer in multilevel inverter with resistive load.
Source: Authors, (2021).

Figure 15 shows the voltage, current and power waveforms obtained by the prototype for a resistive-inductive load fed by the multilevel inverter, and figure 16 shows the voltage and current waveforms for the Fluke 43B system.

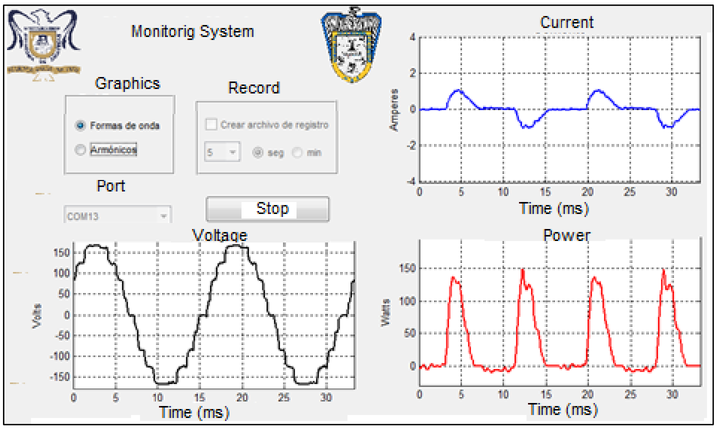

Figure 15: Waveforms obtained with the prototype in the multilevel inverter and inductive-resistive load.
Source: Authors, (2021).

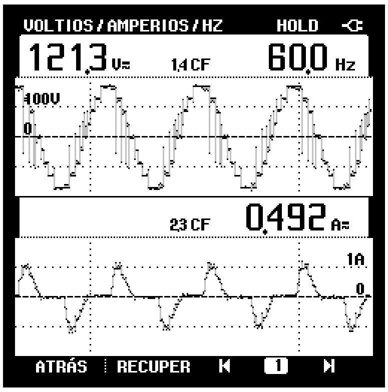

Figure 16: Waveforms Obtained by Fluke 43B Analyzer on Multilevel Inverter with Resistive Inductive Load.
Source: Authors, (2021).

Figure 17 shows the graphs of voltage, current and power harmonic components obtained by means of the prototype for a resistive-inductive load fed by the multilevel inverter, and figure 18 shows the voltage, current and power harmonic components corresponding to the Fluke 43B system.

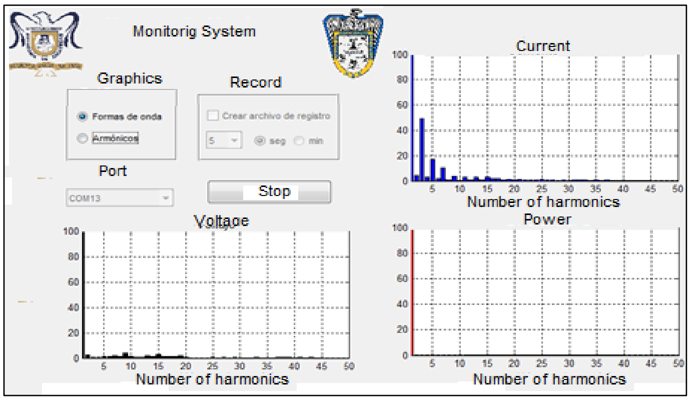

Figure 17: Harmonic components obtained through the prototype in the multilevel inverter with inductive-resistive load.
Source: Authors, (2021).

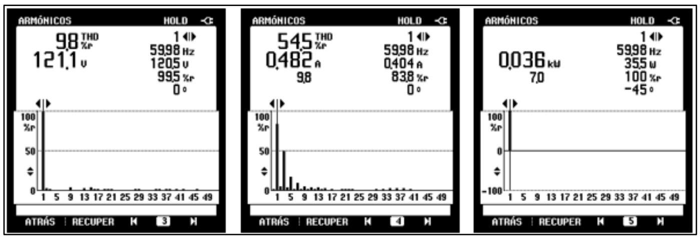

Figure 18: Harmonic components obtained by Fluke 43B analyzer in multilevel inverter with inductive-resistive load.
Source: Authors, (2021).

VII. CONCLUSIONS

Using the methodology developed in this article, the system reproduces the waveforms of voltage, current, power and harmonic components present in the electrical network, in addition, it calculates values of voltage and effective current, active, reactive and apparent power, network frequency and power factor with an acceptable level of precision which allows an accurate record of electrical energy consumption to be carried out.

For the control of the multilevel inverter, the selective harmonic elimination (SHE) technique was used, which is a static modulation technique, so the prototype works autonomously, adjusting to the frequency changes of the electrical NETWORK, which It was synchronized by a transformer.

The prototype shows a low percentage of error compared to the values obtained using commercial systems.

With the magnitudes of voltage, current, power and harmonic components, obtained with the prototype, the quality of electrical energy can be improved, thus avoiding penalties from the electricity company.

VIII. AUTHOR'S CONTRIBUTION

Conceptualization: Francisco Eneldo López Monteagudo, Jorge de la Torre y Ramos and Erick Bernal Guerrero.
Methodology: Francisco Eneldo López Monteagudo and Jorge de la Torre y Ramos.
Investigation: Francisco Eneldo López Monteagudo, Jorge de la Torre y Ramos, Erick Bernal Guerrero, Francisco Bañuelos Ruedas, Rafael Villela Varela, Claudia Reyes Rivas, Carlos Alberto Olvera Olvera, Santiago Villagrana Barraza and Luis Octavio Solís Sánchez.
Discussion of results: Francisco Eneldo López Monteagudo, Jorge de la Torre y Ramos and Erick Bernal Guerrero.
Writing – Original Draft: Francisco Eneldo López Monteagudo, Jorge de la Torre y Ramos and Erick Bernal Guerrero.
Writing – Review and Editing: Francisco Eneldo López Monteagudo, Jorge de la Torre y Ramos and Erick Bernal Guerrero.
Resources: Francisco Eneldo López Monteagudo, Jorge de la Torre y Ramos and Erick Bernal Guerrero.
Supervision: Francisco Eneldo López Monteagudo, Jorge de la Torre y Ramos and Erick Bernal Guerrero.
Approval of the final text: Francisco Eneldo López Monteagudo, Jorge de la Torre y Ramos and Erick Bernal Guerrero.

IX. ACKNOWLEDGMENTS

We thank the Autonomous University of Zacatecas and the Zacatecano council of science and technology for the support for the realization of this article

X. REFERENCES

[1] H. Catalán, «Impacto de las energías renovables en las emisiones de gases efecto invernadero en México», RPD, vol. 52, n.º 204, dic. 2020. A. Fragoso Altamirano, México y su transición energética: un cambio en pro de la energía Renovable, LADEE, vol. 1, n.º 1, pp. 26-42, nov. 2020.

[2] C. Bonilla, La regulación de las energías renovables en México, RILCO, ISSN 26956098, Nº. 6 (Abril), 2020.

[3] J. Gutiérrez Villegas, R. Quiroz Martínez, R. Torres Núñez y G. Mejía Pérez, Evolución de la normatividad y su impacto en el aumento de los Sistemas Fotovoltaicos instalados en México, ROT, Septiembre 2018 Vol.2 No.7 1-6

[4] M. Pietzch García, "Convertidores CC/CA para la conexión directa a red de sistemas fotovoltaicos: comparación entre topologías de 2 y 3 niveles" Bachelor's Thesis, Universidad Politécnica de Cataluña, 2004.

[5] R. Mahalakshmi and K. Thampatty, "Grid Connected Multilevel Inverter for Renewable Energy Applications", Procedia Technology, vol. 21, pp. 636-642, 2015.

[6] M. Bakhshizadeh, H. Iman-Eini and F. Blaabjerg, "Selective Harmonic Elimination in Asymmetric Cascaded Multilevel Inverters Using a New Low-frequency Strategy for Photovoltaic Applications", Electric Power Components and Systems, vol. 43, no. 8-10, pp. 964-969, 2015.

[7] Shehu, T. Yalcinoz and A. Kunya, "Modelling and Simulation of Cascaded H-Bridge Multilevel Single Source Inverter Using PSIM", International Science Index, Energy and Power Engineering, vol. 8, no. 5, pp. 756-761, 2014.

[8] C. Sarkar, S. Saha, P. Saha and G. Panda, "Selective Harmonics Elimination Of Cascaded Multilevel Inverter Using Genetic Algorithm", International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE), vol. 2, no. 12, pp. 935-939, 2013.

[9] R. Cabrera Ovalle, "Implementation of an electrical energy quality and consumption monitoring system in a multilevel single-phase inverter," M.S. thesis, University of Zacatecas, Zacatecas, ON, Mexico, 2019.

[10] https://programarfacil.com/blog/arduino-blog/arduino-mega-2560/, Accessed August 10, 2021.

Journal of Engineering and Technology for Industrial Applications

ITEGAM-JETIA

Manaus, v.8 n.33, p. 13-20. Jan/Feb, 2022
DOI: https://doi.org/10.5935/jetia.v8i33.802

ISSN ONLINE: 2447-0228

RESEARCH ARTICLE OPEN ACCESS

PHOTOVOLTAIC GENERATION PREDICTION USING THE DEEP LEARNING LONG SHORT TERM MEMORY MODEL

Reinier Herrera Casanova*[1] and Lesyani León Viltres[2]

[1, 2] Central University "Marta Abreu" of Las Villas. Santa Clara, Cuba.

[1] http://orcid.org/0000-0002-3303-2063, [2] http://orcid.org/0000-0003-1822-2480

Email: *herreracasanovareinier@gmail.com, lesyani.leon@gmail.com

ARTICLE INFO

Article History
Received: December 15th, 2021
Accepted: February 21th, 2022
Published: February 28th, 2022

Keywords:
Photovoltaic system,
PV power prediction,
LSTM,
Deep learning.

ABSTRACT

Solar photovoltaic energy is a renewable, clean and safe energy source that is currently used worldwide. However, it presents a dynamic and intermittent behavior, caused by the variation of climatic conditions. Due to this, it has been necessary to develop different methods for the prediction of the energy generated in photovoltaic systems. The present work is focused on analyzing the prediction of the power generated in a photovoltaic plant connected to the grid, by means of the Long Short-Term Memory (LSTM) deep learning model. In order to carry out the study, a database obtained from the photovoltaic plant of the Central University "Marta Abreu" of Las Villas (UCLV) with a nominal installed power of 1.1 MW is used. Initially, the correlation between the different variables with respect to the photovoltaic power generated is analyzed, then the LSTM model is implemented to make the prediction. The results obtained show that the predictions made for different time horizons and for days with different behavior are adequate, which demonstrates the effectiveness of this prediction method.

I. INTRODUCTION

Currently, the planet shows an increase in energy needs driven by the technological and economic development of society. One of humanity's major problems is its dependence on fossil fuels, as they cause a strong environmental impact, in addition to various changes in the economic sphere. The challenge is to ensure that renewable energy sources gradually replace traditional fossil fuels. The main advantage of renewable energies is their lower environmental impact, as they reduce the number of pollutants in the atmosphere, as well as their less concentrated territorial distribution. They are continuous and inexhaustible energy sources, making them the alternative of the future [1].

One of the most widely used renewable sources today is solar energy. Photovoltaic (PV) systems connected to electrical grids are one of the distributed generation technologies with the greatest impact and growth in recent years. In fact, the world's annual solar PV capacity has increased exponentially over the last ten years. It is now the cheapest type of energy in a large number of countries due to substantially lower production costs of PV modules [1].

Atmospheric variables, such as solar irradiance, temperature, humidity and cloud properties, can directly and indirectly influence PV power generation. The dependence of the electrical energy generated in a photovoltaic farm on weather conditions, and the high variability of these conditions, make the problem of predicting the energy generated in a photovoltaic farm a complex task [2].

The future time period for PV generation prediction, or the duration between the actual time and the effective time of prediction is the forecast horizon [3]. Some researchers propose three categories for the forecast horizon: short term (up to 24 hours), medium term (1 day-1month), and long term (1month-1year). Others have added a fourth category based on the requirements of the decision-making process for smart grids or microgrids, aptly named very short-term or ultra-short-term (less than 1 hour) forecast horizon. However, so far there is no universally agreed classification criterion [4].

The large-scale penetration of PV in today's power systems requires forecasting models to operate the power grid economically and reliably [5]. Accurate solar forecasting eliminates the impact of uncertainty of solar PV power production, improves system stability, increases the penetration level of the PV system, and reduces the maintenance cost of auxiliary devices. In addition, it is a powerful tool that helps power system operators and designers to model and manage solar PV plants efficiently [6].

Since the very emergence of photovoltaic plants, several techniques have been developed to achieve predictive models that contribute to the improvement of the management of these plants. Currently, intensive work is being done in the application of artificial intelligence tools for the development of these types of models, based on the proven capacity of these techniques in the handling of information contained in large volumes of data obtained from the systems under study.

The photovoltaic plant of the Central University "Marta Abreu" of Las Villas (UCLV), in the province of Villa Clara in Cuba, has a nominal power of 1.1 MW, was put into operation in 2019 and is located in the southwest area of the Faculty of Electrical Engineering of the Central University "Marta Abreu" of Las Villas, at 22.4° north latitude and 79.96° west longitude.

This photovoltaic plant has the necessary characteristics to develop prediction models that can contribute to the above mentioned. In particular, it has a large group of historical measurements of the following variables: solar irradiance, ambient temperature, temperature of the photovoltaic modules and power generated. In other words, we have the necessary elements to carry out the study in this plant. Therefore, the main objective of this work is to predict the power generated in the UCLV photovoltaic plant using the Long Short-Term Memory (LSTM) deep learning model.

II. THEORETICAL REFERENCE

II.1 PREDICTIVE MODELS BASED ON ARTIFICIAL INTELLIGENCE TECHNIQUES WITH MACHINE LEARNING

Different international publications have addressed the issue of predicting the different variables associated with photovoltaic systems using artificial intelligence techniques.

Reference [7] presents a hybrid model for the long-term prediction of the photovoltaic power generated in a photovoltaic installation based on Artificial Neural Network (ANN) and fuzzy logic. It uses temperature, dew point, wind speed and direction, and solar irradiance as input variables. The proposed model is compared with other prediction models and in all cases presented a superior performance with a Mean Absolute Percentage Error (MAPE) value of 29.60 %.

In reference [8] a Neural Network Ensemble (NNE) prediction model trained by Particle Swarm Optimization (PSO) is proposed to predict the day-ahead power in a smart grid. The model uses as inputs historical data of PV power, solar irradiance, wind speed, temperature and humidity. The performance of the model was measured against five other prediction methods and the NNE method was superior with a MAPE value of 9.75%.

Reference [9] presents a Support Vector Regression (SVR) model to predict the power output of a PV plant for a short-term time horizon. It uses as inputs PV power measurements and solar irradiance forecast from the Numerical Weather Prediction (NWP). The model is able to generate good predictions for clear and cloudy sky conditions with a Root Mean Square Error (RMSE) value of less than 15%. The results obtained are compared with a physical model.

II.2 PREDICTIVE MODELS BASED ON DEEP LEARNING ARTIFICIAL INTELLIGENCE TECHNIQUES

Most conventional approaches to solar power forecasting are not capable of digging deep into the time series and uncovering implicit and relevant information. With the huge data of the modern power system, the use of conventional approaches is not adequate to ensure accurate prediction. Deep learning approaches are becoming increasingly popular due to their good ability to describe dependencies in the time series. Recently, deep learning approaches have emerged as powerful tools that enable complicated pattern recognition, regression and prediction analysis [10], [11].

Reference [12] proposes an LSTM deep learning model for predicting PV power. The proposed model is compared with two other models and proved to be the best performing model with an RMSE value of less than 21%.

Reference [13] presents a LSTM model coupled with a deep neural network. The model is used to predict the load and PV power generated in a smart grid. The performance of the model is compared with other models and a satisfactory result is obtained.

In [14], a Deep Convolutional Neural Network (DCNN) model is used to predict the power of a PV system. The accuracy of the model is compared with a persistent model and a SVR model resulting superior with a Normalized Mean Absolute Percentage Error (nMAPE) value of 11.80%.

Reference [15] proposes a forecasting algorithm to predict PV power generation using a LSTM neural network and a synthetic weather forecast. The proposed model is compared with several machine learning models: a Recurrent Neural Network (RNN), a Generalized Regression Neural Network (GRNNN) and an Extreme Learning Machine (ELM) and the results of the LSTM model were superior in all cases analyzed.

III. MATERIALS AND METHODS

III.1 RECURRENT NEURAL NETWORKS

Recurrent neural networks (RNN) [16] are a type of neural networks in which the connections between units form a directed cycle. This creates an internal state of the network that allows it to exhibit dynamic temporal behavior. Unlike feed-forward neural networks, RNNs can use their internal memory to process arbitrary sequences of inputs.

The key idea of RNNs is to use sequential information. In a traditional neural network, all inputs and outputs are assumed to be independent of each other. However, for many applications, this assumption is not always true. RNNs are called recurrent because they repeat the same task for each element of a sequence, and the output depends on previous computations. In other words, RNNs have a memory that captures information about what has been computed so far [16].

Figure 1 illustrates a typical RNN structure, where x_t is the input at time step *t* , s_t is the hidden state at the at time step *t*, and o_t is the output at time step *t*. In detail, it is shown how an RNN is unfolded into a complete network. By unfolding the RNN, the network is presented in a full sequential format.

Note that the hidden state at time step *t* is also known as the network memory and is calculated from the hidden state at the previous time step and the input at the current time step, as suggested in the following equation:

$$s_t = f\left(U_{st} + W_{s_{t-1}}\right) \quad (1)$$

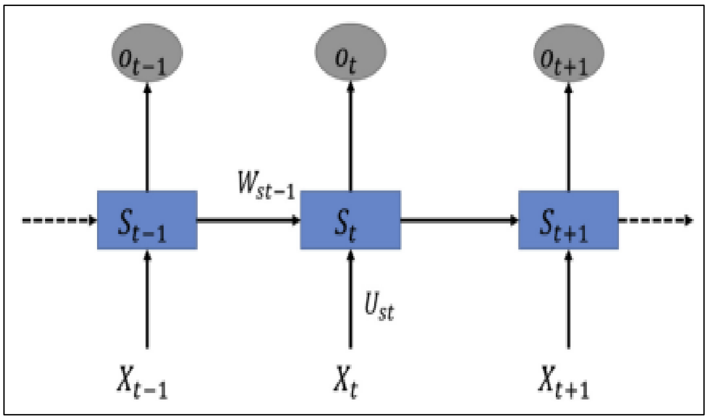

Figure 1: Basic structure of an RNN.
Source: [16].

RNNs use the same model to perform the sequence prediction at different time instants t. Due to this property, they can be used to process variable and large sequences. When working with RNNs, it is first necessary to select the type or architecture of RNN to be used, since the transition function and the handling of the internal state of the network will depend on the RNN architecture [17].

After selecting the RNN architecture, it is recommended to preprocess the data beforehand, so that the model can use them efficiently. After preprocessing the data, the best model is selected based on a performance measure. While the RNN model has proven to be a powerful tool in terms of handling the data sequence assuming that the current time step depends on previous time steps; it also suffers from some limitations, as it has little ability to learn long-term dependencies due to rapid or explosive gradient decay as it propagates through layers or time instants. To address this problem, new RNN architectures have emerged among which are LSTM recurrent neural networks [17].

III.2 RECURRENT NEURAL NETWORKS OF THE LSTM TYPE

The Long Short Term Memory model (LSTM) [17], [18] arises to overcome the problem of gradient vanishing and thus to learn long term dependencies. In this model, the hidden layer nodes are replaced by special nodes called memory cells. Figure 2 shows the structure of a memory cell of the LSTM model.

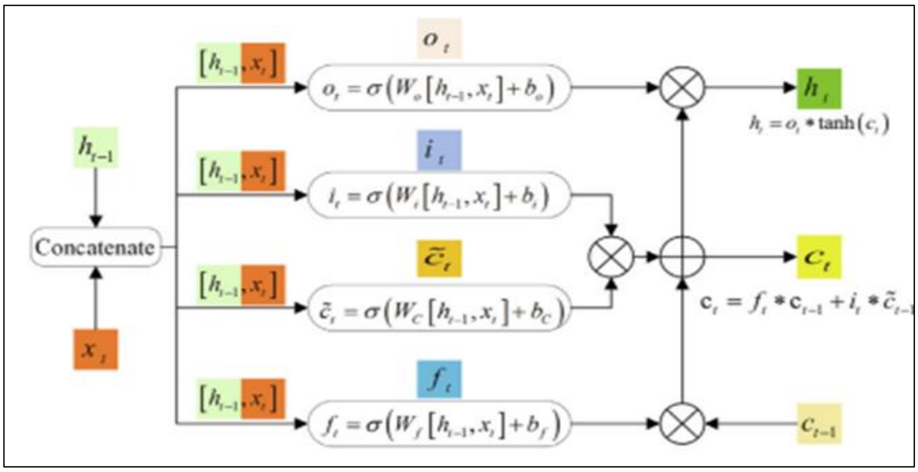

Figure 2: Structure of a memory cell of the LSTM model.
Source: [18].

Each memory cell has a recurring connection with a fixed weight, ensuring that the gradient as it propagates through time does not rapidly diminish or explode. A memory cell is composed of single nodes in a specific connection pattern. Between the nodes that make up a memory cell are a series of gates that are responsible for managing the flow of information in the unit. The components of a memory cell are detailed below [18]:

1. Input node: the input node performs the linear combination of the input vector x_t and the output of the hidden layer at the previous instant h_{t-1}. This node delivers new information to the memory cell.
2. Internal state (c_t): is the main node of the LSTM model, it uses a linear activation function and fixed weights. Since a fixed weight is used in the internal state recurrence, the error propagates through time without the problems of gradient disappearance or explosion.
3. Input gate (i_t): is the first gate used by the LSTM network, it controls the flow of information entering the memory cell, if the value of the gate is zero, no new information enters the memory cell, on the other hand if it is one, all new information enters the memory cell.
4. Forgetting gate (f_t): this gate allows to restrict the information kept in the internal state of the memory cell.
5. Output gate(o_t): the output gate controls the flow of information out of the memory cell. The value finally delivered by a memory cell is given by the internal state of the unit and the output gate.
6. Candidate memory cell ($\tilde{c}_t$): the LSTM model needs to calculate the candidate memory cell $\tilde{c}_t$, its calculation is similar to that of the three gates (input, forgetting and output), but uses a $tanh$ function as the activation function with a range of values between [-1,1].
7. Hidden state (h_t): the $tanh$ function ensures that the value of the hidden state element is between [-1,1]. Note that when the output gate is approximately one, the information in the memory cells is passed to the hidden state to be used by the output layer; and when the output gate is approximately zero, the information in the memory cells is retained by itself.

Given an input sequence $\{x_0, x_{1,} \ldots, x_t\}$ and using the memory cell components, the basic behavior of the LSTM model is described by the following equations:

$$i_t = \sigma(x_t \cdot w_{xi} + h \cdot w_{hi} + b_i) \quad (2)$$

$$f_t = \sigma(x_t \cdot w_{xf} + h_{t-1} \cdot w_{hf} + b_f \quad (3)$$

$$o_t = \sigma(x_t \cdot w_{xo} + h_{t-1} \cdot w_{ho} + b_o) \quad (4)$$

$$\tilde{c}_t = \tanh(x_t \cdot w_{xc} + h \cdot w_{hc} + b_c) \quad (5)$$

$$c_t = \tilde{c}_t \cdot i_t + f \cdot c_{t-1} \quad (6)$$

$$h_t = \tanh(c_t) \cdot o_t \quad (7)$$

Where $w_{xc}, w_{xi}, w_{xf}, w_{xo}$ and $w_{hc}, w_{hi}, w_{hf}, w_{ho}$ are the weights connecting the layers, t is the time instant of the sequence, t-1 is the previous time instant, $h_{t-1}$is the output value of the hidden layer of the network at the previous time instant; b_c, b_i, b_f, b_o are the bias parameters, $tanh$ and σ are the hyperbolic and sigmoid tangent activation functions respectively.

The goal of LSTM neural networks is to learn when to let new information into the internal state and when to let information out of the memory cell. Back-Propagation Through Time (BPTT) is used for learning, and the weights of the gates and the input and output nodes are adjusted [18].

In practice, the LSTM model has a better ability to learn long-term dependencies compared to simple RNNs.

III.3 FORECAST MODEL PERFORMANCE

Performance estimation is critical for assessing the accuracy of a model's predictions. Common tools include: Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE) and Root Mean Square Error (RMSE). MAE estimates the average significance of the errors in a forecast data set, averages the differences between actual observations and predicted outcomes across the entire test sample, and assigns all individual discrepancies equal weight. Similarly, RMSE estimates the mean value of the error by the square root of the average of the squared differences between the predicted values and the actual observations. It is therefore more robust in dealing with large deviations that are especially undesirable, giving the researcher the ability to identify and eliminate outliers. However, both average metrics (MAE and RMSE) can vary from zero to infinity. In contrast, MAPE is a standard prediction technique that measures prediction accuracy and justifies the diversity of predictions for real data sets [1]. The equations for these metrics are as follows:

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|y_j - t_j| \quad (8)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_j - t_j)^2} \quad (9)$$

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\frac{|y_j - t_j|}{t_j} \times 100\% \quad (10)$$

Where y_j and t_j are the corresponding predicted and measured values of PV power and N is the number of test samples.

III.4 PROPOSED METHODOLOGY

Figure 3 shows a summary of the methodology used to predict the power generated in a photovoltaic installation using the LSTM model.

This process takes into account several fundamental steps that include obtaining historical data from the PV plant and preprocessing them to eliminate outliers in each of the time series.

Then, a data filtering process is applied in order to reduce the computational load of the prediction models and the training time; in this process, all the measurements corresponding to the nighttime hours when the plant does not generate active power are removed from the database. Therefore, only 14 measurements are analyzed each day, corresponding to the plant's working hours between 6:00 am and 20:00 pm. A statistical analysis of the data is also performed, including the correlation analysis between the meteorological variables and the power generated, in order to define the inputs of the prediction model.

Subsequently, data normalization is performed to avoid distortion or deviation of the results and to achieve a more accurate prediction, then the data is divided into training data and test data. Then the characteristics of the model are defined and its training is performed, after which the proposed model is validated and tested. Several statistical indicators (MAE, RMSE, MAPE) are used to quantify the accuracy of the developed model. Finally, the designed LSTM model can be used for energy production prediction.

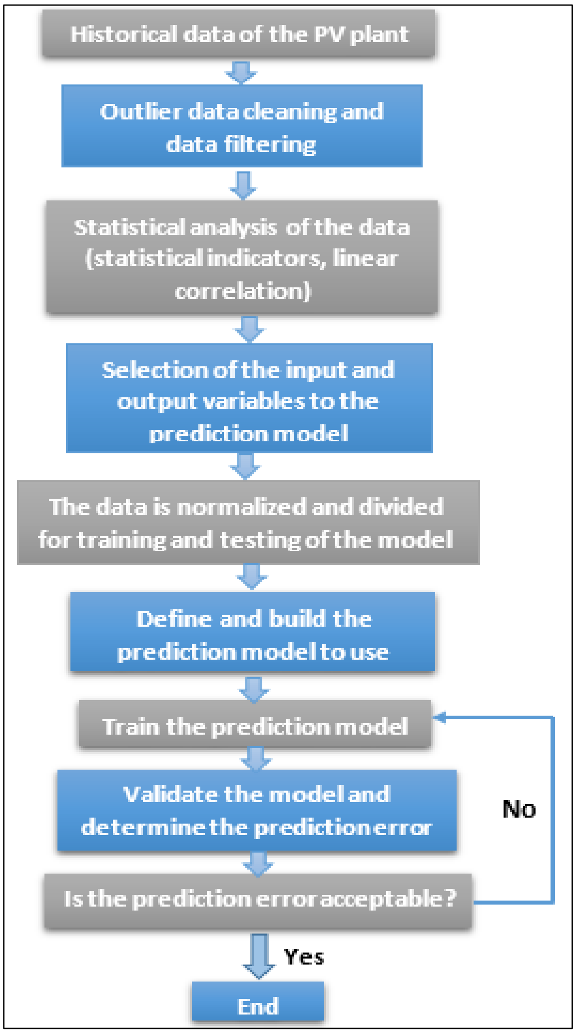

Figure 3: Methodology for PV generation prediction.
Source: Authors, (2021).

IV. RESULTS AND DISCUSSIONS

IV.1 STATISTICAL ANALYSIS OF THE DATA

A database was compiled containing measurements of active power generated (expressed in MW), solar radiation (expressed in W/m²), PV module temperature (expressed in °C), ambient temperature (expressed in °C), wind speed (expressed in m/s) and wind direction (expressed in 0°-360°). Those measurements were taken with a temporal resolution of one hour from July 2018 to April 2021. Figure 4 shows a fragment of the database.

Date	Wind direction	Wind speed	Solar irradiance	T modulo	T ambient	PV power
'17-jul-2018 06:00:00'	109	0	0	22.5	23.9	0
'17-jul-2018 07:00:00'	114.2	0	83.5	25.3	29	0.09
'17-jul-2018 08:00:00'	103.8	1.8	340.5	32	32.1	0.31
'17-jul-2018 09:00:00'	88.8	2.6	566.4	35.1	32.4	0.54
'17-jul-2018 10:00:00'	90.6	2.6	762.5	38	32.6	0.75
'17-jul-2018 11:00:00'	84.8	1.8	970.1	42.4	34.1	0.86
'17-jul-2018 12:00:00'	96	1.1	1118.9	41.8	34.5	0.96
'17-jul-2018 13:00:00'	92.5	1.1	1116.2	45.2	34.9	0.94
'17-jul-2018 14:00:00'	91.8	1.1	969.5	46	36.8	0.88
'17-jul-2018 15:00:00'	93.4	1.8	301.4	39.5	34.9	0.29
'17-jul-2018 16:00:00'	50.4	1.8	594.1	43.1	35.4	0.54
'17-jul-2018 17:00:00'	82	1.8	373	39	35.8	0.33
'17-jul-2018 18:00:00'	82.3	1.8	22.7	31.2	31.2	0.01
'17-jul-2018 19:00:00'	57.4	0	0	28.5	29.6	0
'18-jul-2018 06:00:00'	118.9	0	0	22.3	24.1	0
'18-jul-2018 07:00:00'	138.2	1.1	86.3	25.6	29.8	0.09
'18-jul-2018 08:00:00'	131.6	1.8	369.6	31.6	31.1	0.33
'18-jul-2018 09:00:00'	114.6	1.1	566.4	36.8	33	0.53
'18-jul-2018 10:00:00'	111.8	1.8	748.4	41.1	33.1	0.72
'18-jul-2018 11:00:00'	15	1.1	947.1	47.9	33.8	0.82
'18-jul-2018 12:00:00'	58.5	1.8	1040.5	54.2	34.8	0.86
'18-jul-2018 13:00:00'	178.6	1.8	1026.9	52.1	35.8	0.9

Figure 4: Fragment of the UCLV photovoltaic plant database.
Source: Authors, (2021).

Tables 1, 2, 3, 4, 5 and 6 summarize the main statistical indicators of the variables active power generated, solar irradiance, PV module temperature, ambient temperature, wind speed and wind direction for each year that was present in the database.

When analyzing the results shown in the tables above, it can be said that in general the quality of the data was acceptable, although there were values that at first glance could be considered erroneous.

Among these were, for example, minimum values of ambient temperature and PV module temperature equal to zero, maximum values of ambient temperature higher than 40°C, solar irradiance values higher than 1300 W/m² and power values higher than 1.1 MW, evidently all the above mentioned measurements were outliers for each of the time series.

To solve these problems and improve data quality, an outlier cleaning process was applied that took into account the extreme limits of each time series. As for missing measurements, if these corresponded to small data segments (≤ 1 h) they were replaced by the average value of four observations, two points before and two points after to maintain the originality and length of the input sequences.

Finally, when there were large sequences (from several hours to weeks) of missing or defective data, imputation was performed, although this problem was practically absent in the available database.

Table 1: Statistical analysis of the active power generated variable.

Year	2018	2019	2020	2021	Total
Average	0.31	0.38	0.34	0.39	0.35
Standard deviation	0.33	0.33	0.32	0.32	0.33
Minimum	0	0	0	0	0
Maximum	1.03	1.05	1.05	1.01	1.03

Source: Authors, (2021).

Table 2: Statistical analysis of the solar irradiance variable.

Year	2018	2019	2020	2021	Total
Average	340.02	410.61	297.91	438.78	360.81
Standard deviation	370.34	369.99	357.28	380.41	370.80
Minimum	0	0	0	0	0
Maximum	1259.50	1354.20	1401.50	1382.60	1401.50

Source: Authors, (2021).

Table 3: Statistical analysis of the temperature of the PV modules variable.

Year	2018	2019	2020	2021	Total
Average	26.15	30.32	22.72	28.72	26.69
Standard deviation	11.99	8.19	14.39	8.26	12.29
Minimum	0	0	0	0	0
Maximum	59.30	48.90	49.10	50.40	59.30

Source: Authors, (2021).

Table 4: Statistical analysis of the ambient temperature variable.

Year	2018	2019	2020	2021	Total
Average	23.95	28.30	21.44	26.82	24.91
Standard deviation	11.73	5.97	13.03	6.20	10.53
Minimum	0	0	0	0	0
Maximum	37.50	39.50	38.60	40.60	40.60

Source: Authors, (2021).

Table 5: Statistical analysis of the wind speed variable.

Year	2018	2019	2020	2021	Total
Average	0.87	1.10	0.86	1.35	1
Standard deviation	1.10	1.13	1.11	1.23	1.14
Minimum	0	0	0	0	0
Maximum	8.70	10.20	7.20	6.40	10.20

Source: Authors, (2021).

Table 6: Statistical analysis of the wind direction variable.

Year	2018	2019	2020	2021	Total
Average	95.17	127.44	94.13	129.76	110.01
Standard deviation	88.72	97.53	97.43	98.89	97.55
Minimum	0	0	0	0	0
Maximum	359.20	359.40	359.40	359.20	359.40

Source: Authors, (2021).

The correlation analysis of the data was a very important aspect, since it allowed defining which variables were to be taken into account in a prediction model.

In this case, a database of the UCLV photovoltaic plant was available, which contained time series of several variables for a period of time close to 3 years. The variable to be predicted was the PV power generated at the facility. Therefore, in the correlation analysis, each of the variables was analyzed with respect to the PV power generated.

Table 7 shows the values obtained for the correlation of the different meteorological variables with respect to the photovoltaic power generated.

As can be seen, the highest correlation was presented by the solar irradiance variable, followed by module temperature, ambient temperature and wind speed. These correlation values were considered strong, therefore, these variables were selected as inputs to the prediction model.

The wind direction variable presented a very weak correlation and was not considered as an input to the prediction model.

Table 7: Correlation between PV power generated and meteorological variables.

Input variables	**Correlation coefficient with respect to photovoltaic power generated**				
	Year 2018	**Year 2019**	**Year 2020**	**Year 2021**	**Total**
Solar irradiance	0.9868	0.9916	0.9902	0.9875	0.9890
PV module temperature	0.7898	0.7781	0.7752	0.7819	0.7812
Ambient temperature	0.7242	0.6840	0.6683	0.6890	0.6964
Wind speed	0.4367	0.4148	0.4204	0.4317	0.4259
Wind direction	0.0946	0.1041	0.1094	0.1032	0.1028

Source: Authors, (2021).

IV.2 PREDICTION RESULTS USING THE DEEP LEARNING MODEL LSTM

To perform the prediction of the power generated at the UCLV photovoltaic plant, a deep learning model LSTM was implemented, currently recommended in a considerable number of publications, due to its advantages and its proven effectiveness in learning long-term dependencies compared to simple RNNs.

The model that was implemented contained two hidden layers and each layer possessed 200 memory cells. For its training the initial learning rate was set to 0.05, the Adaptive Estimation of Momentum (ADAM) algorithm was used as the optimizer, the number of training epochs was 250. In the training process of the LSTM model, different variants of data splitting were tested. In this process, one of the options that provided the best results was the division of the data according to the seasons of the year. In other words, the measurements of one year of work of the photovoltaic plant were taken and divided into periods of three months so that each period corresponded to a season of the year under study. For the training of the LSTM model, 90% of the station data was used and the remaining 10% was used to test its performance. The model was implemented in MATLAB 2019a and run on a computer with Intel(R) Core(TM) i3 CPU at 2.4 GHz and 8 GB of memory.

To analyze the performance of the proposed model, predictions of the power generated in the PV system were made for three days of different behavior (sunny day, cloudy day and partially sunny day). In this case, a short-term prediction was made (for 14 hours of the following day). The results of these predictions are shown in Figures 5, 6 and 7 respectively.

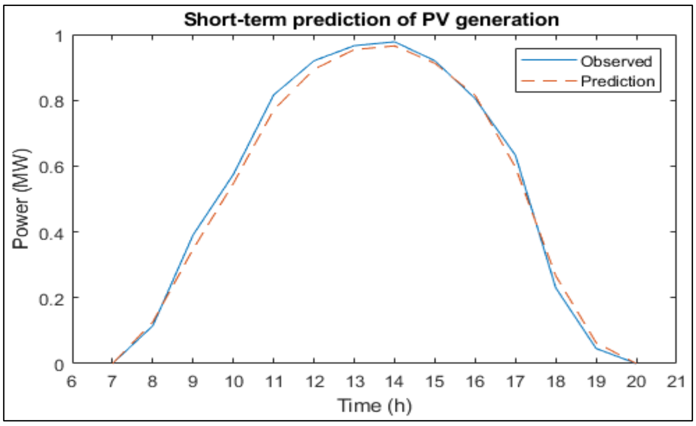

Figure 5: Short-term forecast of PV generation for a sunny day in July 2020.
Source: Authors, (2021).

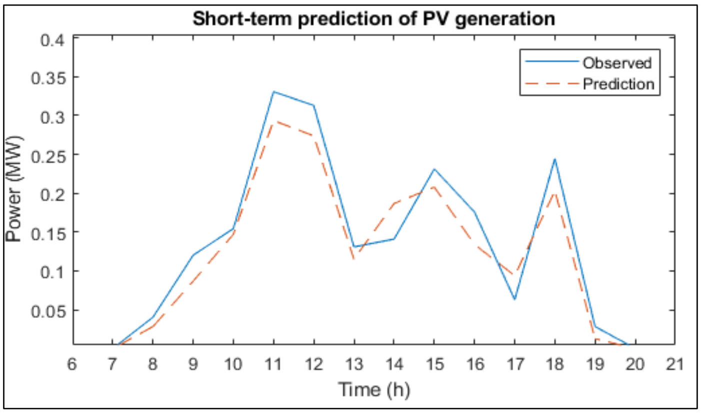

Figure 6: Short-term PV generation forecast for a cloudy day in May 2020.
Source: Authors, (2021).

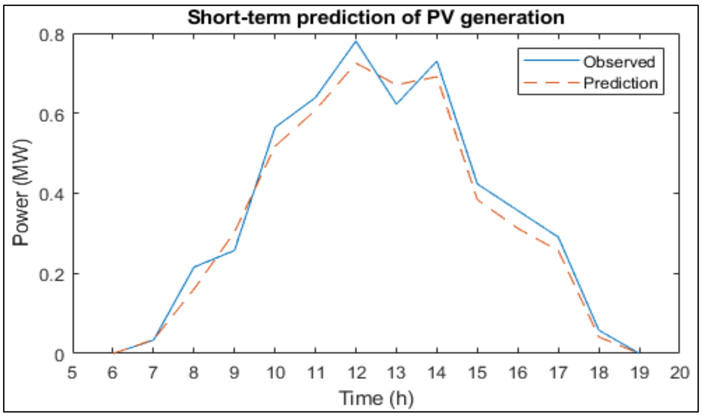

Figure 7: Short-term PV generation forecast for a partly sunny day in January 2021.
Source: Authors, (2021).

As can be seen in the previous figures, the predictions made by the LSTM deep learning model accurately reflected the PV power generation patterns on each day analyzed, even though the behavior of each of these days was different. Evidently the highest accuracy of the prediction model was obtained for the sunny day and the highest uncertainties in the prediction were presented in the cloudy day as expected.

Table 8 shows the prediction accuracy of the LSTM deep learning model for a short-term time horizon (14 hours) and for each of the analyzed day types. Three fundamental metrics were used to determine the quality of the predictions made (RMSE, MAE and MAPE).

The lowest prediction errors were obtained for the sunny day, followed by the partly sunny day and the cloudy day. As the incident cloudiness over the PV plant increased, there was more variation and intermittency in the incident solar radiation and thus in the generated power.

The high variability made generation prediction more difficult and resulted in higher prediction errors compared to other days with more stable behavior.

Table 8: Prediction accuracy for a short-term horizon for different day types.

Type of day	Metrics used to evaluate prediction error		
	RMSE (kW)	MAE (kW)	MAPE (%)
Sunny day	25.22	16.38	5.86
Cloudy day	43.45	32.32	19.25
Partial sunny day	32.14	23.21	9.48

Source: Authors, (2021).

The model performance was also evaluated for a medium-term forecast horizon. Figure 8 shows a medium-term forecast that was performed with the LSTM deep learning model for six days in the month of February 2021 (February 5 - 10, 2021).

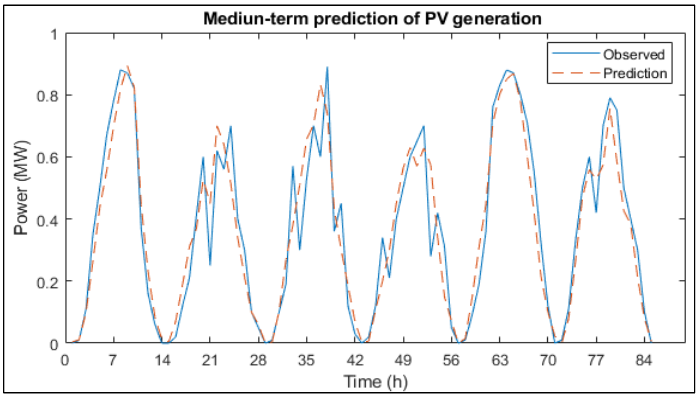

Figure 8: Medium-term forecast of PV power generation from February 5 to February 10, 2021.
Source: Authors, (2021).

The previous figure shows that the predictions of the LSTM model for a medium-term time horizon were accurate, even in the periods of time when there was a high intermittency in the generation due to the cloudiness over the photovoltaic plant, the model was able to adequately adjust to these atypical behavior patterns. Figure 9 shows the behavior of the Mean Absolute Percentage Error (MAPE) for a medium-term prediction horizon.

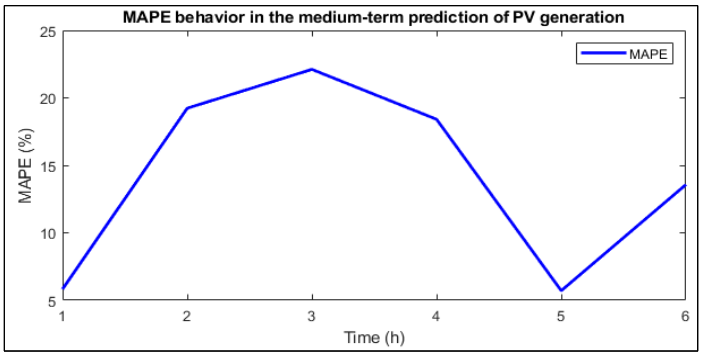

Figure 9: Behavior of the ASM for a medium-term forecast from February 5 to February 10, 2021.
Source: Authors, (2021).

Again the largest prediction errors were obtained on cloudy days (day 2, day 3 and day 4), followed by a partly sunny day (day 6) and finally sunny days (day 1 and day 5). The LSTM model that was implemented due to its characteristics was able to learn long-term temporal dependencies in the time series and was able to adequately predict PV power generation on days with different behavior and for different time horizons.

V. CONCLUSIONS

The prediction of electric power generation in photovoltaic installations is a difficult task of great importance nowadays. In the present work, a deep learning artificial intelligence model (LSTM model) is proposed. The model is trained with historical data obtained from the UCLV photovoltaic plant, such data is statistically analyzed and prepared with the objective of achieving more accurate and faster predictions. The LSTM model is used for short-term (14 hours in the future) and medium-term (6 days) prediction of the power generated by the photovoltaic installation on days with different behavior (sunny day, cloudy day and partially sunny day), obtaining good results in all cases, with acceptable values of the prediction error.

The main contribution of the work lies in the development of a simple but effective methodology to achieve the proposed objective, which is applicable to any photovoltaic solar farm. However, other deep learning models should be analyzed and their results compared with the proposed model in order to select the most appropriate one according to the type of prediction to be presented.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Reinier Herrera Casanova.
Methodology: Reinier Herrera Casanova.
Investigation: Reinier Herrera Casanova.
Discussion of results: Reinier Herrera Casanova.
Writing – Original Draft: Reinier Herrera Casanova.
Writing – Review and Editing: Reinier Herrera Casanova.
Resources: Reinier Herrera Casanova and Lesyani León Viltres.
Supervision: Lesyani León Viltres.
Approval of the final text: Reinier Herrera Casanova and Lesyani Leon Viltres.

VII. REFERENCES

[1] R. Ahmed., et al., "A review and evaluation of the state-of-the-art in PV solar power forecasting: Techniques and optimization", Renew Sustain Energy Rev, vol. 124, pp. 109792, March 2020, doi: 10.1016/j.rser.2020.109792.

[2] S. Zhang, J. Wang, H. Liu, J. Tong & Z. Sun, "Prediction of energy photovoltaic power generation based on artificial intelligence algorithm", Neural Computing and Applications, vol. 33, no 3, pp. 821-835, 2021, doi:10.1007/s00521-020-05249-z.

[3] A. Nespoli, et al., "Day-ahead photovoltaic forecasting: a comparison of the most effective techniques", Energies, vol. 12, no. 9, pp. 1621, 2019, doi:10.3390/en12091621.

[4] T. Fan, T. Sun, H. Liu, X. Xie, & Z. Na, "Spatial-Temporal Genetic-Based Attention Networks for Short-Term Photovoltaic Power Forecasting", in IEEE Access, vol. 9, pp. 138762-138774, 2021, doi: 10.1109/ACCESS.2021.3108453.

[5] M. N Akhter., S. Mekhilef, H. Mokhlis, & N. M Shah., "Review on forecasting of photovoltaic power generation based on machine learning and Metaheuristic techniques", IET Renew. Power Gener., vol. 13, no. 7, pp. 1009–1023, May 2019, doi:10.1049/iet-rpg.2018.5649.

[6] M. S. Mahdi, M. Longo, & F. Foiadelli, "A-Day-Ahead Photovoltaic Power Prediction Based on Long Short Term Memory Algorithm", 2020 International

Conference on Smart Energy Systems and Technologies (SEST). IEEE, pp. 1-6, 2020, doi: 10.1109/SEST48500.2020.9203481.

[7] B. Sivaneasan, C. Y. Yu & K. P Goh., "Solar forecasting using ANN with fuzzy logic pre- processing", Energy Procedia, vol. 143, pp. 727–32, 2017, doi: 10.1016/j.egypro.2017.12.75.

[8] M. Q. Raza, N. Mithulananthan, J. Li., K. Y. Lee, & H. B. Gooi, "An ensemble framework for day-ahead forecast of PV output power in smart grids", IEEE Transactions on Industrial Informatics, vol. 15, no. 8, pp. 4624–4634, Aug. 2019.

[9] B. Wolff, J. Kühnert, E. Lorenz, O. Kramer, D. Heinemann, "Comparing support vector regression for PV power forecasting to a physical modeling approach using measurement, numerical weather prediction, and cloud motion data", Sol Energy, vol. 135, pp. 197–208, 2016, doi: 10.1016/j.solener.2016.05.05.

[10] Z. Chen, Y. Chen, L. Wu, S. Cheng, P. Lin, L.You, "Accurate modeling of photovoltaic modules using a 1-d deep residual network based on iv characteristics", Energy Conversion and Management, vol. 186, pp. 168-187, 2019, doi: 10.1016/j.enconman.2019.02.032.

[11] F. Harrou, F. Kadri, & Y. Sun, "Forecasting of Photovoltaic Solar Power Production Using LSTM Approach", In Advanced Statistical Modeling, Forecasting, and Fault Detection in Renewable Energy Systems, London, UK: IntechOpen, 2020.

[12] J. Zhang, R. Verschae, S. Nobuhara, J-F. Lalonde, "Deep photovoltaic nowcasting", Sol Energy, vol. 176, pp. 267–276, 2018, doi.org/10.1016/j.solener.2018.10.024.

[13] L. Wen, K. Zhou, S. Yang, X. Lu, "Optimal load dispatch of community microgrid with deep learning based solar power and load forecasting", Energy, vol. 171, pp. 1053–1065, 2019, doi: 10.1016/j.energy.2019.01.075.

[14] R. Zhang, M. Feng, W. Zhang, S. Lu, F. Wang, "Forecast of solar energy production - a deep learning approach", In: 2018 IEEE international conference on big knowledge. ICBK), pp. 73–82, 2018.

[15] M. S. Hossain and H. Mahmood, "Short-Term Photovoltaic Power Forecasting Using an LSTM Neural Network and Synthetic Weather Forecast", in IEEE Access, vol. 8, pp. 172524-172533, 2020, doi: 10.1109/ACCESS.2020.3024901.

[16] Z. Pang, F. Niu, Z. O'NEILL, "Solar radiation prediction using recurrent neural network and artificial neural network: A case study with comparisons", Renewable Energy, vol. 156, pp. 279-289, 2020, doi: 10.1016/j.renene.2020.04.04.

[17] A. Sherstinsky, "Fundamentals of recurrent neural network (RNN) and long short-term memory (LSTM) network", Phys. D: Nonlinear Phenomena, vol. 404, Art. no. 132306, 2020, doi: 10.1016/j.physd.2019.132306.

[18] Y. Ding, Y. Zhu, J. Feng, P. Zhang & Z. Cheng, "Interpretable spatio-temporal attention LSTM model for flood forecasting", Neurocomputing, vol. 403, pp. 348–359, 2020, doi: 10.1016/j.neucom.2020.04.110.

Journal of Engineering and Technology for Industrial Applications

ITEGAM-JETIA

ISSN ONLINE: 2447-0228

Manaus, v.8 n.33, p. 21-25. Jan/Feb, 2022
DOI: https://doi.org/10.5935/jetia.v8i33.794

RESEARCH ARTICLE OPEN ACCESS

MEASUREMENT OF RADIOLOGICAL PARAMETERS IN HARVESTED SAND IN BUNGOMA COUNTY RIVERS, KENYA

Lazarus Sindani[1], Michael Nakitare Waswa[2], Francis Maingi[3] and Conrad Khisa Wanyama*[4]

[1, 2, 3, 4] Department of Science, Technology and Engineering, Kibabii University, P.O BOX 1699-50200, Bungoma, Kenya.

[1] http://orcid.org/0000-0003-4792-3120, [2] http://orcid.org/0000-0003-2479-862X, [3] http://orcid.org/0000-0002-2358-6775, [4] http://orcid.org/0000-0002-3624-7756

Email: lazarusindani@gmail.com, mwaswa@kibu.ac.ke, fmaingi@kibu.ac.ke, *conradkhs@gmail.com

ARTICLE INFO

Article History
Received: January 07th, 2022
Accepted: February 21th, 2022
Published: February 28th, 2022

Keywords:
Harvested Sand,
Absorbed Dose Rate,
Annual Effective Dose Rate,
Permissible limits.

ABSTRACT

Samples of sand were collected along the course of ten selected rivers two from each river through random sampling. Activity concentration of ^{238}U, ^{232}Th and ^{40}K were measured using high resolution NaI(Ti) gamma ray spectrometer. Activity concentration of the three primordial radionuclides obtained were used to calculate, absorbed dose rate, annual effective dose rate, interna and external hazard indices and radium equivalent. The average activity concentration for the three primordial radioactive nuclides were; 2±0.1Bq/kg with a range of 0± 0.03Bq/kg to 4±0.24Bq/kg for ^{238}U, 55±2.78Bq/kg with a minimum value of 32±1.6Bq/kg and a maximum value of 87±4.38Bq/kg for ^{232}Th and 51±2,56Bq/kg with a minimum value of 27±1.37Bq/kg and a maximum value of 76±3.8Bq/kg for ^{40}K. The mean activity concentrations for ^{238}U and ^{40}K were below the world averages of 33Bq/kg and 420Bq/kg respectively. The indoor and outdoor annual effective dose rate varied from 0±0mSv/y to 0.2±0.01mSv/y with an average of 0.1±0 mSv/y and 0±0.003mSv/y to 0.1±0.009mSv/y with a mean of 0.1±0.006 mSv/y respectively. The annual effective dose rates were below the safe limits of 1mSv/y. Therefore, use of sand from the selected rivers in Bungoma County, Kenya for construction has minimal health risks to the inhabitants.

I. INTRODUCTION

Radioactivity as a result of natural sources is prevalent in man's immediate settings i.e from land, as a result of cosmic rays or as a result of indoor radiations from materials used for construction [1]. Studies have revealed that existence of sources of natural radioactivity such as ^{226}Ra, ^{232}Th and their daughter nuclides and ^{40}K in materials used for construction results in to detrimental internal and external effects to inhabitants. Radioactive nuclides (^{226}Ra, ^{232}Th and ^{40}K) are not evenly concentrated and spread in rocks and soils [2]. They are different on the basis of where they are obtained. Sediments that find their ways in to the rivers are products of disintegration of rock sediments (sand and silts) and erosion of soils and rocks. The natural radioactive nuclides concentration in the soils and rocks affects the radioactivity levels of the sediments of the river sediments.

Radiation exposure to human beings can be as a result of radiations coming from direct from the natural radioactive nuclides or internally as a result of inhalation from radon. [3]. Radon and its products of decay in air are chief suppliers of exposure to human from primordial sources [4]. Radon is the product of decay of natural radioactive nuclides ^{238}U, ^{232}Th and ^{235}U that are found in the earth's crust. Once Radon is formed, it may be released in the atmosphere depending on the rocks type, soil structure, amount of water present and weather-related factors [5]. Radon in houses is as a result of trapped radium present in the mineral particles that are used for construction. Materials used for building have certain level of natural radioactivity especially those that are obtained from radioactive nuclides of ^{238}U, ^{232}Th and ^{40}K [6].

According to UNSCEAR, 2000, the worldwide average value of outdoor gamma absorbed dose rate in air due to terrestrial sources is 54nGy/h and absorbed dose rate in air inside homes is usually higher the outside (20% on average, but sometimes much more) due to the contribution of materials used for construction [7]. Natural radionuclides contribute to radiation exposure in two ways; external and internal exposure. External exposure comes mostly from direct gamma radiation emitted from the decay of the radionuclides of ^{238}U series. Internal exposure is due to alpha particles resulting from the decay of ^{222}Rn and its progeny. Radon is a chemically inert gas which is colorless, odorless and highly radioactive. When inhaled, the alpha particles are directly delivered in the tissues, creating a potential for radiogenic lung cancer.

Radiation exposure is mainly through natural and artificial sources. The main radionuclides which are of concern are ^{238}U, ^{232}Th and ^{40}K and their progenies which are responsible for generation of external gamma radiation. External gamma radiations which arise from NORMs is widely distributed on the earth's surface and contributes to more than 50% to the collective radiation dose received by the world's population. Human activities such as use of fertilizers for agriculture, mining and milling, processing uranium ores and mineral sand and burning of fossil fuel may influence the level of NORMs in the environment [8] Indoor exposure to radiations is dependent on the resources used for building and also on how long one spends indoor [9]. In a house that is made of various materials such as stones, sand, cement and concrete, activities concentration due to internal radiations from the radioactive nuclides are great but simultaneously protecting the building from outdoor radiation [6]. The world's average activity concentration for ^{238}U, ^{232}Th and ^{40}K is 33 Bq/kg, 45Bq /kg and 420Bq/kg respectively [10].

II. MATERIALS AND METHODS

II.1 STUDY AREA

The study was done in Bungoma County which is found in the Western region of Kenya. Bungoma County has a total population of 1,670,570 of which 812,146 are males and 858,389 females as per 2019 census [11]. The county covers an area of 2069km^2 and neighbors the republic of Uganda to the North West, Trans-Nzoia County to the north East and South East, and Busia county to the West and South West. The county stretches between latitudes 0.4213˚N and 1.1477˚N and longitudes 34.3627˚E and 35.0677˚E. The county has several rivers. This study considered the following rivers: rivers Malakisi, Kuywa, Khalaba, Teremi, Sosio, Nzoia, Kiminini Kibisi, Chwele and Toloso. A total of thirty samples were collected using random sampling from these rivers where three samples were obtained from each river. Each sample collected had a net weight of 500g. This area is considered for study because of numerous activities that takes place in this region ranging from sand harvesting, transportation of the harvested sand and small irrigation along the rivers. These activities may pose risks of radiations to workers and therefore research had to be undertaken to determine the extent of risks associated to workers. Figure 1 show the map of Bungoma County.

Figure 1: The map of Bungoma county showing distribution of rivers.
Source: [11].

II.2 COLLECTION OF SAMPLES AND PREPARATION

Two samples were collected from rivers listed above either upstream, in the course of the river or downstream when the river almost exit the county at accessible points where sand harvesting is done. A total of twenty samples were considered for study. Sand was scooped from the river using a shovel. The point at which sand samples was taken was determined by the use of a phone with GPS and then recorded. Samples obtained were put in plastic containers and labelling done depending on the position from which the sample was taken from. Sieving was be done on the samples to achieve uniformity on the size of the grains using a sieve of diameter 2mm. Samples were then dried up in an oven at a temperature of around 105℃ to do away with any dampness. Samples were crushed by the use of the mortar and pestle and every time the mortar and pestle were used for grinding, they were washed to ensure samples are not contaminated. Samples were then packed in 500ml containers which were labelled and referenced and tightly closed to avoid leakages. They were then kept for a period of around thirty days to allow for secular equilibrium between ^{226}Ra, ^{238}U, ^{232}Th and their daughter nuclides. Gamma ray spectrometer was used to determine the activity concentration of the radioactive nuclides in every sample for around 5000 minutes to increase the accuracy of radioactive measurements [12].

II.3 MEASUREMENT TECHNIQUES AND PRINCIPLES

Specific concentration of radionuclides in the samples was done using NaI(TI) gamma ray spectrometer. Calibrations were done before counting the detector. This was done using standard point sources which are: ^{22}Na (1368.6keV), ^{133}Ba (356.1keV), ^{60}Co (1173.2 & 1332.5keV), ^{137}Cs (661.9keV) and ^{26}Ra (186.2keV) supplied by the International Atomic Energy Association (IAEA) [13]. Each sample was put in a highly shielded Na I(Ti) detector and measured for a period of around 10 hours. An inbuilt software was used in the analysis of each of the measured gamma ray spectrum.

II.4 ACTIVITY CONCENTRATION OF THE RADIONUCLIDES

The activity concentration ^{238}U was determined using the counts of ^{214}Pb and ^{214}Bi. ^{232}Th was calculated from the counts of ^{228}Ac & ^{212}Pb and finally the concentration of ^{40}K were established from the counts of 1460.83keV. Equation 1 shows the analytical equation used in determination of the specific radionuclide activity concentration in Bq/kg [14].

$$A_c = \frac{N_D}{P.n.m} \quad (1)$$

Where N_D is the net count rate (cps); measured count rates minus background count rates, p is the gamma ray emission count probability (gamma ray yield), n is the absolute counting efficiency of the detector system, m is the mass of the sample.

II.5 ESTIMATION OF ABSORBED DOSE RATE

Absorption dose rate refers to the energy that is put in an absorbing channel those radiations that cause ionization per unit mass. This quantity was determined from activity concentration of ^{238}U, ^{232}Th ^{40}K using the activity concentration-dose (nGy^{-1} per Bq/kg) conversion factor 0.462, 0.622 and 0.0432 respectively [4]. Equation 2 shows how to calculate the dose rate:

$$ADR\ (nGyh^{-1}) = 0.427A_U + 0.622A_{Th} + 0.043A_K \quad (2)$$

Where A_U, A_{Th} and A_K is the average activity concentration of ^{238}U, ^{232}Th and ^{40}K in Bq/kg respectively in the sand samples.

II.6 ANNUAL EFFECTIVE DOSE RATE (AED)

The factor 0.7Sy/Gy was used in estimating the effective dose rate received by the inhabitants due to radioactivity in sand. It was presumed that adults spend 80% indoor while 20% outdoor. In this research thus, the indoor and the outdoor level of occupancy were given as 0.8 and 0.2 correspondingly [4]. The indoor effective dose as well as the outdoor annual effective dose rates received by the population was calculated using the equation 3 and 4:

$$E_{in}(msvy^{-1}) = ADR(nGyh^{-1}) \times 8760(hy^{-1}) \times 0.8 \times 0.7(SvGy^{-1} \times 10^{-6}) \quad (3)$$

$$E_{out}(msvy^{-1}) = ADR\ (nGyh^{-1}) \times 8760(hy^{-1}) \times 0.2 \times 0.7(SvGy^{-1} \times 10^{-6}) \quad (4)$$

Where E_{in} and E_{out} is the effective dose rates for both the internal and external environments [15].

III. RESULTS AND DISCUSSIONS

III.1 SPECIFIC ACTIVITY CONCENTRATION

Activity concentration levels of the samples varied from 0±0.03 Bq/kg to 4±0.24Bq/kg with average activity concentration of 2±0.1Bq/kg for ^{238}U, 32±1.6Bq/kg to 87±4.38Bq/kg with average activity concentration of 55±12.78Bq/kg ^{232}Th and 161±8.05Bq/kg to 689±34,45Bq/kg with an average activity concentration of 366±18.34Bq/kg for ^{40}K. The activity concentration of ^{232}Th exceeded the world agreed average value of 45Bq/kg while the activity concentration of ^{238}U and ^{40}K were below the world agreed averages of 33Bq/kg and 400Bq/kg respectively [16].

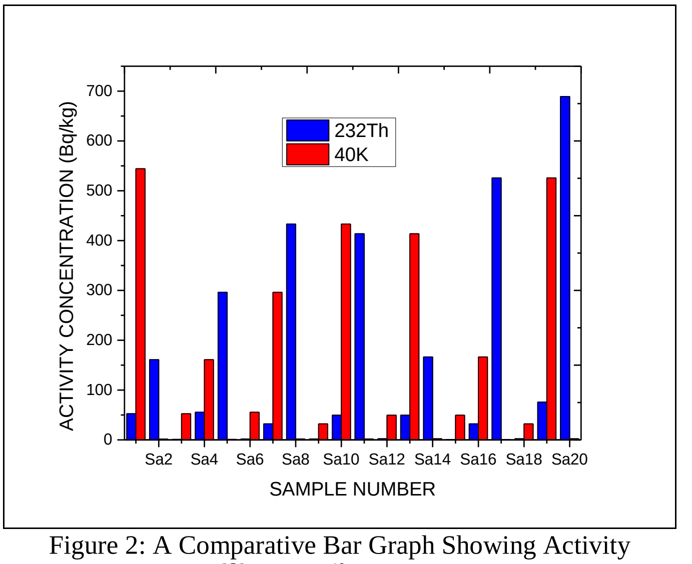

Figure 2: A Comparative Bar Graph Showing Activity Concentration of ^{232}Th and ^{40}K in the Collected Samples.
Source: Authors, (2021).

From figure 2, the activity levels of ^{40}K ranged from 161 ± 8.05 Bq/kg to 689 ± 34.45 Bq/kg with an average of 366 ± 18.34 Bq/kg, 32 ± 1.6 Bq/kg to 87 ± 4.38 Bq/kg with an average activity of 55 ± 2.78 Bq/kg for ^{232}Th as shown in Figure 5.1. The results indicate a great variation in the mean activity level of the analyzed naturally occurring radionuclides (^{40}K and ^{232}Th) in the sand samples. The variation in the activity concentrations in the sand samples varied with the sample location due to the geological formation and type of rocks across the selected rivers. The mean activity of ^{40}K was generally higher than ^{238}U and ^{232}Th for all the collected samples which are a common behavior in the crustal contents. Since the findings of activity concentration of ^{40}K, ^{232}Th and ^{238}U reported from the collected sand samples were far below the exemption levels of 1000 Bq/kg for both ^{232}Th and ^{238}U and 100,000 Bq/kg for ^{40}K [17], harvesting of sand in the selected rivers of Bungoma County has no potential health threat to the local population.

III.2 ABSORBED DOSE RATE

The mean absorbed dose rates for sand samples was 51±2.56nGyh^{-1} with the range between 27±1.37nGyh^{-1} and 76±3.81nGyh^{-1}. This is below the world averages of 60nGyh^{-1} [18]. Figure 3 shows a graph of absorbed dose rate against the sampling sites.

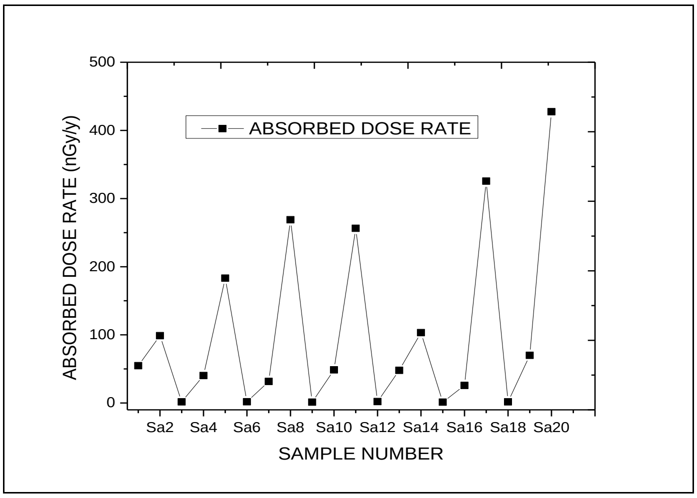

Figure 3: A Line Graph Showing Absorbed Dosed Rate for the Collected Samples.
Source: Authors, (2021).

Most samples recorded a mean which was below the world's average of 60nGyh^{-1}[19]. This could be attributed to the fact that most of these rivers do not flow in areas which are not rich in radioactive substances.

III.3 ANNUAL EFFECTIVE DOSE RATE (AEDR)

To evaluate the radiological risks of exposure, absorbed dose rates were converted to annual effective dose rates which is a reliable representation of the likely health effects to the general population. Table 1 shows the annual effective dose rate of the primordial radionuclides for the samples considered in this study.

Table 1: Annual Effective Dose rate values of the sampled Sand in selected Bungoma County, Kenya Rivers.

	AED_{in}(mSv/y)	AED_{out}(mSv/y)
MAXIMUM	0.2±0.01	0.1±0.009
MINIMUM	0.1±0	0±0.003
AVERAGE	0.1±0	0.1±0.006

Source: Authors, (2021).

Annual effective dose rate due to indoor exposure ranged from 0.1±0 mSvy^{-1} to 0.2±0.01 mSvy^{-1} with a mean of 0.1±0 mSvy^{-1} while the annual effective dose rate due to outdoor exposure varied from 0±0.003mSvy^{-1} to 0.1±0.009 mSvy^{-1} with a mean of 0.1±0.006 mSvy^{-1}. All the annual effective dose values were below the permissible limit of 1mSv/y [17]. Hence the sand harvested in the selected rivers in Bungoma County, Kenya has minimal health risk to the population.

IV. CONCLUSSIONS

Analysis of radioactivity levels in sand in the primordial radionuclides (^{238}U, ^{232}Th and ^{40}K) and their radiation hazards due to sand harvested in the selected rivers of Bungoma County has been determined using NaI(Ti) gamma ray spectrometer. The results obtained were compared with the recommended limits to assess whether sand samples pose any radiological threat to the harvesters and the dwellers of the houses. The average activity concentration for ^{238}U, ^{232}Th and ^{40}K that were obtained were as follows; 2±0.1 Bq/kg with the range of 0±0.03Bq/kg, 55± 2.78 Bq/kg with the range of 32±1.6Bq/kg to 55±2.78Bq/kg and 366± 18.34Bq/kg with the range of 27±1.137Bq/kg to 51±2.56Bq/kg respectively. Generally, the activity concentration of ^{238}U was less than the world recommended value of 33Bq/kg (UNSCEAR, 2008). The absorbed dose rate had an arithmetic mean of 51±2.56 nGyh^{-1} which was below the world average value of 60nGyh^{-1} The annual effective dose rate had an average of 0.1± 0 mSvy^{-1}. This value was below the world average of 0.48 mSvy^{-1} and below the acceptable limit of 1mSvy^{-1}. The use of the harvested sand from the selected rivers in Bungoma County has minimal health risk to the population. Future measurement and analysis of natural radioactivity levels in water (wells, ponds, dams and rivers) and crops around the selected rivers should be carried to determine trends in radioactivity levels.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Lazarus Sindani, Michael Nakitare Waswa and Francis Maingi.
Methodology: Lazarus Sindani and Conrad Khisa Wanyama.
Investigation: Lazarus Sindani and Conrad Khisa Wanyama.
Discussion of results: Lazarus Sindani, Michael Nakitare Waswa, Francis Maingi and Conrad Khisa Wanyama.
Writing – Original Draft: Lazarus Sindani.
Writing – Review and Editing: Lazarus Sindani and Michael Nakitare Waswa.
Resources: Lazarus Sindani and Conrad Khisa Wanyama.
Supervision: Michael Nakitare Waswa and Francis Maingi.
Approval of the final text: Lazarus Sindani, Michael Nakitare Waswa, Francis Maingi and Conrad Khisa Wanyama.

VI. ACKNOWLEDGEMENT

The authors thank the entire staff of the department of Physics Kenyatta University for carrying out measurement of the samples.

VII. CONFLICT OF INTEREST

The authors have no conflict of interest in regard to the publication of this article.

VIII. REFERENCES

[1] Shikali, N, C. (2013). Radionuclide content of sand used for construction in kakamega County and associated indoor radon diffusion.

[2] Xwinel, L., & Zhang, X. (2008). Natural radioactivity measurements in rock samples of Cuihua mountain national geological park, China. *Radiation protection dosimetry*, 128(1), 77-82.

[3] Ngachin, M., Garavaglia, M., Giovani, C., Njock, M. K., & Noureddine, A. (2007). *Assessment of natural radioactivity & associated radiation hazard in some Cameroonian building materials. Radiation measurements*, 42(1), 61-67.

[4] UNSCEAR (2000). Sources, Effects and risks of ionizing radiation. United Nations Scientific Committee on the Effects of Atomic Radiation. Exposures from Natural Sources, 2000 report to the General Assembly, *Annex B, New York.*

[5] UNSCEAR, 1993: Exposure from natural sources of radiation, in United Nations Scientific Committee on the Effects of atomic Radiation, *United Nations*: New York.

[6] European Commission, EC 1999: Radiation Protection Principles concerning the natural Radioactivity of Building Materials, Directorate- General environment, nuclear safety and civil protection.

[7] Oyeyemi, K. D., Usikalu, R., Aizebeokhai, A. P., Achuka, J.A., & Jonathan, O. (2017, May). Measurements of Radioactivity levels in part of sOta Southwestern Nigeria: implications for radiological hazards ondices and excess lifetime cancer-risks. *In journal of physics: Conference series (vol. 852, No. 1, p.012042). IOP publishing.*

[8] Matsitsi, S. M., Linturi, J. M., Kebwaro, J. M., & Maweu, O.M. (2019). Effects of seasonal change on the levels of Geogenic Radionuclides in sand and rocks from Tyaa river deposits in Kitui county: Geophysics. *International Journal of Fundamental Physical Science*, 9(1), 14-19.

[9] Kamunde, K. B. (2016). *Radi ation exposure levels associated with construction* sand from Tharaka- Nithi County, Kenya.

[10] UNSCEAR (2008). UNSCEAR 2008 Report vol.1: *Sources of Ionizing Radiation*.

[11] Kenya National Bureau of Statistics, 2019. Population of Bungoma County retrieved from en.m.wikipedia.org>wiki>Bungoma-county.

[12] Tzortzis, M., Tsertos, H., Christofides, S., & Christoduolides, G. (2003). Gamma-ray measurements of naturally occurring radioactive samples from Cyprus characteristics geological rocks. *Radiation measurements, 37(3), 221-229.*

[13] Odongo, W. O. G., Hashim, N., & Chege, M. W (2021). Gamma Ray Spectrometric Analysis of Sand Samples from mSelected Beaches along Kenyan Coastline. *The scientific world journal, 2021*.

[14] Ebaid, Y. Y (2010). Use of Gamma Ray Spectrometry for Uranium isotopic Analysis of Environmental Samples. *Rom J phys 55(1-2): 69-74.*

[15] Tsai, T., Lin C., Wang, T. and Chu, T (2008). Radioactivity concentrations and dose Assessment for Soil Samples around nuclear power plant IV in Taiwan. *Journal of Radiological Protection, 347:347-360*.

[16] UNSCEAR. (2010). Sources and effects of ionizing radiation. Report to the General Assembly, with scientific annexes. New York: United Nations.

[17] ICRP. (2015). Occupational Intakes of Radionuclides: Part 1. (Oxford Pentagon press: ICRP; Publication) 130.

[18] United Nations Scientific Committee on the Effects of Atomic Radiation (2017). Sources, Effects and Risks of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation. (UNSCEAR) 2016 Report, *Report the general sAssembly, with Scientific Annexes United Nations.*

[19] UNSCEAR, (2008). United Nations Scientific Committee on the effects of atomic radiation, sources, and effects of ionizing radiation. Report to General Assembly, with Scientific Annexes United Nations. United Nations, New York.

Journal of Engineering and Technology for Industrial Applications

ISSN ONLINE: 2447-0228

ITEGAM-JETIA

Manaus, v.8 n.33, p. 26-32. Jan/Feb, 2022
DOI: https://doi.org/10.5935/jetia.v8i33.793

RESEARCH ARTICLE OPEN ACCESS

CONSTRUCTION AUDIT-AN ESSENTIAL PROJECT CONTROL FUNCTION

Reuben A. Okereke[1], Usman Muhammed*[2] and Emmanuel C. Eze[3]

[1, 2] Department of Quantity Surveying, Imo State University, Owerri, Nigeria.
[3] Quantity Surveying Department, Federal University of Technology, Owerri, Imo State, Nigeria.

[1] http://orcid.org/0000-0003-1337-8179, [2] http://orcid.org/0000-0002-0892-8634, [3] http://orcid.org/0000-0001-7919-6322

Email: raphica2013@gmail.com, *qsusman@gmail.com, emmanuel.eze@futo.edu.ng

ARTICLE INFO

Article History
Received: January 06th, 2022
Accepted: February 21th, 2022
Published: February 28th, 2022

Keywords:
Auditing,
Fraud and corruption,
Nigeria,
Project control,
Public construction project.

ABSTRACT

Construction projects are known to overrun their budgets and schedules, poor quality of works, wastages, loss of value and experiences increase in financial frauds. Construction audit is a critical tool for the control and monitoring of frauds and other corrupt practices. The failure of construction organisations to recognise how critical auditing and its practices are in the management of construction projects have been blamed for the poor project performance outcome. The purpose of this study is to assess the benefits of construction audits to establish that it is a useful tool in controlling projects. Data were gathered from experts in consulting and contracting organizations using the well-structured questionnaire and purposive sampling technique in Port Harcourt, River State, Nigeria. With reliability of above 0.90, the collected data were analysed using frequency, percentage, mean score, and Mann-Whitney U test. It was found that the eve of use of auditing is high and it is recognised as a significant project control tool. The main benefits of audit application in construction are; to reduce cost overrun, financial probity and accountability, aid in the recovery of cost to promote cost savings, to protect the clients from avoidable and unnecessary claims from contractors, and ensure that projects are delivered in accordance with the project contract provision. Auditing should be encouraged in the delivery of private and public projects to ensure that value for money is achieved and losses reduced.

I. INTRODUCTION

In both the developed and developing economies of the world, the construction industry plays an appreciable and recognisable role in stimulating the growth and development of nations. The construction sector proved to be useful to the national development and economic growth of countries, and the most obvious impacts are in the provision of housing and infrastructure, wealth creation, employment creation and contribution to the income of nations [1, 2]. However, construction projects are known to overrun their budgets and schedules, poor quality of works, wastages, loss of value [1], and experiences increase in financial frauds. This is attributed to the multiple stakeholders involved [3], the number of companies and huge monies involved in the delivery of construction projects [4].

The failure of construction organisations to recognise how critical construction audits and their practices are in the management of construction projects has been blamed for the poor project performance outcome. According to [5] privately and publicly financed building and engineering construction projects in developed and developing nations are confronted by a myriad of problems such as corruption, frauds, poor procurement practices, poor quality, design deficiencies, lack of attainment of value for investors/clients monies, cost and time overruns, and project delivery issues. These ultimately result in the dissatisfaction of the clients/investors and other critical stakeholders in the construction sector. An audit is a planned and documented activity of ascertaining via investigation, evaluation of objective evidence, compliance with established processes and standards, or applicable documents and the implementation effectiveness [6, 4]. Construction audit involves the review of a project to ensure it is performing as planned and contained in the contract. It is therefore a crucial tool for keeping activities under check and within the approved budget. The job of auditing must be carried out without any interference. Construction auditing is carried out in all newly approved construction contracts whether is it publicly or privately owned and in renovation and expansion projects [4]. Whether in new or refurbishment projects, auditing should be not stopped after the final account but should extend to the post-contract stage.

Construction contract administration often ends at the final measurement and final account [7]. Cross-checking of work executed is an important post-construction cost control system that should not be neglected. A construction project audit is meant to reconcile the value of work done with the resources committed to it during the construction stage. According to [8] project audit is carried out to make sure that the value of monies received during the execution of a project is proportionate to the amount spent. The ultimate aim was to ensure that the principles of economy, efficiency and effectiveness are attained during the construction phase. The audited project must show that the contents of the contract documents reflect that the contract is not inflated [9]. While construction auditing has gained ground in the top developed nations of the world, developing countries in Africa have not embraced this system appropriately. Nigeria is a developing country where the performance of construction managers is below satisfactory, especially in carrying out construction audits (4, 8]. The role of auditing is however adjudged to be cumbersome and confusing as a result of inadequate knowledge and training on how to effectively carry out construction auditing.

A review of construction management literature shows that construction auditing is less explored by researchers and academia. This lack of appreciation of construction audit and practices as an essential aspect of project management responsibilities as submitted by [5], has led to continuous use of defective procurement, financial related fraud and corruption and other social and contractual ills that lead to poor project performance. This is despite how critical construction project audit is in ensuring that clients achieve value for money and controlling fraudulent and corrupt practices by contractors and other construction experts. It is based on the foregoing that this study entitled 'construction audit-an essential project control function' is embarked upon. This study aim will be achieved through an assessment of the benefits of construction audits with a view to showing how useful it is in control of the project. This study leveraged the experiences of the consultants and contractors in the delivery of publicly funded construction projects to achieve its aim. Public construction clients (both state and federal governments), academia and construction experts will find this study useful in areas of checking improper and fraudulent practices across the entire supply chain management. This study will also add to the scanty literature on construction audit, especially in developing countries like Nigeria and others.

II. BENEFITS OF CONSTRUCTION AUDIT

Construction projects are usually time-consuming and involve huge capital outlay and with most of the projects having 1 to 2% overcharges [10]. With multiple activities and stakeholders and tasks being carried out simultaneously, it becomes a difficult and tedious job to manage construction works effectively and stair it out of trouble when it is derailing out of budget and plans. Construction audit (CA) is a relevant and effective measure of unearthing good and failed or bad project performance practices, be it in new or refurbishment construction projects [5, 11]. Construction audit is conventionally involves accounting, auditing and construction management disciplines [5].

Independent construction audits help to ensure that overcharges and fraud are avoided in construction contracts. Construction audit helps the project to know its place in the industry. It enables comparison of project management processes, schedule and cost control with best practices in the industry. [4] reported that the topmost vital importance of CA is; checking and prevention of corruption, accountability and financial probity, ensuring that there is efficiency, economic consistency and standard for meeting the quality target, ensuring adherence to practices and procedures, and reduction of cost overrun.

Better ways of managing a construction projects risks, ensuring proper functioning of control measures and procedures, and enabling parties to the contract, to be honest in their dealings are the important function of audit [10]; this is particularly important via contract terms checking and identification of overcharges. Construction audit gives the assurance that the financial aspects of a project are well monitored and managed. This helps to strengthen the relationships of clients and construction organisations. Performing audits help to ensure that the cost structure of projects are verified and reviewed so that closeout time is shortened, and contractors can receive their final payment [10]. In addition, construction companies are better equipped and strengthened to face potential or new projects with the report of audit. This implies that lessons are learnt from the previous project to improve the performance of construction projects and the performing organisations' performances.

Construction audit helps in the recovery of the cost emanating from the default of a party. The parties concerned or responsible for the cost to spiral out of control will have to pay for his/her defaults. An audit also put the project manager into a state of being alert to ensuring that production activities are done correctly and within project scope and requirements [12]. CA help to assess whether a project is progressing well in terms of being ahead or behind schedule and what has been achieved in terms of output. This is important as valuations are based on work done. Furthermore, it ensures that procedures on how to handle dangerous materials, equipment and motions on site are followed. This is important in providing a safe work environment for the artisans and tradespeople and other supervisory management staff. [13] posit that one of the major functions of CA is quality. CA shows what is working and what is not working in terms of quality of work. When the quality of work is to standard, the customers will be satisfied and the project will flow smoothly without any disputes. According to [14], a construction audit when properly applied will ensure that projects resources are kept under control from the inception of a project to the closeout. It particularly ensures that; areas, where risks are likely to be high, are identified, ensure that contracts terms are complied with and the accuracy of charges and billings are verified, project funds are used judiciously, helps in reporting of potential cost savings, recovery or avoidance, helps in eliminating inefficiencies, help to identify areas of improvement in processes, helps in the resolution of identified issues and report status for appropriate remedial action to be taken, and helps in the timely closeout of projects.

[15] posit that Construction projects are audited to ascertain the economy, efficiency, project stakeholders' effectiveness, project compliance with statutory, regulatory and corporate guidelines. Construction audit revolves around finance

and budgeting, procurement processes, project management, technical and legislative issues [5]. However, the fundamental function of auditing centres on finance and budgetary auditing. Auditing the financial aspect of construction activities cover the inspection of all projects' financial records and figures [11]. Therefore, to guarantee value for clients and investors monies, all vital accounting standards and legal requirements must be followed. Failure to carry out an audit means that the real financial situation of the project as well as time and other project resources cannot be assured [16].

The role of auditing the procurement process is to ensure that guidelines for procuring goods and services are followed without deviations. A lot of project resources are wasted, projects have failed to meet their requirements, claims and disputes have evolved; as a result of following the wrong route of procurement. Construction projects have even been abandoned as a result of fraudulent procurement. Therefore, controlling the bidding process is a critical aspect of construction projects that must not be overlooked or ignored [5]. Construction stakeholders rely on construction audits to make a judgement of the quality of publicly procured projects. Project management audit involves auditing the project management and the management of the daily transaction of the projects. Project management audit reveals the actual performance of every stakeholder against the initial project plan prepared at the inception [15].

Technical Auditing of construction projects helps to check that the prescribed engineering procedures and methods are monitored and evaluated at the project construction phase. [11] submitted that technical auditing also ensures that the technical capabilities of the project staff are within the acceptable standard required by professional regulatory institutions. The Technical skills and expertise of the project team are necessary for a better project outcome. Professional technical skills auditing has attracted a lot of attention recently by both researchers and industry practitioners [17, 15], due to the increased spate of building collapse. The legislative function of CA ensures that construction projects are in conformance with the statutes and regulations of the project location [5]. The legislative dimension of auditing is vital for the successful and satisfactory delivery of critical facilities and infrastructure projects in Nigeria.

The critical areas of applications and functions of construction audit are shown on figure 1 below.

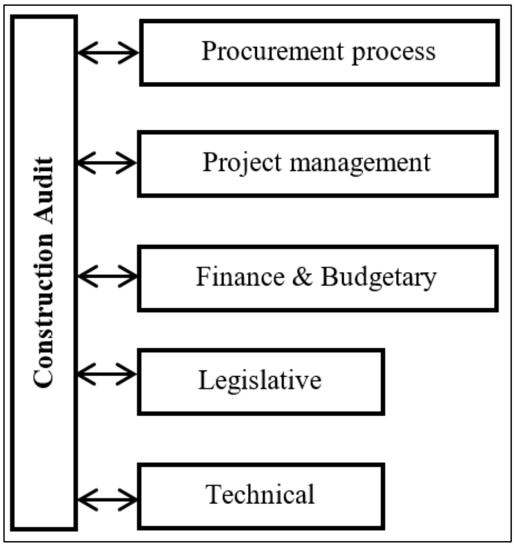

Figure 1: Benefits of Construction Audit.
Source: Modified from [4].

III. MATERIALS AND METHODS

This study assessed the benefits of construction audits with a view to establishing that it is a useful tool in controlling projects. The well-structured questionnaire was used in this study to garner relevant data from consultants and contractors involved in the delivery of both public and private projects, especially in Port Harcourt, River State, Nigeria. Port Harcourt is the state capital of rivers state which is one of the states in Nigeria that is very rich in oil and gas and other natural resources. The presence of these natural resources attracts a lot of construction organisations, oil exploration companies as well as other companies. Investors, professionals, construction tradespeople as well as people from all works of life are also attracted to the state because of the many building and infrastructure projects being undertaken by both state and federal government [18, 19].

The questionnaire is simple, easy to use and has the capacity to reach wider audiences in a shorter time and lower cost [20]. The questionnaire used gathered data on the respondents' background information, Frequency of use of auditing to control construction projects, Level of agreement of construction audit as a project control tool and the benefits of construction audit in project control. The questionnaire was designed based on a 5-point Likert scale in which 1 is the lowest scale and 5 is the highest scale.

Five (5) active construction sites and six (6) recently completed projects that are publicly owned were identified during a preliminary survey of the study area. This makes is a total of 11 construction projects that were sampled. The consultants and contractors involved in the projects were identified, contacted and sampled. The lead consultants and main contractors were involved in the study. This was to ensure that quality data are obtained and that experienced experts on the subject of this study participate in it. Three (3) management level personnel from the consultant organisation participated in the study. Five (5) management level personnel of the contracting organisations were sampled. These represent a total sample size of 88 (33 experts from consulting and 55 experts from the contracting organisations). It is the understanding of this study that this sample size is representative enough for the study.

The purposive sampling technique was adopted in the administration of the questionnaire by the researchers. This sampling technique is suitable in a study where the experienced of the participants is very important as well as their availability for the survey. 100% of the administered questionnaires were retrieved and this response rate was achieved due to the several follow-up calls and repeat site visits to remind the participants of the importance of the study.

Data analysed were done through the use of frequencies, percentiles, mean scores and Mann-Whitney U. The mean scores of the assessed variables were used to rank the benefits of construction audit while an independent sample test was used to determine the relationship in the perception of the consultants and contractors. The reliability of the research instrument was tested using Cronbach's alpha test. An alpha value of 0.916 was obtained for data on the benefits of construction audits (See Table 1). This implies that the instrument is reliable and data obtained are of good quality and unbiased. The methodological flow chart is shown in figure 1 below.

Table 1: Reliability Test.

			N	%
Case Processing Summary	Cases	Valid	88	100.0
		Excluded[a]	0	0.0
		Total	88	100.0
Reliability Statistics	Cronbach's Alpha		0.916	
	N of Items		20	

Source: Authors (2021).

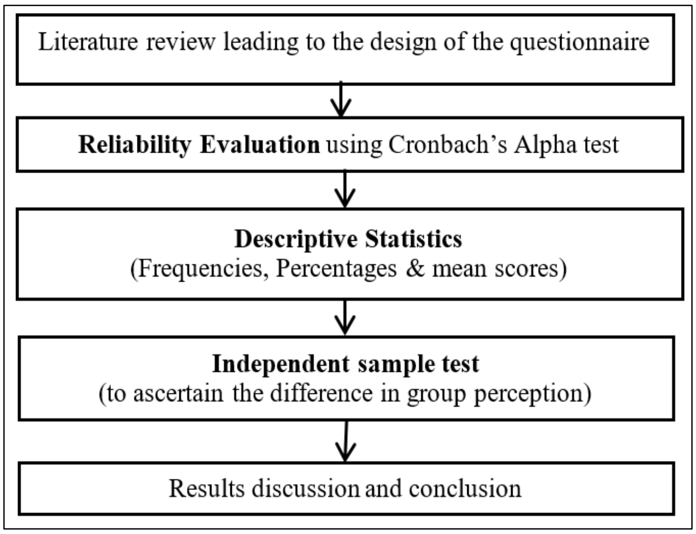

Figure 2: Study Methodological procedure.
Source: Authors, (2021).

IV. RESULTS AND DISCUSSIONS

IV.1 BACKGROUND INFORMATION OF RESPONDENTS

From Table 2 37.50% of the respondents are from consultants and 62.50% are from the contractors' organisations. The profession of the participants showed that Architects are (26.14%), Builders (11.36%), Engineers (36.36%), and Quantity surveyors (26.14%). In terms of their years of experience, it can be seen 32.95% have spent between 5-10 years in the industry, 37.50% have spent 11-15years, 15.19% had spent 16-20years, and those who have spent over 21 years are 13.64%. The educational qualification of the participants indicates that those with HND are (22.73%), PGD (13.64%), BSc/B.Tech (38.64%), M.Sc/M.Tech (22.73%), and PhD holders are 2.27%. Furthermore, the professional qualification of the respondents indicates that the majority of them are corporate members of their various organisations and 11.36% are probationer members of their professional bodies.

It is evident that the respondents are academically and professionally qualified and have the requite experiences to give information that will aid in meeting the subject of this study.

Table 2: Respondents and organisation profile.

Variables	Classification	Freq.	%	Cum. %
Organisations	Consultants	33	37.50	37.50
	Contractors	55	62.50	100.00
	TOTAL	**88**	**100.00**	
Participants professions	Architect	23	26.14	26.14
	Builders	10	11.36	37.50
	Engineers (Civil/structural & Services)	32	36.36	73.86
	Quantity Surveyors	23	26.14	100.00
	TOTAL	**88**	**100.00**	
Years of experience	0-4years	0	0.00	0.00
	5-10years	29	32.95	32.95
	11-15 years	33	37.50	70.45
	16-20 years	14	15.91	86.36
	21-above	12	13.64	100.00
	TOTAL	**88**	**100.00**	
Highest Educational Qualification	Higher National Diploma (HND)	20	22.73	22.73
	Postgraduate Diploma (PGD)	12	13.64	36.36
	Bachelor of Science/Technology (B.Sc./B.Tech)	34	38.64	75.00
	Master's Degree (MSc./M.Tech.)	20	22.73	97.73
	Doctorate (PhD)	2	2.27	100.00
	TOTAL	**88**	**100.00**	
Participants Professional Affiliation	Member Nigerian Institute of Architect (MNIA)	18	20.45	20.45
	Member Nigerian Institute of Builders (MNIOB)	10	11.36	31.82
	Member Nigerian Society of Engineers (MNSE)	29	32.95	64.77
	Member Nigerian Institute of Quantity Surveyors (MNIQS)	21	23.86	88.64
	Probationer	10	11.36	100.00
	TOTAL	**88**	**100.00**	

Source: Authors, (2021).

IV.2 FREQUENCY OF USE OF AUDITING TO CONTROL CONSTRUCTION PROJECTS

Figure 1 shows the result obtained from the analysis of the data gathered on how frequent auditing has been used to control construction projects. It is obvious from fig.1 that the frequency of use of auditing to control projects ranges from moderate to very high. This shows that construction auditing is a recognised practise in the construction industry of Nigeria.

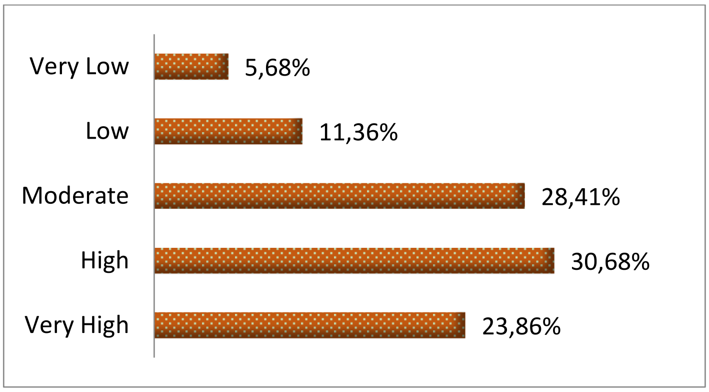

Figure 3: Frequency of use of auditing in projects.
Source: Authors, (2021).

IV.3 CONSTRUCTION AUDITS PLAY SIGNIFICANT ROLE IN PROJECT CONTROL

Figure 4 shows that the participants from the contracting and consulting firms strongly agreed that construction audit plays a significant role in the control of projects. This further shows the consciousness of stakeholders in the construction industry to key project resources under control and proper management. This report supports the finding in figure 3 above.

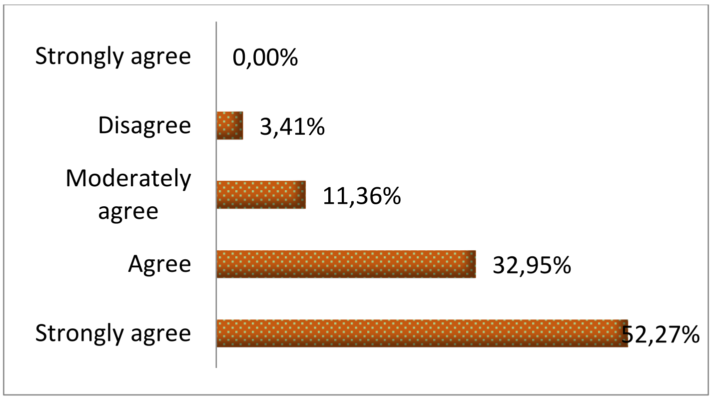

Figure 4: Construction audit a project control tool.
Source: Authors, (2021).

IV.4 BENEFITS OF CONSTRUCTION AUDIT

The result of the analysis of data gathered on the benefits of construction audit is shown in Table 3. The top 5 most important benefits of audit application in construction are; to reduced cost overrun (mean=4.76), Financial probity and accountability (mean=4.59), aid in the recovery of cost to promote cost savings (mean=4.57), to protect the clients from avoidable and unnecessary claims from contractors (mean=4.53), and ensure that project are delivered in accordance with the project contract provision (mean=4.51). while the least ranked benefits of auditing are; helps to establish actual progress and work done on a project (mean=4.02), Ensure the provision of a safe working environment for workers (mean=4.01), ensure that projects are delivered in accordance with legislative provisions of the location (mean=3.98), to ensure the compliance of all practice and procedures. (Mean=3.90), and help improve return on investment (mean=3.80).

Overall, regardless of the relative ranking of these variables, they still represent the vital benefits obtained from the application of auditing services on construction projects. This is based on the range of the mean scores with a maximum mean of =4.76 and the Minimum=3.80. This study revealed that the major benefits of audit application in construction are; to reduce cost overrun, financial probity and accountability, aid in the recovery of cost to promote cost savings, to protect the clients from avoidable and unnecessary claims from contractors, and ensure that projects are delivered in accordance with the project contract provision. This finding supports that report of [4, 15, 5, 10]. Honesty in dealing with parties in a construction contract is the bedrock for prudent project management and success. Construction audit reveals areas of dishonesty by the contractor as over change, and manipulations of invoices and frauds are detected and sanctions mated. As a major project management function, auditing helps in ensuring that projects are delivered within budget and planned duration. It helps contractors to get their payment faster without undue delays [10]. The quality of the finished building is assured, and the number of accidents on site is reduced where construction audits are frequently performed [16, 5]. Construction audit is a critical project control function as its application ensures that project activities are monitored from inception to completion and facility management stages. There will be savings in cost, fewer claims and disputes, lesser interruption of work progress, and the achievement of good health and safety and quality records and performance on a project that implement auditing.

Mann-Whitney U-Test was carried out to; compare the perceptions of the two groups of participants; especially in determining the variables the respondents' view differs significantly and the percentage of the variables with the same rating pattern by the consultants and contractors. Mann-Whitney U-Test revealed that the participants' views converge in 16(80.0%) of the variables. These variables have a significant p-value of above 0.05; this implies that there is no significant statistical difference in the way the participants rated these variables. A significant statistical difference was observed in the perception of the consultants and contractors on 4(20.0%) of the variables. These variables have a significant p-value of less than 0.05. These variables are; Failures caused by time and cost overrun are prevented through audit of projects (Z=-2.145), help improve return on investment (Z=-4.598), to ensure production efficiency, consistency and standard to meet the quality target of a project (Z=-2.125), Analysis of problem areas of the project to generate data for improving future contract delivery (Z=-2.433), and used to check project management functions of project stakeholders (Z=-0.173).

Table 3: benefits of auditing in construction projects.

S/No	Variables	mean score	S.D	Rank	Mann-Whitney U	
					Z	Sig.
1	To checkmate fraud and corrupt practices	4.42	1.1113	8th	-1.245	0.213
2	to reduce cost overrun	4.76	0.5672	1st	-1.898	0.058
3	Financial probity and accountability	4.59	1.0130	2nd	-0.379	0.705
4	to protect the clients from avoidable and unnecessary claims from contractors	4.53	1.1442	4th	-1.117	0.264
5	To improve understanding of project environment for proper control	4.50	1.0283	6th	-1.732	0.083
6	Failures caused by time and cost overrun are prevented through audit of projects	4.09	1.3615	15th	-2.145	0.032**
7	helps in controlling and mitigating project risks	4.15	1.1894	14th	-0.928	0.354
8	ensure that projects are delivered in accordance with legislative provisions of the location	3.98	1.5461	18th	-1.752	0.080
9	ensure that projects are delivered in accordance with the project contract provision	4.51	0.9942	5th	-1.845	0.065
10	improve the internal control of processes and procedures of organisations	4.23	1.1619	12th	-0.217	0.828
11	aid in the recovery of cost to promote cost savings	4.57	0.8549	3rd	-0.971	0.332
12	Improves understanding of performance opportunities, penalties, incentives, rights and obligations.	4.27	1.3107	11th	-0.352	0.725
13	Ensure the provision of a safe working environment for workers	4.01	1.4739	17th	-0.177	0.859
14	help improve return on investment	3.80	1.6129	20th	-4.598	0.000**
15	to ensure production efficiency, consistency and standard to meet the quality target of the project	4.48	0.9823	7th	-2.125	0.034**
16	Analysis of problem areas of the project to generate data for improving future contract delivery	4.34	1.1733	10th	-2.433	0.015**
17	used to check project management functions of project stakeholders	4.23	1.2292	12th	-0.173	0.862
18	Ensure compliance and adherence to best practices in construction contract procurement and management	4.41	1.0574	9th	-0.878	0.380
19	helps to establish actual progress and work done on a project	4.02	1.3303	16th	-0.237	0.813
20	To ensure the compliance of all practices and procedures.	3.90	1.4145	19th	-0.701	0.483

**P-value<0.05

Source: Authors, (2021).

V. CONCLUSIONS

This study assessed the benefits of construction audits with a view to establishing that it is a useful tool in controlling projects. The opinion of construction professionals in consulting and contracting organizations was sampled using the well-structured questionnaire and purposive sampling technique in Port Harcourt, River State, Nigeria. The collected data were analyzed, findings made and conclusions drawn.

The study revealed that the frequency of use of auditing to control construction projects is high and it is a significant project control tool. The major benefits of audit application in construction are; to reduce cost overrun, financial probity and accountability, aid in the recovery of cost to promote cost savings, to protect the clients from avoidable and unnecessary claims from contractors, and ensure that projects are delivered in accordance with the project contract provision. Construction audit is a critical project control tool as it focuses on helping clients to achieve value for money. The contractor tries to avoid or reduce unnecessary spending and ensure that works are done are those captured in the contract.

Construction audit helps to instil discipline in the adherence to contract provisions and in the control and management of project resources. Construction project auditing keeps every stakeholder focused on their performance their functions towards meeting the project objectives, reducing wasteful spending, reducing claims and other disputes in the delivery of construction projects, especially of pubic natures. Finance is the life-blood of every construction and developmental project. It is the function of auditing that will ensure that projects are delivered within the planned budget.

Construction experts' consultants and contractors are exposed to the benefits of construction audits. This study adds to the few existing bodies of knowledge on construction audit, especially in Nigeria and other African nations. The imitation of this study is in its sample size and geographical location. Care should be taken when generalizing the finding of this study. A similar study with a larger sample size and geographical coverage is recommended in Nigerian or other African countries. This will provide data for the purpose of comparison. An assessment of the relative application of auditing at pre-contract and post-contract stages of construction projects delivery should be assessed.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Dr. Reuben A. OKEREKE and Usman MUHAMMED.

Methodology: Dr. Reuben A. OKEREKE, Usman MUHAMMED and Emmanuel C. EZE.

Investigation: Dr. Reuben A. OKEREKE, Usman MUHAMMED and Emmanuel C. EZE.

Discussion of results: Dr. Reuben A. OKEREKE, Usman MUHAMMED and Emmanuel C. EZE.

Writing – Original Draft: Dr. Reuben A. OKEREKE, Usman MUHAMMED and Emmanuel C. EZE.

Writing – Review and Editing: Dr. Reuben A. OKEREKE, Usman MUHAMMED and Emmanuel C. EZE.

Resources: Usman MUHAMMED and Emmanuel C. EZE.

Supervision: Dr. Reuben A. OKEREKE, Usman MUHAMMED and Emmanuel C. EZE.
Approval of the final text: Dr. Reuben A. OKEREKE, Usman MUHAMMED and Emmanuel C. EZE.

VII. REFERENCES

[1] Nwaki, W.N., & Eze, C.E. (2020). Lean Construction as a Panacea for Poor Construction Projects Performance. Journal of Engineering and Technology for Industrial Applications, 6(26), 61-72. DOI: https://doi.org/10.5935/jetia.v6i26.723

[2] Onyeagam, O.P., Eze, E.C., and Adegboyega, A. A. (2019). Assessment of Quantity Surveying Firms' Process and Product Innovation drive in Nigeria. SEISENSE Journal of Management, 2(3), 21-37.

[3] Okereke, R.A., Zakariyau, M., & Eze, E.C. (2021). Extension of time (EoT) claims substantiation and associated issues in complex-multi stakeholders' building construction contracts. Journal of Engineering and Technology for Industrial Applications (JETIA), 7(32), 23-31. DOI: https://doi.org/10.5935/jetia.v7i32.782

[4] Usman, N., & Sani, A. (2015a). An Evaluation Of Contract Auditing Practice In Nigerian Building Construction Projects. International Journal of Economics, Commerce and Management, III(4), 1-8.

[5] Bondinuba,F.K., Nansie, A., Dadzie, J., Djokoto, S.D., & Sadique, M.A. (2017). Construction Audits Practice in Ghana: A Review. Journal of Civil Engineering and Architecture Research,4(1), 1859-1872.

[6] Cai, H., Kandil, A., Hastak, M., & Dunston, P. (2012). Construction Research Congress 2012: American Society of Civil Engineers.

[7] Adebola, O. (2000). Contract Auditor in Construction Project. Budgetary Planning for Capital Projects and Construction Contract Auditing. published by Nigerian Institute of Quantity Surveyors, Lagos.

[8] Usman, N., & Sani, A. (2015b). Construction Professionals Perceptions' on Contract Auditing System in Building Projects. Journal of Multidisciplinary Engineering Science and Technology (JMEST), 2(4),716-720.

[9] Anyadike, E. I. (2000). Checklist for contract review and cost auditing, an Agenda for Construction Contract Auditing, Budgetary Planning for Capital Projects and Construction Contract Auditing. Published by Nigerian Institute of Quantity Surveyors, Lagos, 2000.

[10] Wallace, B.S. (2009). Building Wisely: How Construction Audits Can Help Control Project Costs. https://www.bswllc.com/resources-articles-building-wisely-how-construction-audits-can-help-control-project-costs

[11] Nalewaik, A. A. (2007). Construction audit-an essential project controls function, AACE International Transactions,49,20-24.

[12] Steve, B., & Julie, D. (2020). When Should Your Power or Utility Company Seek Construction Audit Services?. https://www.mossadams.com/articles/2020/02/construction-audits-for-power-and-utilities.

[13] Caldeira, E. (2021). Construction Quality Assurance/Quality Control Blog. https://www.firsttimequality.com/Blog/bid/74108/8-Essential-Steps-for-Doing-a-Construction-Project-Quality-Audit.

[14] Construction management partners (CMP) (2017). Implementing a Construction Audit Process is essential to a successful Project Outcome. http://cmpstlouis.com/construction-audit-process/

[15] Dusterwald, R., Palm, S.F. , Giesing, F., Peis, M., & Schwarz, U. (2008). Standard for auditing projects, German Institute for Internal Auditing.

[16] Raffa,P.C. (2003). Hand-out on three (3) Levels of Service, 2003, [Online], www.raffa.com.

[17] Urso, L. (2012). Construction fraud, detecting, controlling and auditing, in: 23rd Annual Association of Certified Fraud Examiners (ACFE), Fraud Conference and Exhibition Working Paper no. 176.

[18] Eze, C.E., Awodele, I.A., Adegboyega, A.A., Onyeagam, O.P., & Guto, J.A. (2020). Assessment of the Triggers of Inefficient Materials Management Practices by Construction SMEs in Nigeria. International Journal of Real Estate Studies, 14(1), 38-56.

[19] Onyejeakor, H.I., Eze, E.C., Onyeagam, O.P., & Adegboyega, A.A. (2020). Factors influencing the deployment of innovative (ICT) facilities by construction organisations in port Harcourt, Nigeria . Independent Journal Of Management & Production, 11(4),1357-1380. DOI: 10.14807/ijmp.v11i4.1096

[20] Tan, W.C.K. (2011). Practical Research Methods. Pearson Custom, Singapore.

Journal of Engineering and Technology for Industrial Applications

ITEGAM-JETIA

ISSN ONLINE: 2447-0228

Manaus, v.8 n.33, p. 33-39. Jan/Feb, 2022

DOI: https://doi.org/10.5935/jetia.v8i33.792

RESEARCH ARTICLE

OPEN ACCESS

ASSESSMENT OF SURVIVAL STRATEGIES OF QUANTITY SURVEYING FIRMS DURING ECONOMIC TURBULENCE

Reuben A. Okereke[1], Dennis Isaac Pepple*[2] and Nneka Mercyjane Ihekweme[3]

[1] Department of Quantity Surveying, Imo State University, Owerri, Nigeria.
[2] Federal Polytechnic of Oil and Gas Bonny Island, River State, Nigeria.
[3] Quantity Surveying Department, Federal University of Technology, Owerri, Imo State, Nigeria.

[1] http://orcid.org/0000-0003-1337-8179, [2] http://orcid.org/0000-0003-0071-4807, [3] http://orcid.org/0000-0002-1549-6307

Email: raphica2013@gmail.com, *dennispepple2@gmail.com, nnekamercyjane@gmail.com

ARTICLE INFO

Article History
Received: January 06th, 2022
Accepted: February 21th, 2022
Published: February 28th, 2022

Keywords:
Construction industry,
Economic turbulence,
Nigerian economy,
QSFs,
Survival strategies.

ABSTRACT

Financial crises occasioned by economic turbulence and stiff competition in the construction sector have forced Quantity Surveying firms (QSFs) and construction firms into finding innovative ways of surviving and staying above completion in most developing nations. The decline in the Nigerian oil and gas production and export has made it difficult for the government who is the largest client of the construction sector to limit its spending, especially in infrastructure and development projects. QSFs now scramble for effective and efficient strategies to survive the dwindling economic construction. This study assessed the survival strategies of quantity surveying firms (QSFs) during economic turbulence in Port Harcourt, Nigeria. The well-structured Quantitative Questionnaire administered using snowball sampling techniques in the study area were adopted in gathering data from the target respondents. With a sample size of 86, the gathered data were analysed using frequency, percentage, and mean item score (MIS). It was found that the most critical Survival strategy adopted by QSFs during economic turbulence are; improved networking systems to increase reach, effective management of knowledge, retaining experienced staff in the company, reduction of service charges, and improved service delivery. This study concludes that the assessed survival strategies have a high level of importance and plays a critical role in ensuring that Quantity Surveying firms survive the economic downturn and the stiff competitive market of the construction sector. It is recommended that the managers of QSFs should focus on those major strategies that will keep them above the competition, in continuous business, sustainable growth, and survival during economic turbulence.

I. INTRODUCTION

After the great depression of 1929, the financial crisis that stroke the world in 2007 is adjudged the most shocking and devastating economic event [1]. Economic recession or turbulence could be caused by internal or external forces. Countries boundaries have continued to remain open as a result of globalization. Liquidation or bankruptcy has hit many businesses as a result of economic shocks from external forces occasioned by globalisation [2]. As a result of this, companies globally were compelled to restructure and are quickened to reduce costs, debts and number of employees; especially during the period of economic and market volatility [3]. Survival became the order of the day for most industries as they scrambles for effective ways and strategies to survive.

The construction sector is not immune to the economic downturn as construction organisations continue to devise new ways and techniques to remain afloat [2]. In Ireland, four out of the major ten construction firms failed to survive a recession. It was posited that the number of companies that failed recession increased from 120 in 2007 to 740 in 2011 [4]. 2,785 construction firms failed in the UK in 2008 and the number increased in 2009

[3]. In Nigeria, construction companies are facing the same challenges, as the economy is monolithic and solely dependent on oil production and export [5-6]. With the economic downturn and the decline in oil production and price volatility in oil price and unpredictability in output [7-8], coupled with the energy independence target of the US and China that are the major buyers of crude oil, The Nigerian economy is further destabilised [5]. In addition to declining oil production and exportation, [9] identified other causes of economic turbulence or recession as; inflation, loss of consumer confidence, excess supply over demand, excess demand oversupply, and global economic-financial crisis. This situation has continued to impact the construction industry and organisations and their competitiveness. According to [10], new projects are hardly commissioned as a result of the recession. Furthermore, new projects are rarely occupied, construction sites are abandoned and equipment and machines are left ideal throughout the country.

While there are existences of studies on survival strategies in the construction industry, a lot of them have focused on construction organisations generally [11-15, 5, 2-3, 16-19]. However, the Quantity Surveying firms which are one of the critical organisations in the delivery of construction projects, especially in areas of cost management of the built environment assets of the construction industry have been under explored. [20] posits that Quantity surveying firms occupy an appreciable proportion of construction organisations in the built environment; thus, their survival is critical to their continuous contribution to the nation's infrastructure development, and the essential influence of the construction industry on national development. Flowing from this knowledge, this study assesses the survival strategies of quantity surveying firms during economic turbulence in Port Harcourt, Nigeria.

[21] state that Quantity Surveying practices explore numerous survival practices that ranges from exploiting new opportunities through diversification, project evaluation, project accounting and auditing, prompt dispute resolution, adoption of technology innovations among other means. Skill development, synergy among professionals and collaborations has been highlighted as a way of producing a health industry that creates a sustainable built environment [22]. The outcome of this study can be leveraged by other countries with similar construction markets as Nigeria to learn strategies on how to stay afloat and remain relevant in times of economic recession and competition. Other proven Survival strategies adopted by other construction organisations in other nations of the world could be applied by construction firms other than QSFs in Nigeria to remain alive, above the competition in periods of economic downturn.

II. LITERATURE REVIEW

II.1 ECONOMIC TURBULENCE AND QUANTITY SURVEYING FIRMS (QSFS) IN NIGERIA

The construction industry plays a significant role in the economic growth and development in both developed and developing countries of the world. The industry drives employment generation, wealth creation, housing and infrastructure provisions, and national income contribution [23-24]. For [14], the construction sector helps to transform various economic resources into finished physical infrastructures that have economic and social impacts. Furthermore, the products of the construction sector are required by other economic sectors. In a challenging economy, construction activities experience a decline, whereas in a healthy and booming economy the reverse is the case [25-26]. [20] submits that in an unhealthy economy, there is usually low patronage of the construction sector in a turbulent economy. A developing country like Nigeria has always been experiencing several economic turbulences.

In 2016 Nigeria experienced two consecutive quarters of economic contraction according to the National Bureau of Statistics. [27] states that even though Nigeria is technical out of recession, businesses have continued to experience economic difficulty. Ups and downs in the economic situation in the country have both direct and indirect effects on the continuity, sustenance and survival of the construction industry as well as the construction organisations of which QSFs are a part [18, 28]. The government both at the state and federal level are the largest client of the construction industry and their patronage declines in periods of economic recession. The government are compelled to limit the number of projects and other developmental projects that are embarked upon.

Quantity Surveyors (QS) are individuals who are professionally trained, qualified and experienced in handling cost management, financial control, contract administration, procurement management, and other management-related functions of constriction projects in the construction industry [29]. Quantity Surveying firms engage these certified quantity surveyors in rendering these services to their clients. Many organisations including QSFs are working hard to ensure that clients, investors, regulators and competitors are satisfied, especially due to the stiff competition of the construction sector [30]. QSFs are dependent on the skills, expertise and knowledge of the QS to meet the numerous needs and demands of clients and other stakeholders [31].

QSFs are service-based organisations that provide expert advice and consultancy services to customers, thus, they cannot do without employees who are mostly QSs. This implies that the recruitment of qualified QSs is central to the survival and success of the QSFs. As businesses move towards achieving sustainable growth, the QSFs need to embrace a new paradigm in order to remain globally competitive [32].

II.2 SURVIVAL STRATEGY OF QSFS DURING ECONOMIC TURBULENCE

One of the ways of measuring business success besides profits, sales growth, return on investment (ROI), corporate reputation, the numerical strength of employees, is the survival and competitive strength [12]. The formulation of a sound strategy is useful to construction-based organisations towards their survival and achievement of sustainable growth and progress, especially when faced with a turbulent and volatile business atmosphere [11]. A review of construction management literature shows that various survival strategies have been adopted by various organisations in different countries and continents to stay afloat during periods of economic downturn.

Differentiation has to do with the activities of the company targeted toward differentiation their products or services offered by creating something Unique [33]. Surviving economic turbulence requires the adoption of differentiation strategies [34]. [35] showed that a stronger relationship with performance can be achieved during excessive competition through differentiation. The Four differentiation strategies that were highlighted are:

i. Investment in Research and development/new technologies (focus on technology/innovation)
ii. Enhancing marketing and advertising (i.e. focus on marketing)

iii. Strengthening stakeholders relationships (i.e. focus on marketing)
iv. Focus on enhancing products offered or services rendered (focus on technology/innovation)

In a critical review by [3], differentiation strategies were found to be the major survival strategies adopted by construction companies during an economic recession. Similarly, it was drawn from pilot case studies from Irish and UK construction contractors' response strategies to economic recession and concluded that cost leadership aimed at cost reduction and cost minimisation are the major response strategies adopted by Irish and UK contractors. With the generic category, the Irish and UK construction contractors adopt common strategies such as human resource/personnel strategies which include staff retraining/upskilling, bonuses cutting, cutting staff engaged on a project, training staff to cut costs.

[11] in Malaysia found that construction firms survived two different periods of economic downturns through the adoption of major survival strategies such as management style, market penetration, quality improvement, market development and product development. In a similar but different study in Malaysia, [36] reported that QSFs adopts survival strategies like branding, relationship, marketing, reputation, and innovation, among others. [20] stressed the need for Quantity Surveyors to improve on their skills and the embracing innovative technologies to achieve sustainable growth. Achieving sustainable development will provide quantity surveyors with the avenue to move beyond the traditional cost management functions to providing leadership in other relevant areas of the delivery of construction n projects that have an economic impact.

[2] found that during prolong the economic recession, contractors in Singapore adopts three major survival strategies, and they are; contracting-related actions, cost-control related actions, and financial-related actions. The most ranked survival strategies under the contracting-related actions are; bidding for more projects that are within the firm's resources and capabilities, setting limits on project size so that any failure of one project would not endanger the firm's operation, entering into forwarding contracts with suppliers and subcontractors to protect the firm against cost escalation, bidding for projects with tiny/zero profit margins, diversifying into other construction-related business, undertaking short-term and fast track projects, and undertaking smaller contracts. The most ranked strategies under the cost-control related actions groups are; implementing stricter site management to reduce material wastage, implementing stricter financial management on company cash flow, implementing stricter procurement procedures, freezing salaries of employees, and freezing staff recruitment. The major financial-related strategies are; creating uncommitted financial resources, negotiating for alternative loan services, and investing in machinery that has a high liquidity value. [14] appraised the survival strategies of organisations within the built environment and found that the major cluster of strategies adopted by construction organisations are; Organisation and workforce management strategies, Organisation's innovation strategies, Diversification strategies, financial management strategies, and Organisation's networking strategies. The organisation and workforce management strategies include; training and multi-tasking, staff layoff/redundancy and cutting back on employment, improving problem-solving skills, change in geographical location, and improving organisational culture. The strategies under the organisation's innovation strategies are; adopting new technologies/innovations, improved service delivery standards, effective marketing, and improving the organisational structure. The Diversification strategies are; diversifying into other construction-related businesses, investing in different businesses that are not construction-related, diversifying into related practices based on the competencies, acquisition of resources. The financial management strategies are reduction in service charges, financial management, and reduced cost incurred on the contract dispute. The organisation's networking strategies include an improved networking system to increase reach and collaborative partnerships.

In a recessionary period, [20] in a study conducted in Lagos, Nigeria, found concluded that the top essential practices for the survival of construction firms are; improved service delivery, improved networking, effective knowledge management and retaining experienced staff in the company. [18] found that the seven critical groups of factors that can ease the survival of construction organisations are; human resource management factor, marketing factor, bid strategy factor, financial management factor, organizational culture factor, smart work methods factor and firm strategy factor. To extend the frontiers of knowledge in the QS profession, [37] suggested 'think tank' strategies to be adopted by the Nigerian Institute of Quantity Surveyors (NIQS) to be driven by the education committee of the institute. The aim is to enrich the curriculum of QS education in Nigeria, provide novel directions and develop other areas of core competencies for advancing knowledge through postgraduate studies.

Marketing is central to the survival and sustenance of companies, individuals; as it provides employment opportunities and impacts the living standards of the people [38-39]. The role of marketing strategies was assessed by [39], and it was found that keeping a pool of strong professionals, crating social bonds with clients, political bids inclusion in bids, effective communication among others were key to ensuring that companies sustain their competitive advantages, growth and survival in the industry they operate.

III. MATERIALS AND METHODS

This study leveraged a quantitative research approach using a well-structured questionnaire as the primary means of data collection from QSFs in Port Harcourt rivers state, Nigeria. The questionnaire was developed following a critical literature review. This study followed the use of a research questionnaire in a similar study by [20, 18, 14]. The questionnaire is economical and covers wider audiences in a shorter time.

To ensure that quality and unbiased data are collected, the following sample selection criteria were set; 1) participants must have spent at least 5years in the construction industry of Nigeria, 2) must have participated in the delivery of construction projects in the study area, 3) must have experienced in stirring a company out of trouble, and 3) must be willing to participate in the survey. A snowball sampling technique was adopted in the administration of the questionnaire among the quantity surveying organisations. The snowball sampling technique is dependent on referrals and it has the capability to increase the sample size [40-41]. The snowball sampling technique was adopted since it was impracticable to obtain a database/separate list of QS organisations in the study area that met the study criteria. The Questionnaire was administered by self and through the help of trained research assistants who were well brief of the purpose of the study. The questionnaire was designed to collect data on the background of the respondents and on the most important survival strategies adopted during times of economic turbulence and hardship.

During a survey period of twelve (12) weeks, 86 Quantity surveyors were sampled and this response rate was deemed fit for the analysis. The garnered data were analysed using frequency, percentages, and mean item score (MIS) and independence sample test. The background information was analysed using frequency and percentages. The data collected on the survival strategies were analysed using MIS. The reliability of the research instrument was determined using Cronbach's alpha test. The test showed an alpha value of over 0.70 for the assessed variables. This implies that the data is of good quality and unbiased. It further means good reliability of the research instrument.

Table 1 shows the cut-off points for establishing how important the strategies are. These cut-off points were obtained from [42-43]. The percentage weight will be derived from dividing the obtained mean scores by the highest Likert scale of 5. The entire methodological flow chart is shown in figure 1.

Table 1: Cut-off for the level of importance.

S/N	Per cent cut-off	Description
1	90 - 100	very high importance
2	70 - 89	High importance
3	50 - 69	moderate importance
4	30 - 49	little importance
5	1 - 29	very little importance

Source: [42-43].

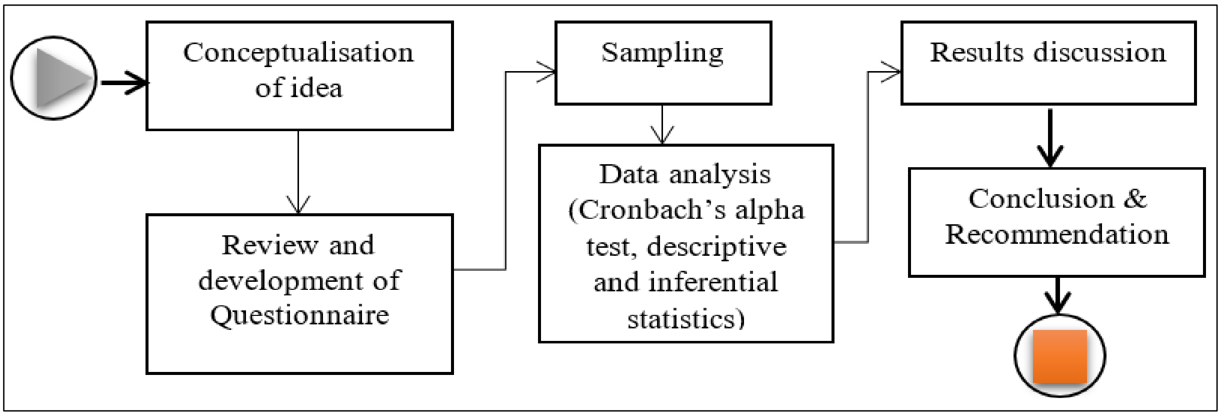

Figure 1: Research methodological flow chart.
Source: Authors, (2021).

IV. RESULTS AND DISCUSSIONS

IV.1 RESPONDENTS BACKGROUND CHARACTERISTICS

From the respondents' profiles in Table 2, The responsibility/ranks in their organisations show that 17.44% are project managers,12.79% are principal/managing partners, 26.74% are procurement managers, 22.09% are commercial managers, 13.95% are contract managers, and 6.98% are senior estimators/quantity Surveyors. In terms of years of experience, 29.07% have between 5-10years of experience, 38.37% have spent between 11-15years in the industry, 18.60% have spent 16-20years, and 13.95% have over 20 years of industry experience. The distribution of their years of experience shows that they have considerable industry experiences that can aid in meeting this study aim.

Their highest education qualification shows that 24.42% have HND, 18.60% have PGD, B.Sc/B.Tech (30.23%), MSc./M.Tech. (24.42%), and PhD is 2.33%. This shows that they are educationally qualified to contribute meaningfully to the subject of this study. The professional status of the respondents shows that a larger proportion of them are corporate members of the Nigerian Institute of Quantity Surveyors, NIQS. This shows that they are professionally qualified to participate in the subject of this study.

Table 2: Respondents profile.

Variables	Classification	Freq.	%	Cum. %
Ranks/Responsibility	Project managers	15	17.44	17.44
	Principal/Managing partners	11	12.79	30.23
	Procurement managers	23	26.74	56.98
	Commercial managers	19	22.09	79.07
	Contract managers	12	13.95	93.02
	Senior estimators/Quantity Surveyors	6	6.98	100.00
	TOTAL	**86**	**100.00**	
Years of experience	5-10years	25	29.07	29.07
	11-15 years	33	38.37	67.44
	16-20 years	16	18.60	86.05
	21-above	12	13.95	100.00
	TOTAL	**86**	**100.00**	
Highest education qualification	HND	21	24.42	24.42
	PGD	16	18.60	43.02
	BSc/Btech	26	30.23	73.26

Variables	Classification	Freq.	%	Cum. %
	M.Sc/M.Tech	21	24.42	97.67
	PhD	2	2.33	100.00
	TOTAL	**86**	**100.00**	
Professional status	Corporate member of NIQS	79	91.86	91.86
	Probationer member	7	8.14	100.00
	TOTAL	**86**	**100.00**	

Source: Authors, (2021).

IV.2 SURVIVAL STRATEGY OF QSFS DURING ECONOMIC TURBULENCE

The result of the analysis of the data gathered on the Survival strategy adopted by QSFs during economic turbulence is shown in Table 3. The top ten (10) survival strategies are; Improved networking system to increase reach (MIS=4.58; S.D=0.7587), Effective management of knowledge (MIS=4.40; S.D=1.1301), Retaining Experienced staff in the company (MIS=4.36; S.D=1.1052), Reduction of service charges (MIS=4.33; S.D=1.1002), Improved service delivery (MIS=4.29; S.D=1.0501), Usage of new technologies/innovations (MIS=4.28; S.D=1.1024), Adoption of Innovative ideas (MIS=4.27; S.D=1.1106), Effective marketing (MIS=4.24; S.D=1.0396), cutting back on employment and Staff layoff/downsizing (MIS=4.12; S.D=1.1316), and Mergers, acquisitions, and joint ventures (MIS=4.08; S.D=1.2387). While the least five (5) ranked survival strategies are; Diversifying into other construction-related ventures (MIS=3.81; S.D=1.4101), Change in geographical location (MIS=3.80; S.D=1.4375), Workforce training and retraining (MIS=3.73; S.D=1.4586), Improving organisational culture (MIS=3.72; S.D=1.5002) and Improving organizational structure (MIS=3.66; 1.5232).

Although these strategies have a varying ranking based on the different mean weighting, they all have a high impact on the survival of Quantity Surveying firms. This is premised on the average mean weight for the assessed variables of 4.07(81.32%) and a maximum and minimum mean weighting of 4.58 (91.63%) and 3.66 (73.26%) respectively. Furthermore, it can be observed from (column 7 of Table 3) that based on the cut-off points for determining the level of significance or importance of the assessed survival strategies, 95.45% of them have a high level of importance to ensuring the survival of QSFs. This assertion is premised on the range 70-89%. Only one (4.55%) of the variables showed a very high level of importance to the survival of QSFs. Overall, the assessed variables have a significant impact on ensuring that QSFs can survive the economic downturn in Nigerian and by extension QSFs in other developing countries with similar construction markets and the economy as Nigeria.

The findings of this study support the findings of [14, 20, 36, 18, 35, 2]. Building a stronger bond with important stakeholders and enhancing the quality of services renders or products offers are key aspects of marketing differentiation that impact the survival of construction organisations [35]. Skill development has been emphasised by a previous study of [20]. This is achieved through training and education to ensure continuous improvement in products and services. Embracing innovation techniques and technologies is a sustainable way of attaining sustainable growth, development and survival [14, 20]. Retaining experienced staff and a pool of professionals is one of the survival strategies that has been successful in delivering construction organisation during economic hardship and stiff competition. This was emphasized by the studies of [39, 18, 14, 20].

Reducing services charges and improvement in products and survives rendered are ways of surviving the economic downturn. During periods of economic hardship, clients like other construction industry stakeholders are hit by a reduction of funds to invest or embark on development projects. Reducing services charges is a customer-attracting and enticing strategy for keeping and ensuring continuous patronage by customers. Since clients and their investors in the construction projects are facing financial issues; they will naturally be attracted to firms that will deliver their project at a reduced cost and professional fee. During financial hardship, QSFs could channel the limited resources available can be channelled productively to improve their services rendered and products offered. With improved products and services, new clients could be attracted and existing clients' loyalty improved. Reducing services charges and improvement in products and survives rendered is part of the major strategies reported by [14, 20, 36, 18].

Downsizing and reducing the number of employment made is another proven strategy for surviving the economic downturn. During times of economic turbulence when companies are without jobs or reduced projects, reducing the number of workers on their payroll or cutting back on the number of employees engaged on regular basis is a way of reducing expenses, that have proved to be critical to firms survival and remaining in business. This strategy was found as important to the survival of construction firms like the QSFs in similar previous by [14, 20, 2]. Going into some sort of partnerships, mergers, joint ventures is another way of surviving economic turbulent that has been found to be useful to companies. Pooling resources and sharing areas of competencies and weaknesses can help QSFs survive during hard times.

Table 3: Survival strategy of QSFs during economic turbulence.

S/N	Variables	MIS	S.D	Rank	%	Remark
1	Improved service delivery	4.29	1.0501	5	85.81	High
2	Improved networking system to increase reach	4.58	0.7587	1	91.63	Very High
3	Retaining Experienced staff in the company	4.36	1.1052	3	87.21	High
4	Effective management of knowledge	4.40	1.1301	2	87.91	High
5	Usage of new technologies/innovations	4.28	1.1024	6	85.58	High
6	Documentation of improvement in process	3.87	1.3442	16	77.44	High
7	Proper Financial management	3.90	1.2081	15	77.91	High
8	Improving organizational structure	3.66	1.5232	22	73.26	High
9	Adoption of Innovative ideas	4.27	1.1106	7	85.35	High

S/N	Variables	MIS	S.D	Rank	%	Remark
10	Going after work in new areas	4.02	1.1780	14	80.47	High
11	Reduction of overheads	3.84	1.3272	17	76.74	High
12	Change in geographical location	3.80	1.4375	19	76.05	High
13	Workforce training and retraining	3.73	1.4586	20	74.65	High
14	Diversifying into other construction-related ventures	3.81	1.4101	18	76.28	High
15	Diversifying into areas of competence such as procurement management, risk management, etc.	4.03	1.1827	13	80.70	High
16	Reviewing organizational policy	4.05	1.2263	12	80.93	High
17	Mergers, acquisitions, and joint ventures	4.08	1.2387	10	81.63	High
18	cutting back on employment and Staff layoff/downsizing	4.12	1.1316	9	82.33	High
19	Reduction of service charges	4.33	1.1002	4	86.51	High
20	Effective marketing	4.24	1.0396	8	84.88	High
21	Improving organisational culture	3.72	1.5002	21	74.42	High
22	Freezing salaries of employee	4.07	1.1457	11	81.40	High

Source: Authors, (2021).

V. CONCLUSIONS

This study assessed the survival strategies of quantity surveying firms (QSFs) during economic turbulence in Port Harcourt, Nigeria. The questionnaire administered using snowball sampling techniques in the study area were adopted in gathering data from the target respondents. After the analysis of the gathered data, some critical findings were made and a conclusion was drawn.

The study found that the most critical Survival strategy adopted by QSFs during economic turbulence are; improved networking systems to increase reach, effective management of knowledge, retaining experienced staff in the company, reduction of service charges, improved service delivery, usage of new technologies/innovations, adoption of innovative ideas, effective marketing, cutting back on employment and staff layoff/downsizing, and mergers, acquisitions, and joint ventures. This study concludes that the assessed survival strategies have a high level of importance and plays a critical role in ensuring that Quantity Surveying firms survive the economic downturn and the stiff competitive market of the construction sector. It is recommended that the managers of QSFs should focus on those major strategies that will keep them above the competition, in continuous business, sustainable growth, and survival during economic turbulence.

The outcome of this study is critical to the success of the managers of Quantity surveying firms (QSFs) in improving their decisions regarding innovative techniques that will change the fortune of their firms. The Quantity surveyors engaged by QSFs are aware of the need to network to improve the reach and engagement with potential clients and other stakeholders.

This study took place in Port Harcourt, and this is a limitation of this study. In addition, the sample size is small and this could impact the generalisation of the results. Flowing from this, a similar study should be carried out in other states or regions of Nigeria. This is important for other results that could be compared to the outcome of this study to be available. Management is a key to the survival of every construction organisation. The role of management on the survival of QSFs or other construction-based organisations during economic turbulence and stiff industry competition should be investigated.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Dr. Reuben A. OKEREKE and Dennis Isaac PEPPLE.

Methodology: Dr. Reuben A. OKEREKE, Dennis Isaac PEPPLE and Nneka Mercyjane IHEKWEME.

Investigation: Dr. Reuben A. OKEREKE, Dennis Isaac PEPPLE and Nneka Mercyjane IHEKWEME.

Discussion of results: Dr. Reuben A. OKEREKE, Dennis Isaac PEPPLE and Nneka Mercyjane IHEKWEME.

Writing – Original Draft: Dr. Reuben A. OKEREKE, Dennis Isaac PEPPLE and Nneka Mercyjane IHEKWEME.

Writing – Review and Editing: Dr. Reuben A. OKEREKE, Dennis Isaac PEPPLE and Nneka Mercyjane IHEKWEME.

Resources: Dr. Reuben A. OKEREKE, Dennis Isaac PEPPLE and Nneka Mercyjane IHEKWEME.

Supervision: Dr. Reuben A. OKEREKE, Dennis Isaac PEPPLE and Nneka Mercyjane IHEKWEME.

Approval of the final text Dr. Reuben A. OKEREKE, Dennis Isaac PEPPLE and Nneka Mercyjane IHEKWEME.

VII. REFERENCES

[1] Papademos, L. (2009). ECB Financial Stability Review June 2009: opening remarks. Bank for International Settlements, available at: www.bis.org/review/r090618b.pdf.

[2] Lim, B.T.H., Bee, L.O., & Ling, F. (2010).The survival strategies of Singapore contractors in prolonged recession Engineering, Construction and Architectural Management Vol. 17 No. 4, pp. 387-403. DOI 10.1108/09699981011056583

[3] Tansey, P., Meng, X., & Cleland, D. (2013). A critical review of response strategies adopted by construction companies during an economic recession In: Smith, S.D and Ahiaga-Dagbui, D.D (Eds) Procs 29th Annual ARCOM Conference, 2-4 September 2013, Reading, UK, Association of Researchers in Construction Management, 679-689.

[4] Scully, P. (2012). Below cost tendering, CIF Annual Conference, Dublin, 12 September.

[5] Akaeze,N.S.,& Akaeze, C. (2017). Exploring The Survival Strategies For Small Business Ownership In Nigeria. Australian Journal of Business and Management Research, 05(07),35-48.

[6] Sampson, E. (2013). Oil Resource Dependency: Emerging Threats and Concerns. Zenith Economic Quarterly, 9(4), 30-38.

[7] Zannawaziri, B., Kyari, A. K., & Masud, A. (2012). Global renewable energy consumption and oil and gas export: An empirical analysis of the Nigerian economy. The International Journal of Applied Economics and Finance, 6(4), 148-156.

[8] Agbaeze, E. K., Udeh, S. N., & Onwuka, I. O. (2015). Resolving Nigeria's dependency on oil – the derivation model. Journal of African Studies and Development, 7(1), 1-14. doi:10.5897/JASD2014.0303

[9] Oyesiku, O. (2009). Global economic recession, the environment and sustainable development in Nigeria. College Distinguished Annual, College of Management and Social Sciences, (n, d.), Lecture Series, 1.

[10] Tunji-Olayeni, P. F. (2016). Performance, challenges and prospects for the Professional in a global economic recession. Paper presented at a 2day workshop and investiture, NIQS Oyo State.

[11] AbuBakar, A. H., Awang,A., Yusof,M.N., and Adamy,A. (2011). Strategies for Survival During Economic Downturn in Construction Industry A Survey on Construction Companies in Malaysia. World Applied Sciences Journal, 13 (9), 1967-1974.

[12] Adu, E.T., Lamptey-Puddicombe, A.D., & Opawole, A. (2020). Consultants` Perspectives of Survival Strategies for Small and Medium Construction Firms at Infancy Stage. Journal of Construction Business and Management, JCBM,4(1), 34-47.

[13] Ye, K., & Tekka, R.S. (2020). A Prioritization Model of Strategies for Small and Medium Firms in Less-Developed Countries: A Tanzania Case. Hindawi-Advances in Civil Engineering, Volume 2020, Article ID 8857741, pp.1-23. https://doi.org/10.1155/2020/8857741

[14] Aghimien, D.O., Aghimien,E.I., Fadiyimu, A.O., & Taiwo, F. A. (2018).Survival strategies of built environment organisations in a challenging economy. Engineering, Construction and Architectural Management, Vol. 25 Issue: 7, pp.861-876,https://doi.org/10.1108/ECAM-06-2017-0106

[15] Scott, B.M. (2011). Survival strategies of services subcontracting firms in an economic downturn. Department of Construction, Unitec, Auckland

[16] Geroski, P.A., Mata, J. , & Portugal, P. (2003). Founding conditions and the survival of new firms. Banco De Portugal Econ Res Dep, available at: www.druid.dk/uploads/tx_picturedb/wp07-11.pd (accessed 23 May 2017).

[17] Iorun, J.I. (2014). Evaluation of Survival Strategies of Small and Medium Enterprises in Benue State, Nigeria. International Journal of Academic Research in Accounting, Finance and Management Sciences, 4(2), 255-263.

[18] Ogbu, C.P. (2017). Survival practices of indigenous construction firms in Nigeria, International Journal of Construction Management, DOI:10.1080/15623599.2016.1277056

[19] Eneh, O.C. (2010). Survival Strategies for Entrepreneurs in Dwindling Nigerian Economy. Asian Journal of Industrial Engineering, 2(2), 52-62

[20] Adegbembo, T.F., Ajiferuke, O.O., & Ogbodo, V. (2020). Survival Strategies of Quantity Surveying Firms In Lagos State, Nigeria During Economic Recession. The Lagos Journal of Environmental Studies, 10(2), 84-95.

[21] Githaiga, F.M. (2005). Quantity surveying practice across Africa – The Kenyan experience. Paper presentation: The Third Triennial General Assembly of the Africa Association of Quantity surveyors. New partnership for Africa's Development (NEPAD): challenges for built–environment professionals in Africa.

[22] Ajanlekoko, J. O. (2002). National Development and Challenges of Leadership, Paper presentation the 20th Biennial Conference of the Nigerian Institute of Quantity Surveyors (NIQS). Theme: Building the Blocks of National Development – challenges, Conflicts and prospector: organised by the Nigerian Institute of Quantity Surveyors (16 – 17).

[23] Onyeagam, O.P., Eze, E.C., & Adegboyega, A. A. (2019). Assessment of Quantity Surveying Firms' Process and Product Innovation drive in Nigeria. SEISENSE Journal of Management, 2(3), 21-37.

[24] Nwaki, W.N., & Eze, C.E. (2020). Lean Construction as a Panacea for Poor Construction Projects Performance. Journal of Engineering and Technology for Industrial Applications, 6(26), 61-72. DOI: https://doi.org/10.5935/jetia.v6i26.723

[25] Olatunji, S.O., Oke, A.E., Aghimien, D.O.,& Seidu, S.A. (2016).Effect of construction project performance on economic development of Nigeria, Journal of Economics and Sustainable Development, 7 (12), 142-149.

[26] Aibinu, A.A., & Jagboro, G.O. (2002). The effects of construction delays on project delivery in Nigeria construction industry, International Journal of Project Management, 20(8), 593-599.

[27] Bakare, T. (2017). Nigeria out of recession, world economic declares. The Guardian, 18 April, available at: https://guardian.ng/news/nigeria-out-of-recession-world economics-declares/

[28] Aniekwu, N.N., Anthony, C.I., & Kehinde, O.M. (2014). Critical issues in reforming the Nigerian construction industry, British Journal of Applied Science and Technology, 5(3), 321-332.

[29] Aje, I. O., and Awodele O. A. (2006). A study of the ethical values of quantity surveyors in Nigeria. Paper presented at a 2-day national seminar on Ethical issues and the challenges in construction professionals' service delivery. Nigerian Institute of Quantity Surveyors, Ondo state chapter.

[30] Squire, M. M., & Snyman, R. (2004). Knowledge Management in Three Financial Institutions, ASLIB proceedings: New Information Perspectives, 56(4), 234-242.

[31] Aluthwela, A., &Perera, B.A.K.S. (2016). Characteristics of Qs Firms And Their Impact On Performance, (Online), Available at https://www.researchgate.net/publication/319507375

[32] Okereke, R.A., Ihekweme, N.M., & Awodele, I.A. (2021a). Building Information Modeling (BIM) And Quantity Surveying Consultancy Services In Nigeria. Journal of Engineering and Technology for Industrial Applications,7(32), 44-49. DOI: https://doi.org/10.5935/jetia.v7i32.787

[33] Porter, M. E. (1980). Competitive Strategy: Techniques for analysing industries and competitors. New York: Free Press.

[34] Li, S., & Ling, F.Y.Y. (2012). Critical strategies for Chinese architectural, engineering and construction firms to achieve profitability. Engineering, Construction and Architectural Management, 19 (5), 495-511.

[35] Cheah, C.Y.J., Kang, J., & Chew, D. (2007). Strategic analysis of large local construction firms in China. Construction Management and Economics, 25(1), 25–38.

[36] Abidin, N. Z., Adros, N. A., & Hassan, H. (2014). Competitive strategy and performance of quantity surveying firms in Malaysia. Journal of Construction in developing countries, 19 (2). 15-32.

[37] Ogunsemi, D. R. (2008). The New partnership for African Development (NEPAD) opportunities and Quantity surveyors' penetration: Paper presentation at 23rd biennial conference and general meeting: quantity surveying and the millennium development Goals.

[38] Olaniyi, J. O., Sanni, M. & Garba, A. (2011). Marketing of professional services in Nigeria. (A case study of quantity surveying profession) Environ - Tech CES, Kaduna Polytechnic Journal, 1(2): 35-42.

[39] Eze, E.C., Sofolahan , O., Onyeagam, O.P., & Muhammed, U. (2018). Construction Professionals' Perception Of The Marketing Strategies Employed By Construction Firms In Abuja, Nigeria. Journal of Construction Project management and Innovation,8(2), 1905-1925.

[40] Heckathorn, D. D. (2011). Comments: Snowballing versus respondent-driven sampling. Sociological Methodology, 41(1), 355–366. https://doi.org/10.1111/j.1467-9531.2011.01244.x.

[41] Atkinson R., & Flint J. (2001). Accessing Hidden and Hard-to-reach Populations: Snowball Research Strategies. Social Research Update, University of Surrey, 33, 1–4.

[42] Okereke, R.A., Zakariyau, M., & Eze, E.C. (2021b). Extension Of Time (EoT) Claims Substantiation And Associated Issues In Complex-Multi Stakeholders' Building Construction Contracts. Journal of Engineering and Technology for Industrial Applications,7(32), 23-31. DOI: https://doi.org/10.5935/jetia.v7i32.782

[43] Saidu, I., & Shakantu, W. M. (2016). Effects of material-waste causes on project-cost overrun in Abuja, Nigeria: A site management perspective. Proceedings of the 9th Annual Quantity Surveying Research Conference, Port Elizabeth, 19-21 October 2016, pp.246-257.

Journal of Engineering and Technology for Industrial Applications

ISSN ONLINE: 2447-0228

ITEGAM-JETIA

Manaus, v.8 n.33, p. 40-43. Jan/Feb, 2022

DOI: https://doi.org/10.5935/jetia.v8i33.791

RESEARCH ARTICLE OPEN ACCESS

RADIOLOGICAL MEASUREMENT OF HAZARDOUS LEVELS IN CONSTRUCTION TILES IN BUNGOMA COUNTY, KENYA

John Simiyu Nalianya[1], Michael Nakitare Waswa[2], Francis Maingi[3] and Conrad Khisa Wanyama*[4]

[1, 2, 3, 4] Department of Science, Technology and Engineering, Kibabii University, P.O BOX 1699-50200, Bungoma, Kenya.

[1] http://orcid.org/0000-0002-1200-1954, [2] http://orcid.org/0000-0003-2479-862X, [3] http://orcid.org/0000-0002-2358-6775, [4] http://orcid.org/0000-0002-3624-7756

Email: johnnalianya2008@gmail.com, mwaswa@kibu.ac.ke, fmaingi@kibu.ac.ke, *conradkhs@gmail.com

ARTICLE INFO

Article History
Received: December 29th, 2021
Accepted: February 21th, 2021
Published: February 28th, 2022

Keywords:
Construction tiles,
Radium equivalent,
External hazard index,
Permissible values.

ABSTRACT

Twenty (20) different local and imported tiles were sampled from major hardware's in Bungoma. The samples collected were separately ground, sieved, through a 0.5mm mesh, dried at 110° C, weight and packed in a 200ml stoppered plastic bottles. The samples were stamped with identification numbers and kept for 30 days for secular equilibrium to be reached between the activity of ^{238}U,^{232}Th ,^{40}K radium and their progeny. The average activity concentration of ^{238}U, ^{232}Th and ^{40}K was found to be 109±5.48Bqkg^{-1}, 11±0.55 Bqkg^{-1} and 1574±78.7 Bqkg^{-1} respectively. The average absorbed dose rate was found to be 140±7.03 nGyh^{-1} which is higher than the worlds average value of 60 nGyh^{-1}. The average radium equivalent was found to be 288±14.44 Bqkg^{-1} which is lower than the world limit value of 370Bqkg^{-1}. External and internal hazard indices were found to be 0.70±0.03 msvy^{-1} and 0.80±0.04 msvy^{-1}respectively. Therefore, the sampled tiles used in Bungoma county for construction has minimal radiological threat to population.

I. INTRODUCTION

The average human being lives in an environment that is exposed to radiations of varying degrees. These radiations are primarily from two sources: earth's surface and the space [1]. One is therefore susceptible to interact with gamma rays emanating from the earth's surface and cosmic rays from space. It is the terrestrial gamma rays that one is likely to interact with when in contact with soil and rocks; and by extension, their by-products like tiles. The terrestrial gamma rays are emitted by natural radioactive nuclides (^{238}U, ^{232}Th and ^{40}K) found in the soil due to their decay [2]. Whereas the earth's crust is naturally radioactive due to the dispersion of naturally occurring radionuclides, there are other factors that could make these radionuclides radiological hazards. These include the continual accumulation of phosphate fertilizer in the soil, burning of fossil fuels, mining and construction activities [2]. Besides the human activities that affect the concentration of radionuclides in the environment, there are also natural processes like soil erosion and geological formations that also affect their accumulation, as noted by [2]. Even though these NORMS – naturally occurring radioactive materials – often occur at low concentration, soil materials (rocks, ceramics and minerals) that contain NORMs(naturally occurring radioactive materials) with elevated levels of radionuclides could be hazardous [3].

There is need for building materials to be examined for acceptable levels of radiation [4]. Research shows that humans spend close to 80% of their time indoors, hence much of the exposure to radiation that humans experience is highly connected to the building materials within houses [5]. These findings corroborate the WHO study conducted in 1972 that established that long-term exposure of humans to radiation from natural sources constitutes about 80% of the radiation dose an average person receives [6]. Humans are often exposed to radiation within houses when they come into contact externally with gamma emitting radionuclides (^{226}Ra) or internally when they inhale ^{222}Rn and ^{220}Rn from tiles within the room [1]. These radiations often originate from the walls and flooring that include tiles.

Ceramic tiles are common among many households, due to the beauty they provide. They can be used on any surface within the house that include the floors, walls and table surfaces for finishing. The building material for ceramic tiles is ceramic, which is derived from clay and tile glaze [7]. Even though the concentrations of natural radioactive nuclides in the ceramic materials depends upon the local topographical conditions [8], it has been established that under normal circumstances, their concentration is often higher than that of the natural soil [9]. Thus, even after the zirconium which contains traces of radioactive elements is purified and supposedly reduced to low levels [10] at the production stage, it has never been confirmed if imported tiles follow such guidelines. Besides, Tiles used for finishing also contain glazes, pigments and other intermediate products as those which are atomized, hence prone to decay and emit harmful radiations [11]. This therefore means that humans are always at risk of exposure to radiations that are above the recommended levels. To avert the life-threatening effects of ionizing radiation, several radiological surveys have been done using different detectors and the findings published widely.

The existing data on radiometric surveys show that, though human beings receive radiation doses of varying ranges from different sources, the radon gas and its accompanying short lived decay daughters contribute the largest percentage of the mean absorbed dose, followed by building rocks and soil, then man made activities and cosmic rays [12]. These tiles could be a source of radiation within Kenyan homes unless proper measures are undertaken to safeguard the public against tiles with unacceptable levels of radiation. This work delved into investigating the following hazard parameters that has been employed to assess the levels of radiation exposure. These parameters include Radium Equivalent; The Annual Effective Dose; The Absorbed Dose Rate; The Internal Hazard Index and the External Hazard Index.

II. MATERIALS AND METHODS

II.1 STUDY AREA

The study was conducted using tiles commonly found in the hardware's from Bungoma County being a representative of what is on the Kenyan market. The tiles that were considered were those from Egypt, India, Uganda and those which are locally manufactured, i.e the twyford and saj tiles. The random sampling method was used to collect samples.

II.2 SAMPLE DESCRIPTION AND PREPARATION

To assess the radiological hazard in both the local and imported tiles, a total of 20 samples of commercial tiles were sampled. The names of different samples of ceramic tiles are (India: T1, T2, T3, T4. Uganda T5, T6, T7, T8. Egypt: T9, T10, T11, T12, T13. Kenya Twyford: T13, T14, T15, T16. Kenya Saj: T17, T18, T19 and T20). For each country four samples were taken. These particular countries were considered because they were the ones available on the market. All samples were crushed (separately) to a fine powder and sieved through a 0.5mm mesh. Each sample was oven-dried at 110°C for 3hours to reduce the moisture content [13]. Weighed samples of 200g were placed in polyethylene cylindrical beakers, of about 300ml each. These beakers were sealed to prevent the escape of gaseous ^{222}Rn from the samples and stored for 30 days to attain secular equilibrium between ^{226}Ra and ^{232}Th and their decay products.

II.3 SAMPLE ANALYSIS

II.3.1 ACTIVITY CONCENTRATION

The calculations of the activity concentration (A_c) values for the radionuclides from ^{235}U, ^{238}U and ^{232}Th series and ^{40}K present in the selected tile samples was determined as shown by equation 1 [14].

$$A_C = \frac{C_{net}}{\gamma \times \in \times m \times t} \qquad (1)$$

II.3.2 The Radium Equivalent Activity

There is unequal distribution of ^{226}Ra, ^{232}Th and ^{40}K in ceramics. Uniformity of distribution-based exposure to radiation has been defined in terms of radium equivalent activity (Ra_{eq}) in $Bqkg^{-1}$and is used to compare the specific activity of materials containing different amounts of^{226}Ra, ^{232}Th and ^{40}K. It was calculated by the following relation shown by equation 2 [8].

$$Ra_{eq} = C_{Ra} + 1.42C_{Th} + 0.0778C_K \qquad (2)$$

Where C_{Ra}, C_{Th} and C_k are the mean activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in tile samples respectively expressed in $Bqkg^{-1}$.

II.3.3 External Hazard

To limit the external gamma radiation dose from ceramic materials to $1mSvy^{-1}$, the external hazard index (H_{ex}) is determined by equation 3 [10].

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \qquad (3)$$

In this equation, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in tile samples in $Bq.kg^{-1}$ respectively.

III. RESULTS AND DISCUSSIONS

III.1 ACTIVITY CONCENTRATIONS OF NATURAL RADIONUCLIDES

The activity concentrations levels of the three primordial radionuclides of the samples were analyzed using equation 2.1 [14]. The average activity concentration of ^{232}Th for all the samples collected from major hardware's within Bungoma County were calculated and presented in Figure 1. The distribution of the radionuclides was non uniform due the varying activity concentration from the tile samples.

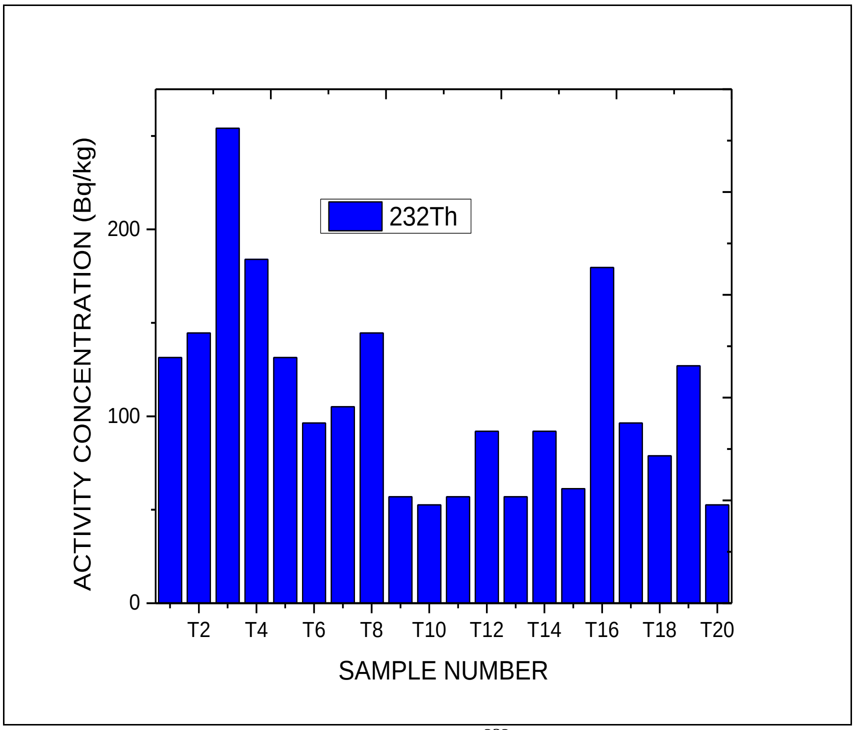

Figure 1: Comparative Bar Graph Showing Activity Concentration of ^{232}Th in the Tile samples from major hardware in Bungoma County.

Source: Authors, (2021).

The average values of Thorium, uranium and potassium were 109±5.48 Bqkg^{-1}, 11±0.55 Bqkg^{-1} and 1574±78.7 Bqkg^{-1} respectively. The minimum activity concentration for ^{232}Th, ^{238}U and ^{40}K were found to be 52±2.62 Bqkg^{-1}, 6±0.32 Bqkg^{-1}and 1165±58.29 Bqkg^{-1} while the maximum values were 254±12.7 Bqkg^{-1} ,31±1.57 Bqkg^{-1} and 2193±109.65 Bqkg^{-1} respectively were obtained. The activity concentration of ^{232}Th and ^{40}K exceeded the worlds agreed average values of 45 Bqkg^{-1} and 400 Bqkg^{-1} respectively. The activity concentration of ^{238}U evaluated was lower than the world's average of 33 Bqkg^{-1} [15]. The mean activity of ^{40}K was generally higher than ^{238}U and ^{232}Th for all the collected samples which are a common behavior in the crustal contents. High potassium levels could be attributed to the presence of minerals such as potash feldspar like orthoclase, micas like biotite [12].

III.2 RADIUM EQUIVALENT AND EXTERNAL HAZARD INDEX

The radium equivalent values calculated by equation 2 ranged from 176 ±8.8 to 487± 24.39. The highest radium equivalent values were obtained from tiles from India which were 487± 24.39 Bq/kg and 411± 20.59 Bq/kg. These values were greater than the world's permissible maximum value of 370 Bq/kg [16]. The average value of radium equivalent in this research was 288±14.44 Bq/kg.

Table 1: Radium equivalent and External hazard index values of the sampled construction tiles.

	Ra_{eq} (Bq/kg)	H_{ex} (mSvy^{-1})
MAXIMUM	487± 24.39	1.3± 0.06
MINIMUM	176 ±8.8	0.4± 0.02
AVERAGE	288±14.44	0.8± 0.04

Source: Authors, (2021).

The evaluation of the external hazard index from activity concentration of the twenty samples was calculated using equation (2.3). The mean value from all the samples was 0.8± 0.04 mSvy^{-1}. The maximum and minimum values calculated were 1.3± 0.06 mSvy^{-1} and 0.4± 0.02 mSvy^{-1} respectively as shown from table 3.1. The average value calculated for the external hazard index was below the permissible level of one unit [17]. Therefore, the use of tiles for finishing has minimal radiological risk since the average value of radium equivalent in the sampled tiles is less than the world's permissible maximum value of 370 Bq/kg [16].

IV. CONCLUSIONS

In this study the activity levels for twenty tiles in Bungoma Kenya has been determined using Thalium doped sodium iodide gamma ray spectrometer. The average activity concentration values of Thorium, uranium and potassium were 109±5.48 Bqkg^{-1}, 11±0.55 Bqkg^{-1} and 1574±78.7 Bqkg^{-1} respectively. The minimum activity concentration for ^{232}Th, ^{238}U and ^{40}K were found to be 52±2.62 Bqkg^{-1},6±0.32 Bqkg^{-1}and 1165±58.29 Bqkg^{-1} while the maximum values were 254±12.7 Bqkg^{-1} ,31±1.57 Bqkg^{-1} and 2193±109.65 Bqkg^{-1} respectively. The activity concentration of ^{232}Th and ^{40}K exceeded the worlds agreed average values of 45 Bqkg^{-1} and 400 Bqkg^{-1} respectively. The activity concentration of ^{238}U evaluated was lower than the world's average of 33 Bqkg^{-1} [12]. The average radium equivalent and external hazard index were below the permissible values of 370 Bq/kg and 1mSv/y respectively. Hence construction tiles used in Bungoma County posses' minimal radiological health risk to the population. Future radiological assessments should be done in order to evaluate the high radioactivity values obtained in some construction tiles.

V. AUTHOR'S CONTRIBUTION

Conceptualization: John Simiyu Nalianya, Michael Nakitare Waswa and Francis Maingi.

Methodology: John Simiyu Nalianya and Conrad Khisa Wanyama.

Investigation: John Simiyu Nalianya and Conrad Khisa Wanyama.
Discussion of results: John Simiyu Nalianya, Michael Nakitare Waswa, Francis Maingi and Conrad Khisa Wanyama.
Writing – Original Draft: John Simiyu Nalianya.
Writing – Review and Editing: John Simiyu Nalianya and Michael Nakitare Waswa.
Resources: John Simiyu Nalianya and Conrad Khisa Wanyama.
Supervision: Michael Nakitare Waswa and Francis Maingi.
Approval of the final text: John Simiyu Nalianya, Michael Nakitare Waswa, Francis Maingi and Conrad Khisa Wanyama.

VI. ACKNOWLEDGMENT

The authors express sincere thanks to the Kenyatta university physics department and laboratory technics for tirelessly carrying measurement of the samples.

VII. CONFLICT OF INTEREST

The authors declare no conflict of interest regarding publication of this article.

VIII. REFERENCES

[1] Joel, E. S., Maxwell, O., Adewoyin, O. O., Ehi-Eromosele, C. O., & Saeed, M. A. (2018). Comparative analysis of natural radioactivity content in tiles made in Nigeria and imported tiles from China. *Scientific reports*, *8*(1), 1-9.

[2] Sowole, O., & Egunjobi, K. (2019). Radioactivity Assessment of 40K, 238U and 232Th in Surface Soil Samples of Igbokoda, Southwest of Nigeria. *Tanzania Journal of Science*, *45*(3), 307-314.

[3] Diffey, B. L. (2010). An overview analysis of the time people spends outdoors. *British Journal of Dermatology*, *164*(4), 848-854.

[4] Tsoulfanidis, N., & Landsberger, S. (2021). *Measurement & detection of radiation*. CRC Wrixon, A. D. (2008). New ICRP recommendations. *Journal of radiological protection*, *28*(2), 161.

[5] Siddeeg, S. M., Suliman, M. A., Ben Rebah, F., Mnif, W., Ahmed, A. Y., & Salih, I. (2018). Comparative Study of Natural Radioactivity and Radiological Hazard Parameters of Various Imported Tiles Used for Decoration in Sudan. *Symmetry*, *10*(12), 746

[6] World Health Organization. (1972). Development of environmental health criteria for urban planning*:* report of a WHO scientific group *[meeting held in Geneva from 1 to 9 June 1971]*.

[7] Uosif, M. A. M., Omer, M., Ali, N. A., El-Kamel, A. H., &Hefni, M. A. (2015). Radiological hazard resulting from using ceramic tile in Egypt. *Int. J. Adv. Sci. Technol*, *80*(19), 10-14257.

[8] Uosif, M. A. M. (2007). Gamma-ray spectroscopic analysis of selected samples from Nile River sediments in upper Egypt. *Radiation Protection Dosimetry*, *123*(2), 215-220.

[9] Peck, D. J., & Samei, E. (2017). How to understand and communicate radiation risk. *Image Wisely* website. http://www. image wisely. org/imaging-modalities/computed-tomography/medical-physicists/articles/how-to-understand-and-communicate-radiation-risk. Accessed March, 29.

[10] Beretka, J., & Matthew, P. J. (1985). Natural radioactivity of Australian building materials, industrial wastes and by-products. *Health physics*, *48*(1), 87-95.

[11] Ortiz, J., Ballesteros, L., &Serradell, V. (2008). Radioactivity reference levels in ceramics tiles as building materials for different countries.

[12] UNSCEAR, (2008). United Nations Scientific Committee on the effects of atomic radiation, sources, and effects of ionizing radiation. Report to General Assembly, with Scientific Annexes United Nations. United Nations, New York.

[13] Abdalla, A.M., & Al-Naggar, T. I. (2019). Estimation of radiologic hazards of radon resulting from ceramic tiles used in Najran city. *Journal of Radiation Research and Applied Sciences*, *12*(1), 210-218.

[14] Uosif, M. A. M., & Abdel-Salam, L. M. (2011). An assessment of the external radiological impact in granites and pegmatite in the central Eastern Desert in Egypt with elevated natural radioactivity. *Radiation protection dosimetry*, *147*(3), 467-473.

[15] UNSCEAR. (2010). Sources and effects of ionizing radiation. Report to the General Assembly, with scientific annexes. New York: United Nations.

[16] ICRP. (2015). Occupational Intakes of Radionuclides: Part 1. (Oxford Pentagon press: ICRP; Publication) 130.

[17] ICRP. (2005). Low-dose extrapolation of radiation related cancer risks. International Commission on radiological protection. Oxford: Pentagon press.

Journal of Engineering and Technology for Industrial Applications

ITEGAM-JETIA

ISSN ONLINE: 2447-0228

Manaus, v.8 n.33, p. 44-52. Jan/Feb, 2022

DOI: https://doi.org/10.5935/jetia.v8i33.796

RESEARCH ARTICLE OPEN ACCESS

TRANSMISSION NETWORK EXPANSION STATIC PLANNING CONSIDERING SECURITY CONSTRAINTS VIA AFRICAN BUFFALO ALGORITHM

João Ricardo Paes de Barros*[1] and Dimitri Albuquerque de Barros[2]

[1] Electrical Power System Consultant and Research. Recife - Pernambuco, Brazil.
[2] Electrical Engineer. Recife – Pernambuco, Brazil.

[1] http://orcid.org/0000-0001-9804-1983, [2] http://orcid.org/0000-0003-4576-3514

Email: *jrpb64@gmail.com, dimitrialbuquerque@hotmail.com

ARTICLE INFO

Article History
Received: January 28th, 2022
Accepted: February 23th, 2022
Published: February 28th, 2022

Keywords:
Transmission expansion planning,
Power system,
DC model,
African buffalo algorithm,
Metaheuristic.

ABSTRACT

In this paper, the African Buffalo Optimization (ABO) is adapted to solve the transmission network expansion static planning problem considering security restrictions (TNESPS). The problem is formulated as a mixed-integer nonlinear programming (MINLP) problem. The ABO is based on the collective intelligence of the African buffaloes searching for food in the savannahs. The proposed algorithm uses the direct current model to represent the network, the transport model to generate the initial population, and two candidate solution improvement procedures, one being cost reduction and the other feasibility of infeasible solutions. The analysis of the specialized literature shows that the proposed algorithm has never been used to solve the static or dynamic TNESP problem, with or without security restrictions. Thus, this paper contributes to a new methodological approach to solving TNESPS problems. To evaluate the performance of the proposed algorithm, three systems that are often used in evaluations of new methodologies were used: Garver 6-bus system, IEEE 24-bus system and the South Brazilian 46-bus system.

I. INTRODUCTION

In a power electric system, the transmission grid is responsible for transporting the energy produced in the electric power generation centers to the large consumption centers. Determining the grid that adequately meets future demand at the lowest possible investment cost is a very complex long-term expansion planning task, as it involves the need to consider, simultaneously, aspects related to: the location of future energy generation and consumption centers, the grid size and topology, the adoption or not of security criteria (N-0 or N-1 criteria), the costs and electrical parameters of circuits (existing and candidate), the candidate circuits, the system modeling (alternating current - AC or direct current - DC) [1] and the number of planning periods (static and dynamic planning), the uncertainties and the solution method.

In static planning [2], it only determines where and how many circuits from the candidate list should be added to the initial configuration. In dynamic planning [3], where several horizon periods are considered, it is also determined when the new circuits should be added.

This work addresses the of transmission network expansion static planning problem considering security constraints (TNESPS). These types of constraints guarantee that future demand will be met even in the event of a simple contingency in any of the circuits of the transmission grid.

This problem presents great mathematical complexity due to the following particularities [4], [5]: (a) has integer and continuous variables, i.e., it is a mixed integer nonlinear programming (MINLP) problem; (b) non-convex search space, causing several types of algorithms to prematurely converge to local optimal solutions; (c) presents the combinatorial explosion phenomenon, causing the amount of candidate solutions to be analyzed to grow exponentially as a function of the system size; (d) requires high computational effort to find the global optimal solution or to find a high quality solution; (e) contains isolated bus.

Currently, there is a wide variety of solving techniques that can cope with the above-mentioned particularities. In the bibliography they are grouped according to the types of algorithms used [4-9]: (i) classical optimization algorithms, (ii) constructive heuristic algorithms and (iii) metaheuristic algorithms.

Algorithms based on classical optimization explore the entire search space and are guided by the gradients of the objective function to move through the search space to find the optimal solution. They usually find the global optimal solution for small systems. However, for large systems, they present problems related to processing time and convergence. Therefore, these algorithms often become unsuitable for solving TNESPS [10]. With these characteristics, TNESPS can be considered an NP-complete type problem [3], that is, there is no method that can solve it in polynomial time.

Constructive heuristic algorithms use simplified procedures that have the ability to identify good quality solutions for small to medium-sized systems with little computational effort. They rarely find the global optimum solution to the problem.

Metaheuristic algorithms use much more elaborate search procedures, usually based on phenomena in nature, to explore the search space and escape from local optimum solutions. For this reason, metaheuristic algorithms frequently obtain solutions of higher quality than the quality of solutions obtained with heuristic algorithms. Moreover, they often find high quality solutions and even the optimal solution with acceptable computational effort, even in large systems [11].

One of the main advantages of metaheuristic algorithms over the other two algorithms is that they generally require little or no information from the TNESPS problem to guide the search process, i.e., they require few adjustments to their parameters [12].

The advantages cited, along with the good compromise ratio (quality of the final solution/computational effort), has caused the amount of research performed with metaheuristic algorithms to grow in the last decades, as shown in the list of published articles described below.

In all the papers in this list, the DC load flow model was used to represent the transmission network. The systems used to test the various proposed algorithms were as follows: Garver-6 bus/15 branches (G-6/15), IEEE-24 bus/41 branches (IEEE-24/41), South Brazilian-46 bus/79 branches (SB-46/79), Colombian-93 bus/155 branches, East Chinese reduced from 18 bus/27 branches and the Brazilian-242 bus/467 branches.

This growth demonstrates the great importance that the TNESPS problem has for researchers and the need to develop algorithms capable of offering a balance in terms of the final quality of the solutions and the computational cost.

As can be observed, the application of the metaheuristic algorithm African Buffalo Optimization - ABO [13], [14] to solve the planning problem, both in the static and dynamic versions, with or without safety constraints, is not included in the list of published articles. This novelty, coupled with the fact that the discussion of the TNESPS subject is still open, was what motivated this work.

The proposed metaheuristic algorithm, named ABO_{N-1} optimizer uses the concepts of the ABO algorithm, along with the two local improvement strategies used by Chu-Beasley (CB) [15], successfully used by Silva et al. [16], to solve the TNESPS problem. One of the strategies seeks to reduce the cost of feasible solutions by removing added circuits that are redundant. The other strategy seeks to enable candidate solutions with load shedding, by adding new circuits. The joint application of these two strategies is very important when the system is large.

In the ABO_{N-1} optimizer, the TNESPS is formulated as a mixed-integer nonlinear programming (MINLP) problem, using the DC model to determine the power flows in the transmission network circuits. The transportation model [17] is used to help generate the initial population.

Updates and improvements to the initial population solutions are made over iterations following the equations and rules established by the ABO algorithm. The other population solutions are generated through random variations in the circuits of the first solution. Throughout the iterations, the initial population solutions are updated according to the equations and rules established by the ABO algorithm, and Chu-Beasley's local improvement strategies.

Aiming to contribute with another solving method to the TNESPS problem, this paper is organized as follows: Section III describes the mathematical model that was used in the problem. Section IV presents the solving method that was used to solve the problem. Section V presents and discusses the results that were obtained by the proposed method in three case studies performed with the G-6/15, IEEE-24/41 and SB-46/79 systems. Section VI presents the main conclusions.

- ***List of Articles***

Silva et al., 2005 [2] - Chu-Beasley Genetic Algorithm (CBGA); Gallego et al., 2006 [18] - CBGA; Jin et al., 2007 [19] - Particle Swarm Optimization (PSO) based on Model Space Theory; Yemula et al., 2008 [20] - Z-bus Based Genetic Algorithm; Verma et al., 2008 [21], [22] - Binary Genetic Algorithm; Gang et al., 2008 [23] - Chaos Optimization Algorithm; Verma et al. 2009 [24] - Adaptive PSO Algorithm; Fan et al., 2009 [25] - Niching Genetic Algorithm; Limsakul et al. 2009 [26] - Ant Colony Optimization; Verma et al. 2010 [27] - Harmony Search Algorithm (HSA); Verma et al., 2010 [28] - Bacteria Foraging and Differential Evolution; Orfanos et al. 2012 [29] - Improved HSA; Shivaie et al., 2013 [30] - Improved HSA; Sarrafan 2014 [31] - Discrete Parallel Particle Swarm Optimization; Correa et al., 2014 [32] - Non-dominated Sorting Genetic Algorithm; Das et al. 2017 [33] - Artificial Bee Colony (ABC); Da Silva et al. 2016 [34] - Adaptive Multi-Operator Evolutionary Algorithm; Da Silva et al., 2017 [35] - Constructive Heuristic and Evolutionary Metaheuristic; Khandelwal et al. 2019 [36] - Grey Wolf Optimization; Nepomuceno et al., 2020 [37] - Spotted Hyena Optimization; Fernando et al., 2020 [38] - Constructive Metaheuristic Algorithm.

II. MATHEMATICAL MODEL OF THE PROBLEM

The objective of the TNESPS problem is to define the least-cost set of circuits that must be added to the base transmission network in order to meet the total expected load in the event of any simple contingency.

II.1 OBJECTIVE FUNCION OF THE PROBLEM

The objective function used by the ABO_{N-1} optimizer is composed of two terms, as in [2]: the first term evaluates the total cost of investments in new circuits and the second evaluates the load shedding with the network intact and in simple contingency. The second term is necessary in cases where the proposed solution is not able to meet the expected load without violating the transmission capacities of the circuits. The ABO_{N-1} optimizer determines, at each iteration, the set of the least cost circuits such that the second term is zero.

$$Min\ v = \{\textstyle\sum_{(i,j)\in\Omega_r} c_{ij}n_{ij} + \alpha \sum_{(b\in\Omega_b)}(r_b^n + r_b^p)\} \quad (1)$$

In this function, c_{ij} is the cost of the circuit added on branch ij; n_{ij}- number of circuits added on branch ij; r_b^n, r_b^p- load shedding at bus $b \in \Omega_b$, with the network operating with all network circuits and without circuit $p \in$ Lc, respectively; Lc- contingency list; Ω_b- set of load bars; Ω_r- set of network branches; α- unit transformation parameter.

II.2 EQUALITY CONSTRAINTS

In the ABO_{N-1} optimizer, the transmission network is represented by the DC load flow model [1], [2], since it calculates the power flows in the circuits very quickly and accurately compatible with the long-term planning horizon. In this simplified model only the active loads and generations, and the angles of the voltages at the bars are represented. With this simplification, the equality constraints used in TNESPS modeling are represented by equations (2) and (3), adapted from [2]. The parameters β and δ were introduced in order to compact the model.

$$(1-\delta)(Sf^n + g^n + r^n) + \delta(Sf^p + g^p + r^p) = d \quad (2)$$

$$(1-\beta)(1-\delta)\left[f_{ij}^n - \gamma_{ij}\left(n_{ij}^0 + n_{ij}\right)\left(\theta_i^n - \theta_j^n\right)\right] + \delta\left[f_{ij}^p - \gamma_{ij}\left(n_{ij}^0 + n_{ij} - \beta\right)\left(\theta_i^p - \theta_j^p\right)\right] = 0 \quad (3)$$

The two sets of linear constraints (2), one for δ=0 and the other for δ=1, model, respectively, the energy conservation at each bar of the system, for a network operating without and with simple contingency. That is, set (2) models Kirchhoff's first law (Law of Currents) for the two forms of circuit operation.

The two sets of nonlinear constraints (3), one for δ=0 and one for δ=1, model Kirchhoff's second law (Mesh Law) for the transmission network operating without and in simple contingency. The value of the parameter β (4) depends on the location of the contingent branch p, i.e.:

$$\begin{cases} se\ circuito\ ij \neq p\ \ então\ \beta = 0 \\ se\ circuito\ ij = p\ \ então\ \beta = 1 \end{cases} \quad (4)$$

The parameter δ simulates the operating condition of the circuits in the network, and was inserted, along with the parameter β, to present the constraints in a compact form. δ=0 means that all circuits are operating, and δ=1 means that the network is with circuit p in contingency.

We therefore have two sets of constraints that together model the equality constraints of the problem: one that models the network operating without contingency and another that models the network operating with contingency.

In constraints (2) and (3) the meanings of the symbols are as follows: S- bus-branch incidence matrix, transposed, of the network; f- vector of active power flows in circuits ij with the network operating without contingency. Its elements are f_{ij}; f^n and f^p- active power flow vectors with the network operating without contingency and with circuit p unavailable (in contingency). Their elements are f_{ij}^n and f_{ij}^p; g^n and g^p- vectors of active power generations, with the network operating without contingency and with circuit p unavailable. Their elements are g_i^n and g_i^p $(i \in \Omega_g)$; Ω_g- set of generation bus; d- active loads vector; r^n and r^p- load shedding vectors with the grid operating without contingency and with circuit p unavailable. Its elements are r_b^n and r_b^p; γ_{ij}- susceptance of the added circuit on branch ij; n_{ij}^0- number of existing circuits on branch ij of the base grid; n_{ij}- number of circuits added on branch ij; θ_i^n, θ_j^n - angles of the voltages of bus i and j with the grid operating without contingency; θ_i^p, θ_j^p- angles of the voltages of bus i and j with circuit p unavailable.

II.3 INEQUALITY CONSTRAINTS

The inequality constraints used in the ABO_{N-1} optimizer are related to: the limits of capacities of circuit additions in the branches, the limits of active power flows in the circuits, new and existing, the limits of active powers produced in the generation bus and the limits of load shedding in the load bus.

Applying the parameters β and δ to the set of inequality constraints from [2], the constraints present the compact form indicated by inequations (5) to (10). The absolute values are necessary since the active power flows in the circuits can flow in two directions.

In constraints (5) to (10): $\bar{f}_{ij}$- maximum transmission capacity of circuit ij; $\bar{n}_{ij}$- maximum number of circuits that can be added in branch ij; $\bar{g}$- vector of maximum capacities of generators (its elements are $\bar{g}_i, i \in \Omega_g$).

$$(1-\beta)(1-\delta)\left|f_{ij}^n\right| + \delta\left|f_{ij}^p\right| \leq (1-\beta)(1-\delta)\gamma_{ij}\left(n_{ij}^0 + n_{ij}\right)\bar{f}_{ij} + \delta\left|f_{ij}^p\right|\left(n_{ij}^0 + n_{ij} - \beta\delta\right)\bar{f}_{ij} \quad (5)$$

$$0 \leq (1-\delta)g^n + \delta g^p \leq \bar{g} \quad (6)$$

$$0 \leq (1-\delta)r^n + \delta r^p \leq d \quad (7)$$

$$0 \leq n_{ij} \leq \bar{n}_{ij},\ \ n_{ij}\ inteiro \quad (8)$$

$$n_{ij}^0 + n_{ij} - 1 \geq\ 0, inteiro \quad (9)$$

$$n_{ij} \geq 0\ e\ inteiro \quad (10)$$

II.4 COMPLETE PROBLEM MODEL

The set of equations and inequations (1) to (10), which is based on the coupling between active power and the angle of the bar voltage [1], [2] is used by the ABO_{N-1} optimizer to model the TNESPS problem. The problem formulated in this way has the characteristics of a MINLP problem, whose resolution is quite complicated.

When the set of circuits to be added (n_{ij}) is known, problem (1) to (10) is reduced to a linear programming (LP) problem, and the ABO_{N-1} optimizer only checks whether this solution presents load shedding or not.

Applying the pairs of values (β=0, δ=0), (β=0, δ=1), (β=1, δ=0), (β=1, δ=1) to constraints (2), (3) and (5) to (10) yields fifteen constraints, five of which are equality and ten of which are inequality.

III. PROPOSED ALGORITHM

Write in detail the research project, including background and limitations. The selection of materials and methods, procedures and equipment must be justified so that the work can be reproduced. Modifications or new methods must be described in detail. You must clearly define the universe and specify how the sample was selected and why it is representative. Data processing represents the practical development of a theoretical basis, deriving the model equations to program the calculation algorithm, according to the need. In materials, they include the technical specifications and the quantities, the origin and, if necessary, the method for its elaboration.

III.1 CARACTERISTICS OF THE ABO ALGORITHM

This algorithm, as an optimization method, provides a search procedure belonging to swarm intelligence, based on the social behavior of animals. It was created by Odili et al. in 2015, inspired by the movements of buffaloes in the African savannahs in search of food.

As with most metaheuristic algorithms, the ABO algorithm also uses two strategies for exploring the search space: intensification which is directly related to exploring the region where the buffalo are grazing and diversification which is related to exploring new grazing regions. Each buffalo searches for the best grazing region to feed on, and updates its position in the grazing region according to the position of the best buffalo (leading buffalo) in the herd.

The ABO algorithm simulates three buffalo characteristics: i) memory, to not explore pasture regions already visited; ii) cooperation, to exchange information with other buffalo; and iii) intelligence, to issue alarm sounds "Waaa", which is used to warn of the presence of danger and lead the herd to other pasture regions, and alert "Maaa", which is used to encourage buffalo to continue grazing in the same region.

III.2 MAIN STEPS OF THE ABO ALGORITHM

The main steps that the ABO algorithm performs to position buffaloes in pastures are [11]:
Step 1: Randomly distribute each buffalo in the herd to different grassland regions of the savanna;
Step 2: Identify the best buffalo in the herd, using the evaluation function of the problem to be solved;
Step 3: Move each buffalo to a new nearest pasture region, considering its previous position and the position of the leading buffalo;
Step 4: Updates the new position occupied by each buffalo;
Step 5: Identifies the new best buffalo in the herd;
Step 6: Tests if the number of iterations has been reached. If yes, present the best distribution of buffalo in the grazing areas achieved. If no, move each buffalo to a new closest grazing region.

III.3 ANALOGY ABO X TNESPS PROBLEM

The search procedure used by the ABO algorithm, to optimize the distribution of African buffaloes in savanna grassland regions, can be compared to the search procedure used in the TNESPS optimization process, to distribute the circuits on the branches of a transmission system, by making the following analogies:

- Savannah grassland regions ↔ Candidate solutions space;
- Herd ↔ Candidate solutions (population);
- Buffalo ↔ Candidate solution;
- Leading buffalo ↔ Solution with the lowest overall cost;
- Quality of grazing ↔ Cost of the solution.

Figure 1 shows four candidate solutions of a hypothetical system of four branches and different amounts of circuits added per branch.

Branches	1-2	1-4	2-3	2-4	**Costs**	
Added Circuits	3	2	0	0	5	Solution 1
	0	**2**	**0**	**1**	**3**	**Solution 2**
	2	0	2	0	4	Solution 3
	1	2	1	2	6	Solution 4

Figure 1: Representation of candidate solutions.
Source: Authors, (2021).

According to the adopted analogy, it turns out that: i) The herd is composed of four buffaloes; ii) The buffaloes are located in pasture regions of different qualities; iii) The worst pasture region is region 4; iv) The leading buffalo is grazing region 2.

III.4 ABO$_{(N-1)}$ OPTIMIZER ALGORITHM

Figure 2 shows the main steps that the ABO$_{(N-1)}$ optimizer performs to solve the TNESPS problem.

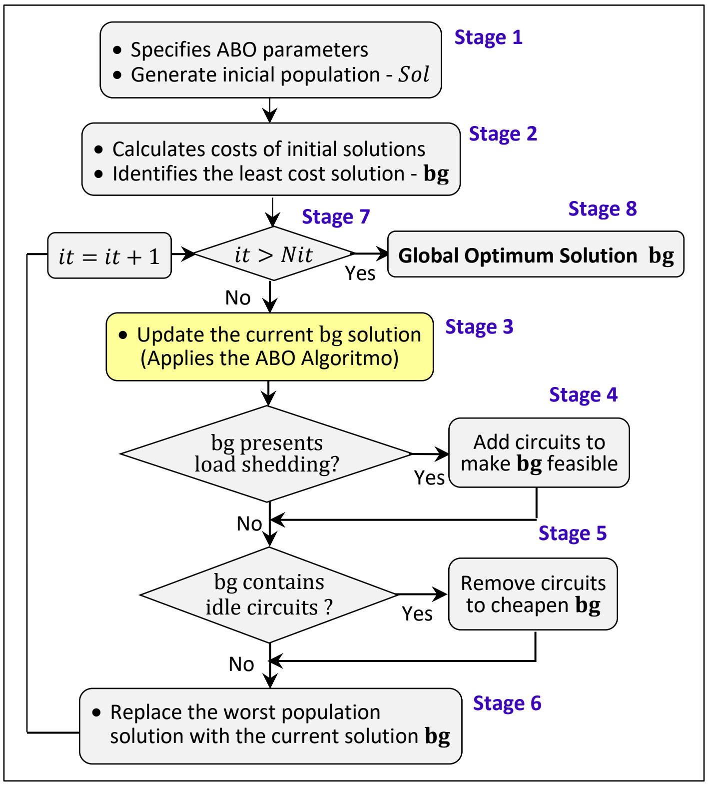

Figure 2: Flowchart of the ABO$_{(N-1)}$ optimizer.
Source: Authors, (2021).

➢ **Stage 1**

In this step the data for the ABO algorithm is provided, i.e., the learning factors lp1 and lp2 used in [14] to adjust the velocities of buffalo displacements from the pasture regions in search of food.

Since TNESPS is a non-convex problem of several local optimal solutions, the generation of the initial population has great influence on the quality of the initial solutions, and can help the search mechanism of metaheuristic algorithms [5], [6]. Thus, the ABO$_{N-1}$ optimizer generates the initial population (Sol), composed of NI solutions ($\{sol_1, \dots, sol_k, \dots, sol_{NI}\}$), as a function of the existing network topology, bar data, existing circuit data, candidate circuit data, and population size (NI), by performing two steps:

Step 1: Solve the transport model, represented by LP problem (11) to (16) [1], [39], [40], using the linprog function of MatLab, to obtain a solution (Sol_1).

$$Min\ v(sol_1) = \sum_{(i,j)\in\Omega_r} c_{ij} n_{ij} \quad (11)$$
$$s.a:$$
$$Sf + g = d \quad (12)$$
$$|f_{ij}| \le (n_{ij}^0 + n_{ij})\bar{f}_{ij} \quad (13)$$
$$0 \le g \le \bar{g} \quad (14)$$
$$0 \le n_{ij} \le \bar{n}_{ij} \quad (15)$$
$$n_{ij} \ge 0,\ inteiro \quad (16)$$

Step 2: It then generates the other (NI-1) initial solutions $\{sol_2, \dots, sol_{NI}\}$, randomly changing the positions and number of circuits of the branches of the solution sol_1, until the population size (NI) is reached.

This way of creating the initial population produces some infeasible solutions (solutions with load shedding), due to the simplified model (11) to (16), which considers only Kirchhoff's first law. However, these solutions are systematically eliminated over iterations.

- **Stage 2**

This step determines the cost of each initial solution (vc_k), the respective amounts load shedding (rc_k), and the least cost solution (bg_k). The cost of each solution (vc_k) is obtained by the product ($\sum c_{ij}n_{ij}$), since after the completion of step 1, the circuit set $\{n_{ij}\}$ of each solution (sol_k) of Sol and the respective costs (c_{ij}) are known. The load cutoff (rc_k), associated with each solution (sol_k), is obtained by solving LP problem (17) to (22) using the linprog function of MatLab.

$$Min\ rc_k = \sum_{(b)\in B}(r_b^n + r_b^p)\} \quad (17)$$
$$s.a:$$
$$Sf + r + g = d \quad (18)$$
$$f_{ij} - \gamma_{ij}(n_{ij}^0 + n_{ij})(\theta_i - \theta_j) = 0 \quad (19)$$
$$|f_{ii}| \le (n_{ii}^0 + n_{ii})\bar{f}_{ii} \quad (20)$$
$$0 \le g \le \bar{g} \quad (21)$$
$$0 \le r \le d \quad (22)$$

- **Stage 3**

The purpose of this step is to update the current best solution (bg_k), modified in step 2, by performing two steps:

Step 1: Generate new solutions (sol_{k+1}), as a function of the current best solution (bg_k) and the solutions (sol_k), (w_k) and (pb_k), using equation (23), adapted from [13]. The rounding operator "round" and the absolute value operator "abs" were included because the number of circuits to be added in each branch of the system must always be integer and positive.

$$sol_{k+1} = round\{sol_k + abs[lp1.(bg_k - w_k) + lp2.(pb_k - w_k)]\} \quad (23)$$

The term $lp1.(bg_k - w_k)$ modifies the number of circuits of the current solution (bg_k), i.e., intensifies the search. Whereas the term $lp2.(pb_k - w_k)$ modifies the number of circuits of the current solution pb_k, i.e., diversifies the search.

Step 2: It obtains a candidate solution w_{k+1} updated as a function of the solution sol_{k+1} and the solution w_k by applying equation (24), adapted from [13].

$$w_{k+1} = round[(w_k + sol_{k+1})/\lambda)],\ \lambda = lp2/lp1 \quad (24)$$

In the first iteration of the ABO$_{(N-1)}$ optimizer the solution pb_k and w_k are equal to the solution sol_k and are updated at each iteration using the costs: $v(sol_{k+1})$, $v(sol_k)$, $v(pb_k)$, and $v(pg_k)$, according to the following rule:

- If $v(sol_{k+1}) < v(sol_k)$, the current solution sol_k is replaced by the solution sol_{k+1};
- If $v(sol_{k+1}) < v(pb_k)$, the current solution pb_k is replaced by the solution sol_{k+1};
- If $v(sol_{k+1}) < v(bg_k)$, the current solution bg_k is replaced by the solution sol_{k+1}.

After these updates only the current bg_k solution is submitted to the local improvement procedures to check if it presents load shedding or to check if its cost can be reduced. This best solution update procedure replaces the procedure used in AGCB [2].

- **Stage 4**

The purpose of this step is to make the current bg_k solution viable in case it has load shedding due to the update done in step 3. The feasibility is done by adding circuits in certain branches of the bg_k solution so that the load shedding is eliminated.

The choice of the most attractive circuit set $\{n_{ij}\}$ for addition is done using the sensitivity index (IS_{ij}) (25), proposed in the constructive heuristic algorithm (AHC) [41].

$$IS_{ij} = max\{n_{ij}.\overline{f}_{ij}; n_{ij} \ne 0\} \quad (25)$$

This algorithm solves, at each AHC step, the LP problem (26)-(33), to verify that the added circuits also meet the CC model. If not, the most attractive circuit is added to the base grid. In the LP problem model, the active power flows in the circuits are separated into two groups: flows in the existing circuits and from the circuits added by the iterative process of the algorithm.

In equation (27): S_0- matrix of incidence, transposed, bar-branch of the base network; S_1- matrix of incidence, transposed, bar-branch of the new network; f_0- vector of active power flows in the base network circuits, with the network without contingency; f_1- vector of power flows in the added circuits, with the network operating without any contingency. The parameters β and δ were introduced to compact the presentation of the model.

$$Min\ v(bg_k) = \sum_{(i,j)\in\Omega_r} c_{ij}n_{ij} \quad (26)$$
$$s.a:$$
$$(1-\delta)(S_0f_0 + S_1f_1 + g) + \delta(S_0f_0^p + S_1^pf_1^p + g^p) = d \quad (27)$$
$$(1-\beta)(1-\delta)\left|f_{ij}^0 - \gamma_{ij}n_{ij}^0(\theta_i - \theta_j)\right| + \delta[f_{ij}^0 - \gamma_{ij}(n_{ii}^0 - \beta)(\theta_i^p - \theta_i^p)] = 0 \quad (28)$$
$$|f_{ij}^0| \le n_{ij}^0\bar{f}_{ij} \quad (29)$$
$$(1-\beta)(1-\delta)\left|f_{ij}\right| \le n_{ij}\overline{f}_{ij} + \delta[|f_{ij}^p| \le (n_{ij} - \beta)\bar{f}_{ij}] \quad (30)$$
$$0 \le (1-\delta)g + \delta g^p \le \bar{g} \quad (31)$$
$$0 \le n_{ij} \le \bar{n}_{ij},\ n_{ij}\ inteiro \quad (32)$$
$$n_{ij} - 1 \ge 0 \quad (33)$$

This model specifies that the basic network must satisfy both Kirchhoff's laws, and the branches formed by the new circuits satisfy only Kirchhoff's first law (Kirchhoff's second law is only applied to the basic network).

If solving this LP model results in $v(bg_k) = 0$ it means that $n_{ij} = 0, \forall(i,j) \in \Omega_r$, i.e., the system operates without overloads with the base topology circuits together with the added circuits. Since these circuits obey both Kirchhoff's laws, then the set of added circuits represents a feasible solution for the DC model.

- **Stage 5**

The purpose of this step is to reduce the cost of the current bg_k solution if it has unnecessary circuits due to the update performed in stage 3 through equations (23) and (24).

To check if there are any circuits added in bg_k that are redundant, they are sorted in descending order of cost, and then each of them is removed from the solution bg_k. If the removal, any of them, does not cause load shedding, it means that it is unnecessary and is eliminated. So only those circuits will be part of the current bg_k solution that if removed does not cause load shedding.

- **Stage 6**

This step is intended to verify whether the solution bg_k can enter the current population as a replacement for the one with the worst quality in terms of investment cost and load shedding.

Two conditions are imposed for the current solution bg_k to be accepted into the population: 1) bg_k must be different from all other solutions, i.e., it must present a circuit configuration that does not exist in the current population, and 2) bg_k must have a lower cost (if feasible) or lower load shedding (if infeasible) than all other solutions in the population.

Three situations are tested: (a) the solution bg_k is infeasible and there are infeasible solutions in the population, then bg_k replaces the highest load-cut solution; (b) the solution bg_k is feasible and there are infeasible solutions in the population, then bg_k replaces the highest load-cut solution; c) the solution bg_k is feasible and there are no infeasible solutions in the population, then bg_k replaces the current highest cost solution.

- **Stage 7**

In this step, the $ABO_{(N-1)}$ optimizer checks if the stopping criterion is reached, i.e., if the current number of iterations (it) is greater than the specified maximum value (Nit), then the iterative process is terminated.

- **Stage 8**

In this step, the $ABO_{(N-1)}$ optimizer presents the global optimal solution bg found in NI iterations, in terms of cost and number of circuits added in each branch of the base network to meet simple contingency.

IV. RESULTS AND DISCUSSIONS

This section presents the results obtained from applying the $ABO_{(N-1)}$ optimizer on three typical systems (G-6/15), IEEE-24/41 and SB-46/79), which have been widely used by researchers to test algorithms. The $ABO_{(N-1)}$ optimizer was implemented in MatLab language and simulations were performed on a computer with an Intel Core i5-7400T, 2.40 GHz, 8 GB RAM processor. The data used to adjust buffalo displacement velocities were lp1=0.9 and lp2=0.7 suggested in [14] to obtain a better balance between intensification and diversification processes of search space exploration.

Since the $ABO_{(N-1)}$ optimizer generates the candidate solutions randomly, there is the possibility of not always obtaining the same optimal solution at the end of iterations by performing several simulations. This possibility increases even more when the system has many bars (NB) and many branches (NR). Therefore, to minimize/eliminate this possibility, the population size (NI) and the number of iterations (Nit) were defined as a function of NB and NR, as shown in rules (34) and (35), except for the Garver system.

$$NI \approx NR \quad (34)$$
$$Nit > 1000(NR/NB) \quad (35)$$

IV.1 GARVER SYSTEM (G-6/15)

This small system has the following characteristics: demand and generation = 760 MW, NB= 6 (bus 6 isolated) and NR=15 (6 are existing). Data for existing and candidate bus and circuits are available in [37]. A maximum of four circuits per branch was allowed. This data results in a total of 515≃3x1010 possible combinations of circuit additions, indicating the enormous difficulty the algorithms face in solving TNESPS problems.

In the simulation of this system, a population size NI = 20 was used and Nit = 100 iterations were performed.

The global optimal solution found by the $ABO_{(N-1)}$ optimizer, without load shedding, contains 10 circuits and costs $298,000.

Figure 3 shows, in red lines, the planned circuits. The graphs in Figures 4 and 5, both produced by the $ABO_{(N-1)}$ optimizer, show the circuits added to the base network and the evolution of the total cost of the best solution.

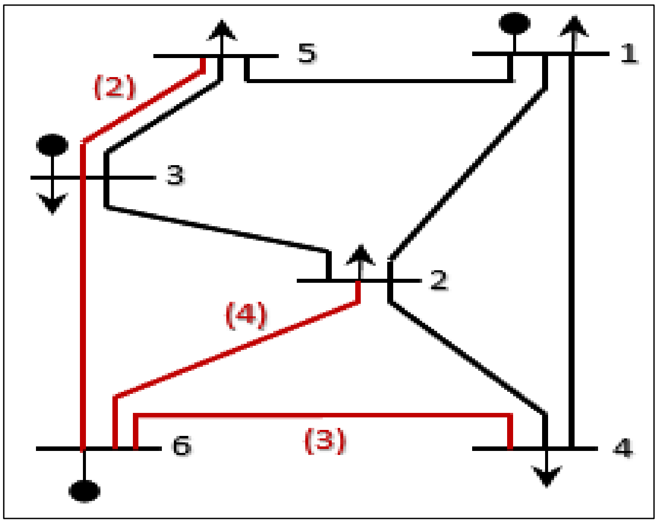

Figure 3: G-6/15 system -Planned network.
Source: Authors, (2021).

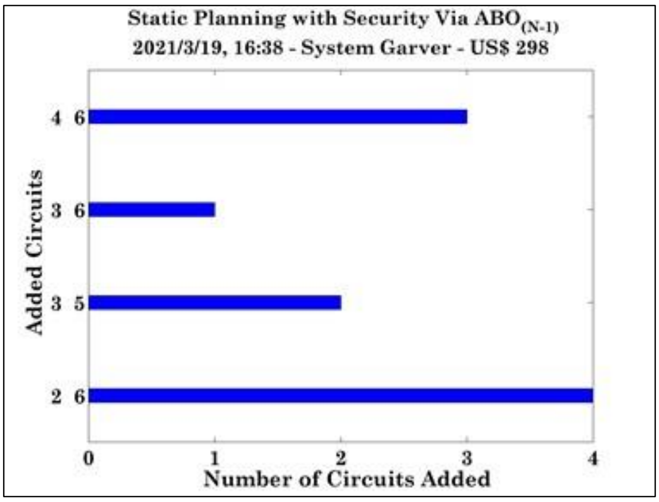

Figure 4: G-6/15 system - Planned circuits.
Source: $ABO_{(N-1)}$ optimizer, (2021).

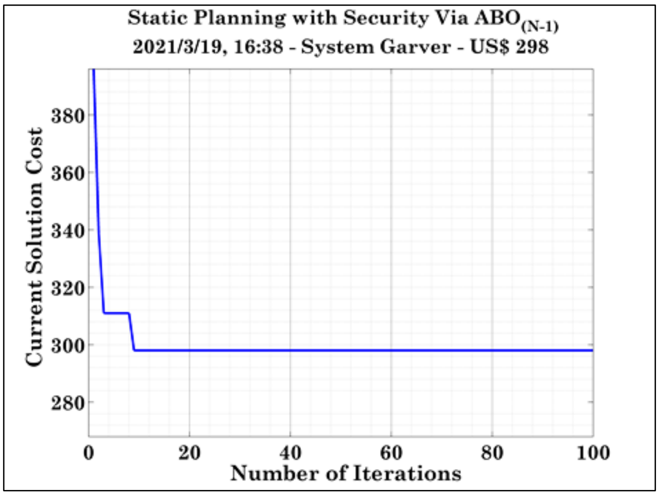

Figure 5: G-6/15 system: Cost evolution of the best solution.
Source: $ABO_{(N-1)}$ optimizer, (2021).

IV.2 IEEE SYSTEM (IEEE-24/41)

This system is one of the most used in testing new models and optimization techniques for TNESPS problems. It has a demand and generation= 8550 MW; NB=24 (generating units are connected on 10 bus and loads connected on 17 bars and there are no isolated bars); NR=41 (34 existing and 7 new). Data for bus and existing/candidate circuits are described in [42]. The generation data are from scenario G1.

A population size NI≈NR=40 was used to solve this system. Since the NR/NB ratio of this system is about 1.71, the number of simulations used was Nit=1800, since by rule (35), Nit must be greater than 1000(NR/NB).

In the simulation, branches with at most 4 circuits were allowed. This gives the total number of circuits to be analyzed 4x41=164 and the number of possible combinations of additions to the branches is about 541≃4.5x1028, i.e., 526 times larger than the number of possible combinations of additions to the G-6/15 system.

The global optimal solution that the $ABO_{(N-1)}$ optimizer found, without load shedding, contains 28 circuits, added on 17 existing branches (n_{01-05}=2, n_{03-09}=1, n_{03-24}=2, n_{04-09}=1, n_{05-10}=1, n_{06-10}=2, n_{07-08}=3, n_{10-11}=1, n_{11-13}=1, n_{14-16}=2, n_{15-16}=1, n_{15-21}=1, n_{15-24}=2, n_{16-17}=3, n_{16-19}=2, n_{17-18}=2 and n_{21-22}=1) and costs $1,071 million.

This same solution was obtained with the following data: a) NI=40 and Nit=2000, b) NI=40 and Nit=5000, c) NI=50 and Nit=2000. Figure 6 shows, in filled red lines, the 28 circuits (the dotted lines are the candidate circuits).

Figure 7 shows the circuits of the best solution obtained with the $ABO_{(N-1)}$ optimizer and Figure 8 shows the evolution of the cost of the best solution, where convergence was reached at the 1199th iteration.

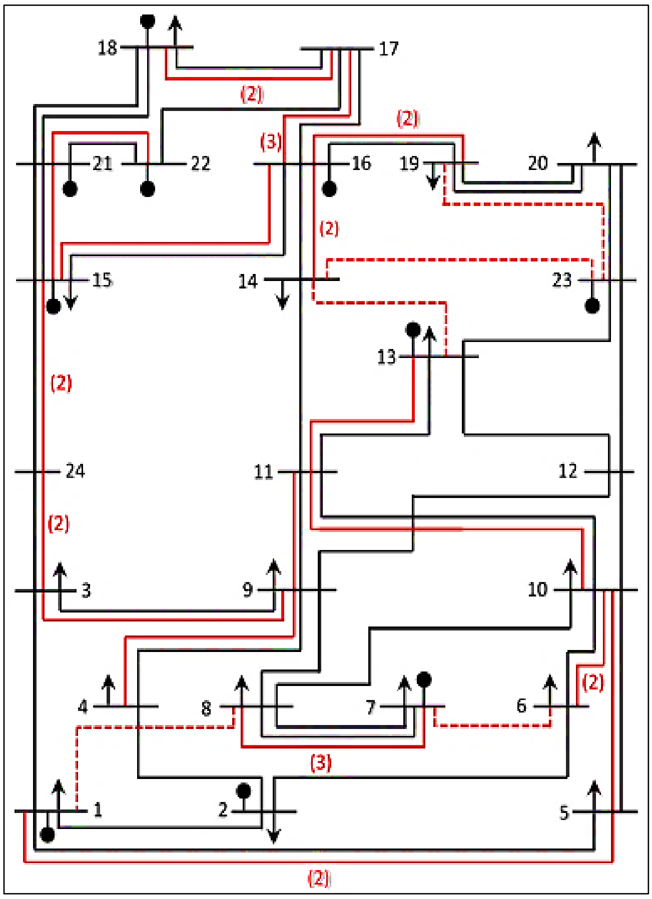

Figure 6: IEEE-24/41 system – Planned network.
Source: Authors, (2021).

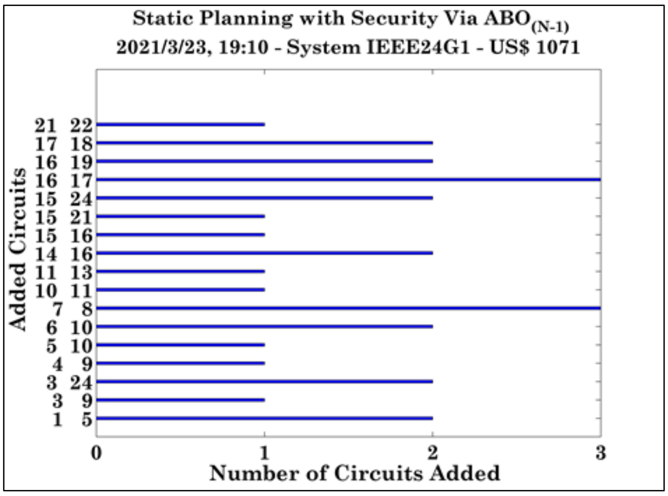

Figure 7: IEEE-24/41 system - Planned circuits.
Source: $ABO_{(N-1)}$ optimizer, (2021).

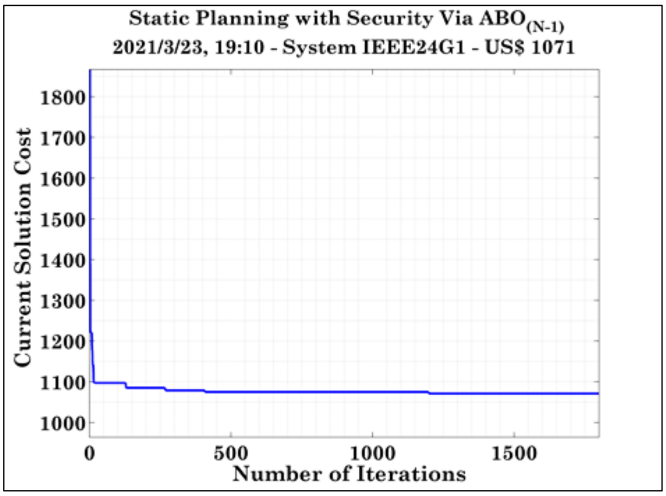

Figure 8: IEEE-24/41 system - Cost evolution of the best solution.
Source: $ABO_{(N-1)}$ optimizer, (2021).

IV.3 SOUTH BRAZILIAN SYSTEM (SB-46/79)

Monticelli et al., 1982 [43], was the first to use this real system to validate an interactive TNESPS solution method and since then it has been used to validate several methods. This system is an old configuration of the power system in the southern region of Brazil, and is therefore a good test for the $ABO_{(N-1)}$ optimizer.

The data for this system are: demand and generation=6880 MW; NB=46 (generators are connected on 12 bus and loads on 19 bus); NR=79 (47 existing/32 new). Existing circuits are connected on bus operating at 500 kV and 230 kV voltages). The bus data and existing and candidate circuit data are described in [40].

This system has 479/541=8x1018 times more possible combinations of circuit additions than the IEEE-24/41 system, and almost twice as many buses (1.71=41/24), and a greater number of isolated bus (11 bus).

The global optimal solution found by the $ABO_{(N-1)}$ optimizer, without load shedding, contains 28 circuits, connected in 18 branches, (n_{02-05}=1, n_{12-14}=1, n_{19-21}=1, n_{17-19}=1, n_{14-22}=1, n_{32-43}=1, n_{20-21}=2, n_{42-43}=3, n_{46-06}=2, n_{19-25}=1, n_{21-25}=1, n_{31-32}=2, n_{28-31}=2, n_{31-41}=1, n_{40-45}=1, n_{24-25}=3, n_{40-41}=1 and n_{05-06}=3), and costs $356,086 million.

Figure 9 shows, in red lines, the 28 circuits. Figure 10 shows the circuits of the solution produced by the $ABO_{(N-1)}$ optimizer in all 6 simulations.

Figure 11 shows the evolution of the cost of the best solution, where convergence was reached at the 398th iteration.

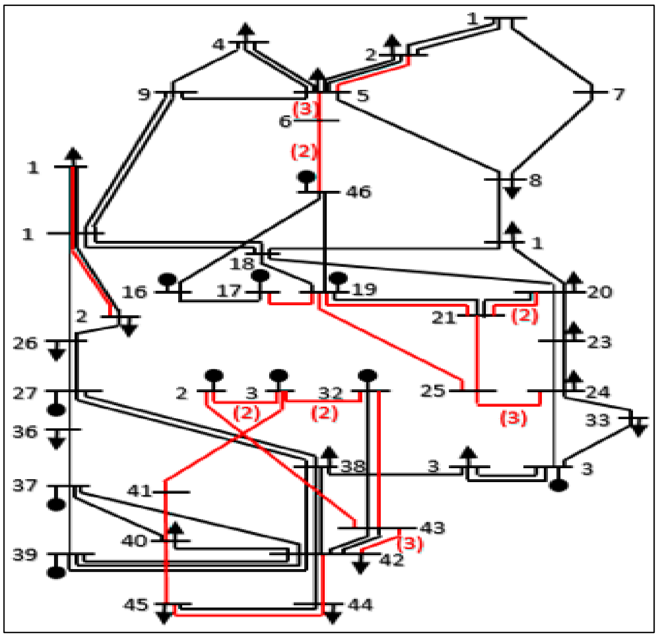

Figure 9: SB-46/79 system – Planned network.
Source: Authors, (2021).

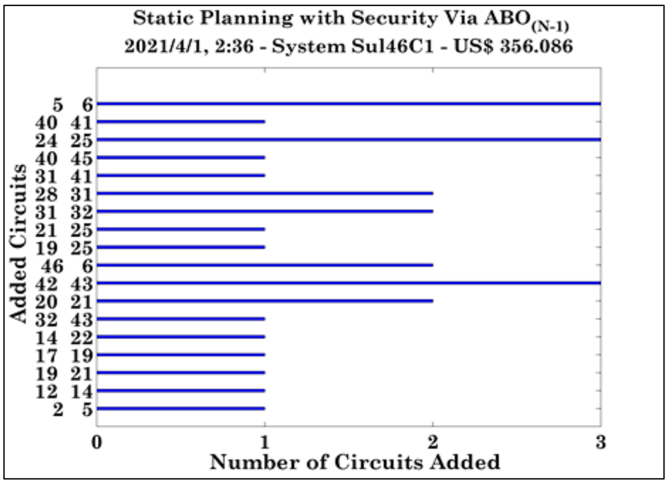

Figure 10: SB-46/79 system - Planned circuits.
Source: $ABO_{(N-1)}$ optimizer, (2021).

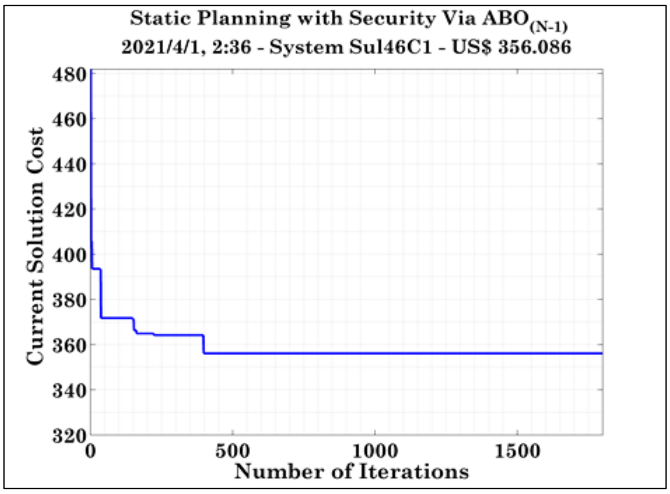

Figure 11: SB-46/79 system - Cost evolution of the best solution.
Source: $ABO_{(N-1)}$ Optimizer, (2021).

V. CONCLUSIONS

This paper presents a new metaheuristic algorithm, called the $ABO_{(N-1)}$ optimizer, for solving TNESPS problems with the network modeled by a DC power flow. An AC power flow model and other metaheuristics can be used in place of the ABO algorithm. To solve this complex nonlinear, non-convex optimization problem with integer and mixed variables, an algorithm based on the movement of African buffaloes in search of food was used.

To reduce costs of feasible candidate solutions and to enable candidate solutions with load shedding, Chu-Beasley's local improvement procedures used in a genetic algorithm were used. Such procedures, in addition to improving the local and global exploration of the search space, transform the MINLP problem into a PPL problem.

The results achieved with the $ABO_{(N-1)}$ optimizer, on three transmission systems widely used as benchmarks (Garver-6 bus, IEEE-24 bus, the South Brazilian-46 bus), attest to its ability to solve TNESPS optimization problems efficiently.

The solutions for the larger systems required longer computational times, due to the larger number of possible combinations and the need to compute more power flows in all branches of the network arising from removing one circuit from each branch at a time.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: João Ricardo Paes de Barros.
Methodology: João Ricardo Paes de Barros.
Investigation: João Ricardo Paes de Barros.
Discussion of results: João Ricardo Paes de Barros.
Writing – Original Draft: João Ricardo Paes de Barros and Dimitri Albuquerque de Barros.
Writing – Review and Editing: João Ricardo Paes de Barros and Dimitri Albuquerque de Barros.
Resources: João Ricardo Paes de Barros and Dimitri Albuquerque de Barros.
Supervision: João Ricardo Paes de Barros.
Approval of the final text: João Ricardo Paes de Barros.

VII. REFERENCES

[1] R. Romero, A. Monticelli, A. Garcia and S. Haffner. "Test systems and mathematical models for transmission network expansion planning", IEE Proceedings Gener. Transmission and Distribution, vol. 149, no. 1, pp. 27-36, 2002.

[2] I.J. Silva, M. J. Rider, R. Romero, and C. A. Murari, "Genetic Algorithm of chu and beasley for static and multistage transmission expansion planning", IEEE Transactions on Power Systems, 2006.

[3] A. H. Escobar, R. A. Gallego, and R. Romero, "Multistage and coordinated planning of the expansion of transmission systems", IEEE Trans. on Power Systems, vol. 19, no. 2, pp. 735–744, 2004

[4] D.H. Huanca, L.A. Gallego. "Chu and Beasley genetic algorithm to solve the transmission network expansion planning problem considering active power losses", IEEE Latin America Transactions, vol. 19, no. 11, pp. 1967-1975, November 2021.

[5] I.M. Mendonça, I.C. Silva Junior, B.H. Dias and A.L.M. Marcato, "Identification of relevant routes for static expansion planning of electric power transmission systems", Electric Power Systems Research, vol. 140, pp. 769-775, 2016.

[6] Niharika, S. Verma and V. Mukherjee, "Transmission expansion planning: A review". International Conference on Energy Efficient Technologies for sustainability, pp. 350-355, 2016.

[7] C.A. Moraes, E.J. De Oliveira, L.W. Oliveira and I.C. Silva Junior, "Static planning of power transmission system expansion through bioinspired

optim1ization technique", 12th CLAGTEE – Latin-American Congress on Electricity Generation and Transmission, pp. 1-8, 2017.

[8] J.T. Jiménez, J.L. Guardado, N.G. Cabrera, J.R. Rodríguez and F. Figueroa, "Transmission expansion planning systems using algorithm genetic with multi-objective criterion", IEEE Latin America Trans., vol. 15, no. 3, pp. 563-568, 2017.

[9] G. Latorre, R.D.J. Cruz., J.M. Areiza and A. Villegas, "Classification of publications and models on transmission expansion planning", IEEE Trans. on Power Systems, vol. 18, no. 2, pp. 938-946, 2003.

[10] R. M. Tejada D., J.M. López-Lezama, "Transmission network expansion planning considering repowering and reconfiguration", International Journal Electric Power Energy Systems, no. 69, pp. 213–221, 2015.

[11] P.V. Gomes and J.T. Saraiva, "State-of-the-art of transmission expansion planning: A survey from restructuring to renewable and distributed electricity markets", International Journal of Electrical Power & Energy Systems, no. 111, pp. 411-424, 2019.

[12] R. Hemmati and R.A. Hooshmand, "State-of-the-art of transmission expansion planning: Comprehensive review", Renewable and Sustainable Energy Reviews, no. 23, pp. 312-319, 2013.

[13] J.B. Odili, M.N.M. Kahar and S. Anwar, "African buffalo optimization: A swarm-intelligent technique, IEEE International Symposium on Robotics and Intelligent Sensors (IRIS), pp. 443-448, 2015.

[14] J.B. Odili, M.N.M. Kahar and A. Noraziah, "Convergence analysis of the African Buffalo optimization algorithm", IEE Inter. Symposium: Systems, Science & Technology, vol. 17, no. 33, pp. 1-6. 2017.

[15] P.C. Chu and J.E. Beasley, "A genetic algorithm for the generalized assignment problem", Computers & Operations Research, vol. 24, no. 1, pp. 17-23, 1997.

[16] I.J. Silva Jr., M.J. Rider, R. Romero, A.V. Garcia and C.A Murari, "Transmission network expansion planning with security constraints", IEEE Proceedings, Generation. Trans. and Distribution, vol. 152, no. 6, pp. 827-836, 2005.

[17] H. Zhao, Z Wang, D.C. Yu and X. Chen, "Transportation model-based hybrid methods for transmission network planning", Electric Power Components and Systems, no. 34, pp. 1191-1200, 2006.

[18] L.A. Gallego and A.E. Zuluaga, "Electric power transmission expansion system planning considering contingencies" (in Spanish), Scientia et Technica, pp. 7-9, 2006.

[19] Yi-X. Jin and J. Su, "Particle swarm optimization based on model space theory and its application on transmission network planning". 6th WSEAS International Conference on Instrumentation, Measurement, Circuits & Systems, vol. 15, no. 17, pp. 120-125, 2007.

[20] P. Yemula, V. S. K. Murthy, A. R. Abhyankar and S. A. Khaparde, "Transmission expansion planning considering contingency criteria and network utilization", 15th National Power Systems Conference (NPSC), pp. 309-396, 2008.

[21] A. Verma, P.R. Bijwe and B.K. Panigrahi, "Transmission network expansion planning with security constraints and uncertainty in load specifications", Inter. Journal of Emerging Electric Power Systems, vol. 9, no. 4, pp. 1-21, 2008.

[22] Aleksandar D. and Kevin T. Boundary load flow solutions, IEEE Trans. on Power Systems, vol 19, no. 1, pp. 348-355, 2004.

[23] G. Qu, H. Cheng, L. Yao and Z. Ma, "Transmission surplus capacity-based power transmission expansion planning using chaos optimization algorithm", 3th Inter. Conference on Deregulation and Restructuring and Power Technologies, pp. 1446-1452, 2008.

[24] A. Verma, P.R. Bijwe and B.K. Panigrahi, "Transmission network expansion planning with adaptive particle swarm optimization", Word Congress on Nature & Biologically Inspired Computation, pp. 1099-1104, 2009.

[25] H. Fan and H. Cheng, "Transmission network expansion planning with security constraints based on bi-level linear program", European Trans. on Electrical Power, no. 19, pp. 388-399, 2009.

[26] P. Limsakul, S. Pothiya and N. Leeprechanon, "Application of ant colony optimization to transmission network expansion planning with security constraint", 8th International Conference on Advanced in Power System Control, Operation and Management, pp. 1-6, 2009.

[27] A. Verma, B.K. Panigrahi and P.R. Bijwe, "Harmony search algorithm for transmission network expansion planning", IET Generation, Trans. and Distrib., vol. 4, no. 6, pp. 663-673, 2010.

[28] A. Verma, B.K. Panigrahi and P.R. Bijwe, "A combination of heuristic and bacteria foraging-differential evolution algorithm for transmission network planning with security constraints", Inter. Journal of Hybrid Intelligent Systems, no. 7, pp. 101-113, 2010.

[29] G.A. Orfanos, A.G. Anastopoulou, P.S. Georgilakis and N.D. Hatziargyriou, "Static transmission expansion planning under an improved harmony search Algorithm", 8th Mediterranean Conf. on Power Gener., Trans., Distrib. and Energy Conversion, pp. 1-6. 2012.

[30] M. Shivaie and M.T. Ameli, "An implementation of improved harmony search algorithm for scenario-based transmission expansion planning", Soft Computing, vol 18, no. 8, 1615-1630, 2014.

[31] E. Sarrafan, "Application of Particle Optimization for Transmission Network Expansion Planning with Security Constraints", Research Journal of Applied Sciences, Engineering and Technology, vol 7, no. 31, pp. 2605-2611, 2014.

[32] C.A. Correa, R. Bolanos and A. Garces, "Enhanced multiobjective algorithm for transmission expansion planning considering N-1 security criterion", International Transactions on Electrical Energy Systems, vol. 25, no. 10: pp. 2225-2246, 2014.

[33] S. Das, A. Verma and P.R. Bijwe, "Transmission network expansion planning using a modified artificial bee colony algorithm", International Trans. on Electrical Energy Systems, pp. 1-23, 2017.

[34] A.M. Leite da Silva, M.R. Freire and L.M. Honório, "Transmission expansion planning optimization by adaptive multi-operator evolutionary algorithms", Electrical Power Systems Research, pp.133: 173-181, 2016.

[35] A.M. Leite da Silva, F.A. Assis, L.A.F Manso, M.R. Freire and S.A. Flávio, "Constructive metaheuristic applied to transmission expansion planning with security constraints", 19th International Conference on Intelligent System Application to Power Systems, pp. 1-7, 2017.

[36] A. Khandelwal, A. Bhargava, A. Sharma and N. Sharma, "Security constrained transmission network expansion planning using grey wolf optimization algorithm", Journal of Statistics and Management Systems, vol. 22, no. 7, pp. 1239-1249, 2019.

[37] L.S. Nepomuceno, A.N. Paula and E.J. De Oliveira, "Optimization via spotted Hyena for transmission expansion planning considering contingency and electricity generation", Brazilian Society of Automatics, pp. 1-7, 2020.

[38] A.A. Fernando, A.M. Leite da Silva and L.A.F. Manso, "Transmission expansion planning of large power networks via metaheuristics with security constraints and load uncertainty analysis", International Transactions on Electrical Energy Systems, pp. 1-19, 2020.

[39] L.L. Garver, "Transmission network estimation using linear programming", IEEE Transactions on Power Apparatus and Systems, vol. 89, no. 7, 1688-1697, 1970.

[40] S. Haffner, A. Monticelli, A. Garcia, J. Mantovani and R. Romero, "Branch and bound algorithm for transmission system expansion planning using a transportation model", IEE Proceedings Generation, Transmission and Distribution, vol. 147, no. 3, pp. 149-156, 2000.

[41] R. Villasana, L.L. Garver and S.J. Salon, "Transmission network planning using linear programming", IEEE Transactions on Power Systems, vol.104, no. 2: pp. 349-356, 1985.

[42] R. Fang and D.J. Hill, "A new strategy for transmission expansion in competitive electricity markets", IEEE Transactions on Power Systems, vol. 18, no. 1, pp. 374-380, 2003.

[43] A. Monticelli, A. Jr. Santos, M.V.F. Pereira, S.H.F. Cunha., J.C.G. Praça. and B.J. Park, "Interactive transmission network planning using a least-effort criterion", IEEE Transactions on Power Apparatus and Systems, vol. 101, no. 10, pp. 3919-3925, 1982.