IOP Conference Series: Materials Science and Engineering

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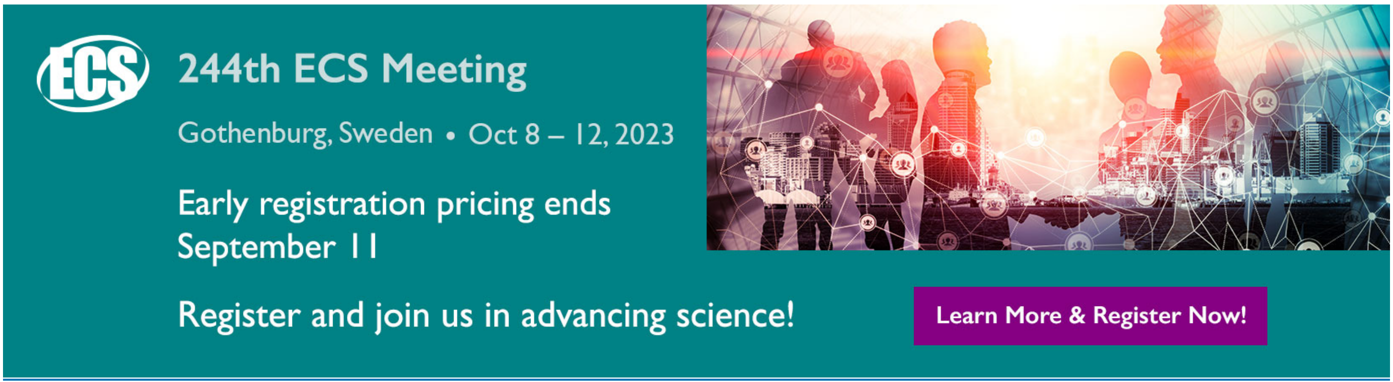
To cite this article: A. A. Olajube *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1107** 012182



BIPV Potentials in Overcoming Energy Challenges in Sub-Saharan Africa

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Abstract-

The incorporation of the solar panels to the building roof envelopes, also referred to as the building integrated photovoltaic (BIPV), is gradually gaining recognition in the energy-efficient systems. Apart from providing aesthetics, it is also a cost-effective, innovative, space-conservative, and pollution-free power generating technology from buildings. This technology is very economical because it helps to save the space required for PV panels that could be used for other infrastructural projects. an enormous power can be generated from buildings and added to the energy mix to help meet the increasing power demand. The BIPV potential for facades, rooftops, and windows is assessed in this article for Sub-Saharan African countries by evaluating the various methodologies that have been used globally, state of the art, and the relevant research areas for the future clean electricity harvesting schemes in buildings.

Key words: Microgrid, reliability, Availability, power system, Solar PV

1. Introduction

As essential as sunlight is to plant for photosynthesis, so is the electrical energy to the modern society to the point that the socio-economic growth and general quality of life of any nation are dependent on the availability of affordable sources of electrical energy. Yet, as at present, mostly in remote areas of Asia and Africa, about 1.2 billion people do not have access to electrical power [1]. Such areas depend on traditional sources of energy to meet their daily power supply needs kerosene for home lighting, wood for heating and cooking, wind and solar power for drying, harvesting, and separation purposes [2]. This accounts for the under-development of African nations. For the attainment of sustainable development goals put forward by the African Union in her agenda 2063, there is a need for increased power supply in the continent.

Currently, many nations of the world depend primarily on fossil fuel for electricity generation, which exposes the globe to adverse environmental impacts, including depletion of the ozone layer, ozone formation at ground level, global warming, and acidic rain, etc. The dependency of many nations on fossil fuel-based generators has aggravated the fear for the rapid depletion of the fuels [3], [4], [5]. There is an increasing campaign against global warming globally [6], [7], [8], and several predictions indicate an aggressive reduction in the fossil reserves within 34-40, 36-70, and 106-200 years for oil, natural gas, and coal respectively [9]. Consequently, a transition renewable energy (RE) based systems are inevitable to satisfy the increasing power demand with no environmental pollution [10], [11].

Renewable energy systems are cost-effective, durable, environmental-friendly, and require low maintenance levels resulting in their recent high penetration into the energy market [12].

These include solar, wind, hydropower, biomass, geothermal, fuel cell, and tidal energy [13] [14].

Among the various source of electricity generation, solar energy stands out as the most effective, abundant, accessible, non-exhaustive, and cleanest. It has a wide range of applications with great potential to provide sustainable power supply [14], [15], [16], [17], [18]. Several technologies that have been employed in harnessing solar energy include solar photovoltaic, solar thermal energy, artificial photosynthesis, solar heating, solar architecture, and building integrated photovoltaic (BIPV) [14], [19]. BIPV has been reported to be the most potent and promising solar technology requiring no extra space, rails, and brackets for installation, but supplies instantaneously electrical energy for buildings in [20], [21], [22], and [23].

1.1 The Building Integrated Photovoltaic (BIPV)

The largest consumers of electricity is building and it accounts for 40% of the energy consumption globally and 36% of the greenhouse gas emission worldwide [24], [25], [26], [27], [28], [29]. Hence, clean energy sources and efficient energy management in buildings are essential. It was in view of the above that the idea of BIPV was conceived. Building Integrated Photovoltaic (BIPV) are photovoltaic components designed to replace the real building envelope elements and function as both solar power generator and building envelop [21], [30]. It is a product of the installation of the photovoltaic (PV) module architecturally into the building envelope [31]. For improved energy performance in buildings in conjunction with high architectural design and aesthetical standards, two techniques or concepts have been used in integrating photovoltaic systems into buildings recently. These include: BAPV (Building Attached Photovoltaic) and BIPV [1], [32], [33], [34] .

In a BIPV system, certain traditional materials for building such as the roofs or facades are replaced with photovoltaic (PV) systems while in BAPV, PV systems are used as add-ons to building envelope [34], [35]. The use of a BIPV system is space-conservative and reduces capital cost as a result of the multi-functionality of the PV components [21].

The BIPV systems were categorized base on PV technology, application type, and market name in [1], as shown in figure 1.

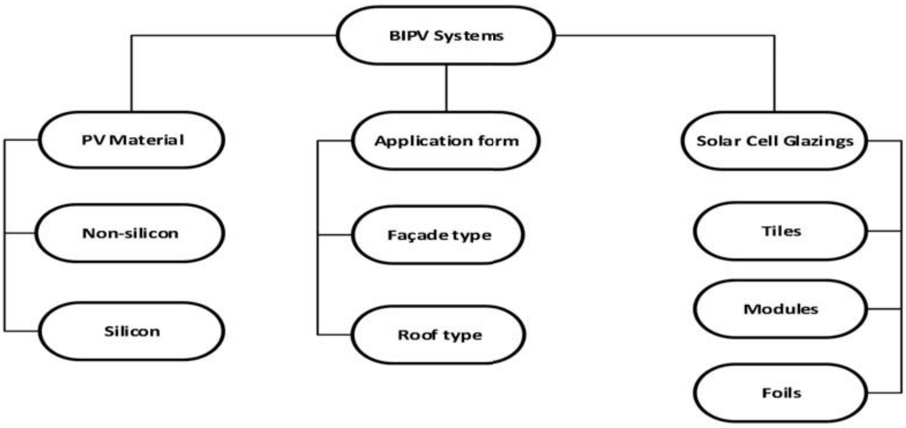

Figure 1: BIPV Systems Categorized [1]

The various BIPV products available today are shown in figure 2

Figure 2: BIPV Product [19]

In new buildings, these products are used as facades or roofing systems or retrofitted into the existing buildings to provide the desired aesthetic while still turning the buildings into a noiseless and clean energy generator [32], [36] [37]. They are designed to outperform traditional building construction materials considering maintainability and technical parameters [37]. Figure 3 shows an example of BIPV roofing system.

Figure 3: Roof Integrated BIPV System [38]

Turning every building into a clean energy generator could result in reduced dependency on the unstable national grid, low CO_2 emission, environmental sustainability, increased access to electricity at affordable cost, and sustainable development. Hence, BIPV technology could be required to overcome the future global energy challenges [39][40][41].

2. Relevant State of the Art Methodologies

The integration of BIPV systems in residential or commercial buildings is currently receiving much attention of researchers [42]. This section covers several methodologies that have been adopted by such researchers to study BIPV technologies for sustainable green energy generation worldwide.

In [43], eQUEST, a building energy package, was used to study a school's building energy production and saving schemes in hot and humid weather. BIPV systems were adopted to meet the school's energy demand. The result showed that zero building energy consumption in the school was achieved using BIPV systems.

Othman and Rushdi [44], studied the BIPV potential of building rooftops in Shah Alam, Malaysia. In their study, measurement of essential parameters (tilt angle, roof form, sun orientation, PV rating, PV type, number of modules used and PV module size) for selected houses were carried out and analyzed in order to decide which orientations and roof form influences the electricity generations potential of buildings. The daily power generation potential in the range 11.18kWh/kWp-29.18kWh/kWp was reported for the houses depending on PV types, the number of modules, location, and slope inclination.

The performance assessment study of BIPV system in existing households in Canada where Canadian Hybrid Residential End-Use Energy and GHG Emissions Model (CHREM) was used as a case study by Asaee, Nikoofard, Ugursal and Beausoleil-Morrison showed a great reduction in greenhouse gas emission and energy savings with the use of BIPV was estimated to be 17 and 18%, respectively [45].

In [46], the cold winter and hot summer zone of China energy-saving potential of building integrated photovoltaic thermoelectric (BIPVTE) were investigated. The annual simulation result revealed a new solution building-integrated solar system with zero energy

Ali, Shafiullah, and Urmee in [47] carried out an investigation of the energy generation prospects of the roof-mounted Photovoltaic system in the Maldives. A combination of the quantity of radiation received, PV module losses, and roof area availability was used for the study. The result showed that the rooftops on Hulhumalé Island have an energy generation capacity of 4.8 – 8.0 GWh per annum.

Nuria and David in [31] stressed the need for matching the PV generation and building's load profiles in order to achieve energy self-sufficiency. In their study, the building's daily load profile, number of facades, building roofs, orientation, surface availability, and solar irradiance were analyzed. Self-consumption and self-sufficiency indices were also calculated for each surface used.

Yang and Zou in [48] carried out the analysis of the benefits, barriers, costs, risks, and improvement strategy for BIPV from supply chain and stakeholder perspectives. The results show that BIPV has significant long term benefits compared to the high initial investment capital cost. Similar work was carried out in Shanghai by Wang et al. in [49] [50], to explore the economic benefit of BIPV facade in a shopping mall in Taiwan with payback period and net present value utilized. The result showed that the façade with a life cycle of 20years would reach its breakeven point in 10 years and 16 years of net present value.

Vulkan, Kloog, Dorman, and Erell in [51] estimated the potential for BIPV power generation in a dense urban residential building with the shading effect from adjacent structures accounted for. The results showed that vertical facades suffer more from mutual shading effect than roofs, but substantial contribution can still be made to the solar potential of urban buildings using facades, especially if they are east and south oriented.

In [30], Akata, Njomo, and Agrawal presented the review of BIPV technologies and their potential in the tropics. In their study, a residential building and BIPV evaluation were done with fitting as rooftop capable of generating 3 kW per day in the tropical climate of Cameroon.

The result showed that the primary energy consumption annually was reduced from 79.58 kW h/m^2 to 13.64 kW h/m^2 plus the reduction in the expenditure on building materials the structured roof and labor.

In [52], a MATLAB based dynamic simulation model was used for high rise facade buildings, assessing the active and passive effects of building integrated photovoltaic/thermal (BIPV/T) system. The results showed a percentage reduction of 56.8 to 10.4% of the heating demand in buildings by utilizing building integrated air open-loop photovoltaic thermal technology. It was concluded that the proposed methodology could help designers in analyzing the effects of BIPV/T systems on the overall energy demands and indoor thermal comfort with consideration for the system design and operating conditions.

Thermal performance based on a 5.25 kWp roof-integrated BIPV system case study in the tropical regions was discussed in [53], comparing the performance of PV with normal construction materials by simulating different scenarios to deduce impact on inhabitant comfort levels. From the data collated and simulated, PV as a roofing material was observed to have caused the occupants serious thermal discomfort. Further quantification and analysis of the comfort level were suggested.

A MATLAB/SIMULINK based model for BIPV evaluation was developed in [54]. This model utilizes validated on a 6kWp BIPV system, which was installed at the Universidad de Bogotá Jorge Tadeo Lozano building in Bogota, Colombia, showing a correlation that was greater than 0.9 between DC and AC power generated by the building integrated photovoltaic system. The calculated model, which was proposed for any weather condition.

A study carried out on the application of BIPV on the façade, and high rise building rooftop in Jakarta was presented in [55]. The econometric spreadsheet program and the Sunny Web Design Software were used to compute the energy generation and required specifications. It was shown that rooftop BIPV produced more energy than façade BIPV as more radiation can be captured by rooftop BIPV on optimum tilt and azimuth angle.

A model that combines Artificial Neural Network and satellite images to predict the power output of BIPV of capacity 9.324 kWp installed at the Solar Energy Research Center rooftop at Almeria in Spain was presented in [56]. The result showed that the prediction with ANN was satisfactory with normalized root mean square error of less than 26% for all-sky conditions. The benefit of matching such two already proven techniques to obtain the results that are spectacular in energy generation prediction.

The economic and technical BIPV potential in six cities in Brazil was presented in [34]. The technical analysis showed the possibility of fully meeting the energy requirement of integrating PV in the office building. In all the cities that were evaluated, the economic study showed that it was more economical to replace the façade building materials with the BIPV.

In [57], Curtius used 43 qualitative interviews with stakeholders of BIPV value chain to identify the barriers and facilitators of BIPV. The study itemized high initial cost and complexity, low awareness, adoption reluctances of architects, as well as political risk as to the significant barriers to BIPV acceptance. It was recommended that policies that will provide clear benefits for BIPV adopters would result in the general acceptability of BIPV. When financial support and inclusion of BIPV in building labels or codes are considered.

In [58], Sozer and Elnimeiri used life-cycle cost analysis for BIPV system cost components identification and established the connection between the building design process and the findings of life-cycle cost analysis (LCCA). This LCCA method used identified Quantifiable variables and measures which were used to compare the cost of building with BIPV and non-

BIPV building. The result showed that BIPV system was costlier than the traditional curtain wall, but the cost can be reduced progressing depending on the initial cost.

An assessment of the environmental impact of an adaptive and dynamic BIPV was carried out in [59]. Production data and Energy Plus simulations were used for the life cycle assessment to calculate the energy demand in a building. Based on the analysis, design recommendations were provided for future dynamic BIPV installations.

Kneraa, Szczepańska-Rosiaka, and Heim in [60] exploited the potential of BIPV façade for electricity generation in an office. In their study, ESP-r simulation tool was used for energy performance and Daysim for daylight luminance distribution calculation considering façade orientation. The results showed that only the room with a south-oriented facade enjoyed supplementary electrical energy generated by BIPV.

Singh and Banerjee [61] estimated the solar PV potential of rooftops in the Mumbai, India, using GIS with micro-level simulations in PVSyst used for the estimation of effective sun hours for the region. The results showed a potential of 2190MW for the city with median efficiency panels, at an annual average capacity factor of 14.8%. The method was recommended for calculating the PV potential of any given region.

In [62], Shukla, Sudhakar, Baredar, and Mamat identified the solar potential for BIPV application, design, and integration strategies in Southeast Asia. The study listed finance, limited expertise, lack of promotion, level of technology, and limited readiness for adoption as the major barriers to BIPV implantation in Southeast Asia.

3. Current Research Problems in Literature

The prevailing problem in the research area of BIPV is that its implementation is yet to be recorded in developing countries, especially in Africa. Its potentials, applications, benefits, products, and design are yet to be exploited on the African continent. As it stands today, it is quite challenging to convince an average man in African that even his own house could be used to meet his energy needs.Even in developed countries that have had BIPV implemented, there is a need to improve the self-consumption solution for BIPV. That is, the occupancy patterns of the building should be studied as the energy consumption in any building is subject to the occupants' loads [37][40].

Most of the researchers in this field did not identify the best BIPV system for a given building. Such studies failed to specify where either the rooftop or façade BIPV is best suited. In as much as there are buildings which location favour the installation of both the façade and rooftop BIPV, there are locations that require the installation of either of the two for optimum energy generation. The study of the effects of location, height, and density of building in the choice of BIPV system to be installed for a given building need more attention from researchers.

In addition, lack of access to available BIPV products in developing countries is a point of concern. Though the prices of such products are judged to be high by many researchers compared to the traditional building material, their unavailability in developing economies make people raise questions as to whether things like that exist [58].

Finally, there is a need for an increased awareness campaign for BIPV adoption for greenhouse gas emission reduction in the building, as many of the researchers blamed the rate of adoption on lack of awareness. To this end, there is a need to unveil the BIPV potential, applications, and benefits in order to boost its awareness in developing countries.

4. Conclusions

Research into the potentials, applications, benefits, and design of BIPV will go a long way to create awareness of the possibility of every building meeting its own energy demand with no negative environmental impact. Sub-saharan African countries can meet their clean energy demand through BIPV, and the economic implication of large space requirements will be nullified. This study will help the structural engineers, building designers, architects, and electrical engineers in making arrangements for the BIPV in building projects for more power generation with appropriate storage systems. The knowledge of its applications and economic benefits will help to improve its adoption worldwide.

Acknowledgements

The authors hereby appreciate Covenant University for supporting this review article.

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