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DERIVATION OF COST BENEFITS AND ENERGY EFFICIENCIES OF MULTI-JUNCTIONED PHOTOVOLTAIC CELLS

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ABSTRACT

A lot of socio-political crises witnessed nowadays are influenced in one way or the other by energy issues. Energy derived from fossil fuels, hydro systems and nuclear resources in events of electricity generation are known to be costly economically, environmentally and otherwise. Alternative options in this direction focused on renewable sources from solar and wind systems which are clearly seen to be powered from free and inexhaustible resources. Other advantages of these systems are relative low maintenance requirements. Initial costs of renewable energy systems coupled with their low efficiencies are twin factors conceived to affect developments and utilizations of photovoltaic cells. Various methods explored to improve efficiencies of photovoltaic cells such as solar energy concentration, polymer photovoltaic, impurity photovoltaic suffered setbacks due to requirements for active and passive cooling, solar tracking, as well as solar energy concentration materials etc, implying that added cost being imminent and excessive heat affecting durability. When individual cells are taken into account by expanding their junctions more solar rays are absorbed resulting in more conversion efficiency. A 35% efficiency was recorded for two-junctioned cell instead of 15% obtained from single cell of gallium arsenide. It is projected that better efficiency could be achieved with multifunction of amorphous silicon or indium diselenide. Increased efficiency in general could influence reduction in the size of solar array for a peculiar energy demand. A development that could lead to reduced initial and running cost as well as minimizing space requirement.

Keywords: Energy Demand, Energy Efficiency, Initial Cost, Maintenance Cost, Multi-junction, Photovoltaic Cells.

I. INTRODUCTION

Increase in demand of energy resources leads to a crisis that has to do with implication on environment such as greenhouse emissions, political turmoil, corruption etc. The ever increase in population growth globally pose a threat to the somehow limited energy resources. Thus, if Beggs' bacteria analogy is in any way to be considered, the energy sourcing, demands and supply is expected to experience an exponential increase, hence more chaos should be expected **[5].** The high demand in electricity influenced increase in power generation which affects the environment through burning of fossil fuels in thermal power plants, emission of gaseous substances such as methane in hydro power plants and struggle by nations to possess nuclear technology despite its radioactive implication and threat to global peace and security.

Emergence of renewable energy technologies seemed to have played a key role in reducing the problems associated with older sources of energy supplies, by contributing up to 19.5% electric power generation globally in 2009 **[4]** and keeps growing annually. Information shown in Table 1 indicates top ten renewable energy based electricity producers in the world. In spite of current developments witnessed in term renewable energy worldwide is that only developed countries have the highest contribution in this regard. The rest of the developing and the underdeveloped world contribute insignificantly to the global renewable energy power generation. Yet most of those countries (developing and the underdeveloped) are located within equatorial region. A region is where abundant solar radiation are obtained at various angles, good enough for energy conversion, as well as coastal and desert areas where winds at different velocities blow constantly, good for wind farms. This is implying that a very large number of developing and under-developed countries have natural potentials of significant global participation in renewable energy generation.

Table1. Top ten global renewable energy electricity producers (GW) **[13]**

S/N	Country	Year	Wind Power	Biomass & Waste	Solar	Geo-Thermal
1	China	2011	73.2	34	3	
2	European Union	2010	149.1	123.3	23.1	5.6
3	United States	2011	119.7	56.7	1.81	17
4	Brazil	2011	2.71	32.2	0.0002	
5	Canada	2011	19.7	6.4	0.43	
6	Russia	2011	0.018	0.036		0.464
7	India	2011	26	4	1	
8	Germany	2012	45.3	40.9	28.0	0.03
9	Norway	2011	1.143	0.265	0.007	
10	Japan	2011	4.36	23.1	3.80	2.89
11	Italy	2012	13.3	9.2	18.6	5.2

The developing and underdeveloped societies also have a relatively high demand in power supplies for residential, commercial and industrial use which could not be served due to insufficient per capita electrical energy generation and supplies. The trend of low per capita energy supply seriously affects their individual gross domestic products (GDPs) as small and medium enterprises hardly break even due to energy costs. This implication for example in Nigeria leads to individual and unauthorized distributed power generation among consumers, a trend very dangerous to safety and environment.

Part of what is seen to be an impediment to the adequate power generation among developing and under-developed societies is high cost of power generation associated with thermal and hydro power plants (in terms of both initial and running costs). In this regard therefore a solution should be utilization of renewable resources such as solar and wind energy resources which are free and readily available. The energy efficiencies and initial costs of harnessing the mentioned resources could similarly continue to remain an issue. It is evidently shown that power generated from renewable resources costs at least three times higher than the other non renewable resources (hydro, thermal etc). The trend indicates an unfriendly gesture for the under-developed societies especially those of Africa and Asia due to affordability. It is therefore important to address one aspect of the problem at this context, which have to do with energy efficiency and initial cost of photovoltaic cells. On this note therefore cheaper and cleaner energy could be achieved if the following research questions are successfully addressed;

- The feasibility of producing photo-voltaic cells with higher energy efficiency.
- The feasibility of producing photo-voltaic cells with reduced initial costs.

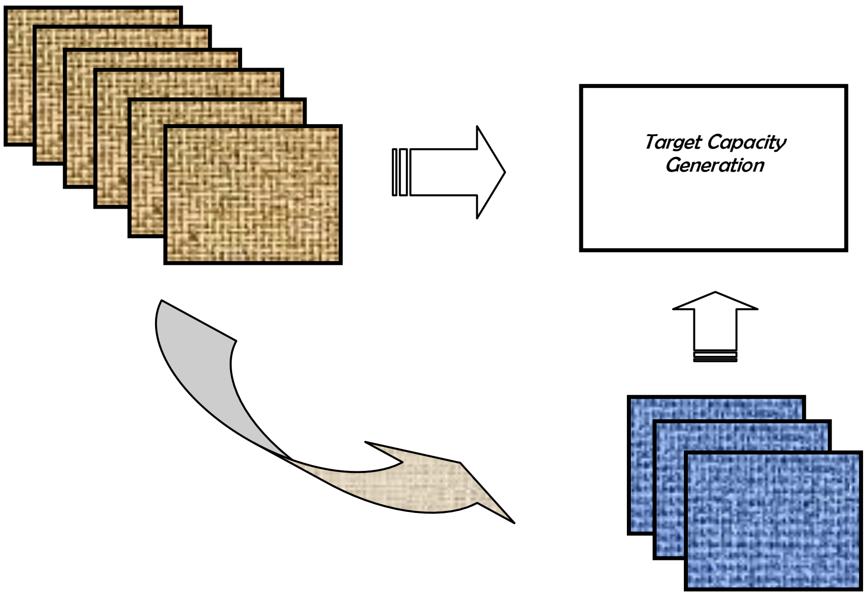


Fig. 1. Solar array size reduction could reduce initial and running cost

Conceptually the two key issues just mentioned are related. The diagram of Fig 1 illustrates the relationships. This can simply be described as increasing an efficiency of PV cell by reducing the size of solar array for a target generation capacity, resulting to a decrease in initial cost of installing the arrays. Reduction in the size of solar arrays could as well reduce the amount of space and reduce maintenance and other running costs. When research issues as such are addressed, it could be possible to have reduction of over-dependence on non-renewable resources which are costly, exhaustible and environmentally unsafe. It is difficult bridging the current energy gap existing among developed and less developed societies, however the impact of lower cost energy could eventually be felt through serving local demands using distributed generation and microgrid technologies. Other benefits of solar photovoltaic cells is that the fuel is totally free, abundant and last forever. The system is as well completely noiseless, and require less maintenance. The following objectives could be set for achieving this aim;

- Exploring various physical, electrochemical, mathematical or other methods to be used in improving the current efficiencies of photovoltaic cells.
- Modelling and optimization of improved photovoltaic cells using functional and appropriate software.
- Simulation of the improved model using a software tool.

II. METHODS OF IMPROVING ENERGY EFFICIENCY OF PHOTOVOLTAIC CELLS

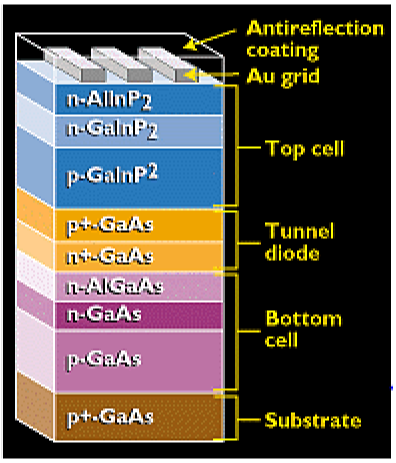
Evolutions in photovoltaic cells' technology indicate that cost was a major limitation that was not clearly addressed. Photovoltaic cells initially came into major use as a source of electrical energy in expensive projects such as satellite and space projects. In fact photovoltaic cells have not reached full commercial applications until 70s during energy crisis **[1]**. The cost was not only major limitation of photovoltaic cells as energy efficiency is another limitation, and the two are directly related with each other. There are numerous methods upon which efficiencies of PV cell could be improved. These include the following;

- *Solar energy concentration methods*: This method employs techniques of concentration of solar rays using materials such as Fresnel lens, parabolic mirrors, reflectors, luminescent concentrators etc in energy efficiency improvement of photovoltaic cells. The method has good advantage of smaller space requirement as less photovoltaic materials are used. Disadvantages of this methods include additional costs due to incorporation of light concentration materials (lens, reflectors, mirrors etc), which could be seen as addition to the initial cost. In event of need for medium or high concentration of light energy passive or active cooling must be part of the system which could as well add to the cost and complications. All these are an addition to its sun tracking requirement. Thus as renewable energy system it has always been a viable alternative despite its discovery over forty years ago **[12]**.
- *Impurity Photovoltaic methods*: The study here concentrates light by doping crystalline silicon solar cells with new impurity in order to realize the effects that could result in improving the energy efficiency of a PV cell **[8].** An attempt in this method, which is seen as a new generation concept to increase efficiency above Shockley Queisser limit is however not yet proven fully.
- *Polymer Photovoltaic Cells Methods*: The methods here involved controlling the active layer growth rate so as to obtain an increase hole mobility and balanced charged transport in a bulk heterojunction of polymer poly(3-hexylthiophene) and methanofullerene.**[10]** Moreover in a related study a high charge-separation efficiency combined with the reduced fabrication costs was opined to be a compelling options for tomorrow's photovoltaics **[11]**. This could be possible by incorporating a few volume per cent of alkanedithiols in the solution used to spin-cast films comprising a low-bandgap polymer and a fullerene derivative. This happens to achieve 2.8 to 5.5% increase in efficiency **[9]**

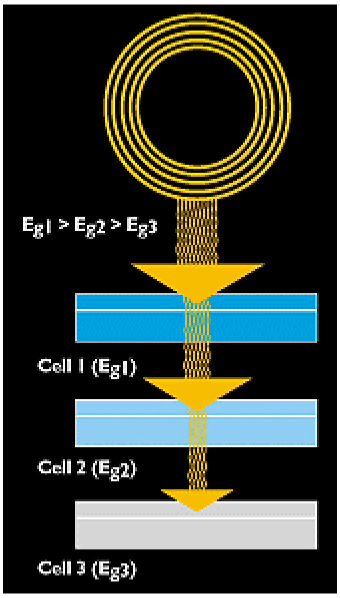
III. THE MULTIJUNCTIONING METHODS

In view of various shortcomings of methods discussed above, research directed at improving the efficiency of photovoltaic cells indicated that using multi-junction instead of single junction for a cell wafer yielded better result of higher efficiency. A trend seen as record breaking achievement that occur within a short span **[8]**. Although voltage and/or current ratings of the photovoltaic cells are increased by series and/or parallel electrical links respectively, it calls for additional photovoltaic modules resulting to large solar arrays for servicing particular demand. The performances of individual cells whose power ratings currently range not more than 1 – 2 watts depend on the adequate photons radiated by the sun. This implies that only photons whose energy equals or greater than band gap of the cell material can free an electron for an electric circuit **[2]**. Development in this field shows that more energy can be converted from light to electricity by forming what is termed as cascade or tandem cells (Fig 1 a and b). The cascade or tandem cells are formation of two or more different cells with more than one band gap and more than one junction. The multi-junction cells succeeded in having higher conversion efficiency. The use of gallium arsenide in multi-junction as one or all of the components of cells proved to have a conversion efficiency of 35% under concentrated sunlight as against 15% efficiency of single junction photovoltaic cell. At the moment studies are carried out on multi-junction devices that may use amorphous silicon and copper indium diselenide.

Fraunhofer Institute confirmed that Sharp has already hit a world record of 44.4% efficiency in 2013 from its triple-junction solar cell **[7]**. Researchers at National Institute of Standards and Technology confirmed that an efficiency of 51.8% under 100-suns illumination could be achieved by simulation, which is an improvement from 43.5% efficiency under 418-suns illumination. These achievements were recorded with no optimization. Although theoretical efficiency of 87% was said to be achieved with infinite multi-junctions, higher simulation efficiency could be realized not only with multi-junctions but with optimal semiconductor materials with combination of band gaps that cover as much of the solar spectrum as possible **[6]**.



(a)



(b)

Fig.1 Multi-junction of a Photo-voltaic cell. (a) Structure (b) photon absorption [1]

In most of the developing and the underdeveloped countries where concentrated sunshine is abundant, and where demand and affordability are major issues, the 35% efficiency needs to be improved. It should be conceived at this instance that further research in multi-junctioning could further increase the efficiency of cells, thereby reducing the size of solar modules (or arrays) per unit of energy supply. Reduction in the size of solar arrays is expected to reduce the initial cost of the system.

A solar energy resource is one of the world's finest sources of electricity. It has so many advantages over other renewable sources and other non-renewable energy sources. It is estimated that if only 4% of the world's desert can be covered with solar arrays, total global electricity demand will be served. But as at 2011 photovoltaic cells contributes only 0.5% of the global installed electricity generating capacity **[3]**.

The growth in demand of photovoltaic cells raised sharply within the last decade, yet the initial cost and energy supply costs much higher than energy from other sources. A kilowatt-hour cost 18 cents for electricity generated from solar energy, approximately three times more expensive than electricity produce from coal or natural gas. Statistics show that about 89% of the total worldwide photovoltaic installed capacities come from Germany, Japan and USA **[3]**. Cheaper modules and accessories may increase chances of poorer societies benefit from abundant free solar energy resources, especially now that the era of cheaper oil and other resources seems to be over.

IV. RESEARCH METHODOLOGY

Although the study intended to be carried out in the proposed work is purely experimental and may however possess qualities of correlation/regression analysis approach. It is experimental because much of the work involves laboratory activities intended to investigate the multi-dimensional methods of multi-junction of photo-voltaic cells using various materials such as gallium arsenide, copper indium, amorphous silicon, etc. The correlation/regression feature in this case will emerge in determining the strong relationship between the two important variables i.e. energy efficiency and cost associated with photovoltaic cells.

Multi-junctioning of photovoltaic cells in this study is expected to be achieved by modelling and optimization techniques. Modelling refers to conceptualization of methods to be deployed in improving the photovoltaic cells characteristics and performance. The current physical, mathematical and chemical models and structures of photovoltaic cells may need to be studied and analyzed. With the studies and analysis, opportunities and limitations of the current models may be identified with the aim of remodeling for improved energy efficiency, which as well could reduce initial and running cost of photovoltaic cells. For example multi-junctioning of photovoltaic cells using gallium arsenide **[1]** was able to achieve 35% efficiency from what was generally obtained as 15 – 23% in the past. If different set of physical structure, mathematical modelling or chemical composition from the previous may be considered in optimization of a photovoltaic cell, an efficiency of more than 35% could be achieved. In this proposed study an efficiency of 60% for a photovoltaic cell (the present efficiency of solar heaters) may be the target.

By optimization, a better modelling of a photovoltaic cell is sure to be achieved. This is a process by which ultimate decision could be taken from large options of system parameters. Optimization in this work is aimed at reaching the highest possible energy efficiency values. Making use of appropriate software tools the optimized model is expected to be simulated, so that the performance of the model may be viewed and analyzed on software domain. The advantage of simulation is to have cheaper, faster and safer operational platform for better analysis.

V. CONCLUSION

The various methods being deployed to improve the energy efficiencies of photovoltaic cells such as concentration, polymer and impurity methods etc, discussed in this paper have major setbacks. As against these setbacks, the Multijunctioning method have greater advantage of conversion efficiency as well as relative cost effectiveness. These are some of the factors conceived to reduce the size of arrays per target generation capacity which could reduce the initial and maintenance costs as well as reduction in space requirements.

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