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Concentrating solar power technologies for solar thermal grid electricity in Nigeria: A review

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ABSTRACT

Grid electricity generation in Nigeria has been unstable for a long time now. With respect to her continued dependence on oil and gas and seasonal variations on water level for hydropower, immediate reliable and steady electricity generation in the country is not guaranteed. Incorporating alternative source of energy like solar is a solution. Solar Chimney technology is not yet technically and economically mature, as investment on it is still low, thereby posing more financial risks at least at the megawatt capacity. Photovoltaic and Solar Thermal technologies are technically and economically more established, but they can only ensure 24-h power supply with the aid of energy storage systems. Solar thermal value addition is on its propensity for thermal energy storage and hybridization with liquid fuels at commercial capacity. Hence, due to technology advancement and the country's high direct normal irradiation potential, concentrating solar power is the more suitable solar power technology for commercial electricity generation in Nigeria. In this paper, concentrating solar power technologies are analysed under operational, environmental and social conditions in Nigeria using data from desktop survey to determine the most suitable technology for solar thermal electric power plant. It is observed that the technical maturity of parabolic trough concentrator distinguishes it for preference to all other technologies and would exert moderate pressure on land requirement even though, it is the most expensive and water demanding technology. In terms of unit cost of electricity and water usage capabilities, parabolic dish concentrator is least expensive and uses least water but lacks proven commercial application. Solar tower is technically simpler and possesses better thermodynamic properties than the rest but its low installed capacity increases its financing risk. Hence, the trough system is the most suitable for immediate and medium term projects given its proven technology maturity and flexible financing mechanism.

1. Introduction

In the face of challenges of electricity generation, transmission and distribution in Nigeria, alternative sources of electricity to the conventional gas fired and hydropower plants in the country are being explored. Solar thermal power will be the promising source of sustainable and reliable alternative source of electricity in the country as has been proven in many countries of the world. Concentrating solar power (CSP) or solar thermal electricity projects are not beyond the reach of developing countries like Nigeria and the rest of sub-Saharan Africa, if there is a strong political will by the governments and investors to build the plants even though they are capital intensive. However, prior to the commencement of such projects, energy stakeholders, namely the government, investors, researchers and indeed the general public should understand the fundamental issues to consider in the choice of any type of CSP technology to adopt for the project. Of the many studies on renewable energy and solar thermal technologies in the country, limited attention has been given to the topic considered in this paper.

The objectives of this paper are

i) to review the progress in the development and use of concentrating solar power (CSP) and other solar-to-electricity conversion technologies,
ii) to provide data on the solar resource of Nigeria, water and land availability in the northern part of Nigeria and
iii) To provide a guide on the selection of a suitable CSP technology for a short and medium term scalable solar thermal electric power plant (STEPP) in Nigeria based on the level of development, technical, economic, social and environmental requirement of each

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technology.

The review will support in forming decisions and identify good approaches to the selection of a CSP technology for energy access interventions in the northern part of Nigeria and the country in general. This study however, is not aimed at studying the feasibility of a given CSP technology at a given location in Nigeria because there is no such proposal yet to site a STEPP in any part of the country.

The paper first reviews and compares different solar power technologies and further settles on the development of CSP technologies up to the end of 2016. In chapter 2, it discusses CSP in Nigeria while in subsequent chapters, the major factors that will affect decision on selecting a CSP technology and further studies that need to be undertaken are discussed.

1.1. Solar power

Owing to the devastating impacts of fossil fuel consumption in electricity and thermal energy generation, the development of alternative sources of energy has become major concern in decision and policy making arms of the governments and energy stakeholders especially from climate change point of view. This has led to the increase on investments, research and development of solar power devices that can harness the abundant energy from the sun for electricity generation. The major solar power technologies which have attained different degrees of maturity and integration in electricity generation are shown in Fig. 1. Solar power technologies can convert the solar radiation (solar energy) directly or indirectly to electricity without an intermediate medium or by first converting to thermal energy that drives a generator for electricity production respectively. The former comprises solar photovoltaic (PV) which converts solar radiation into electricity by movement of electrons while the latter comprises the solar thermal technologies which convert solar radiation to thermal energy first, followed by electricity generation using the thermal energy to drive turbines. Solar thermal technologies comprise the solar chimney (SC) and the concentrating solar power (CSP) technologies. The individual technology's power block responsible for the conversion of solar energy to electricity is also shown in Fig. 1. Solar power plants are a group of solar technologies whose primary installation objectives are for electric and/or thermal power production and reduction/elimination of pollutants from fossil energy input in power utilities. Solar thermal devices are further classified into concentrating solar technologies, which focus the solar radiation from large field area on to a small area where the thermal energy absorption material is placed, and the non-concentrating technologies (usually flat plate solar collectors).

The solar photovoltaic component converts the solar energy (radiation) directly to electric power without intermediate heat generation especially if the system is made from non-concentrating PV systems. However, modern PV modules manufacturing has included concentrating photovoltaic thermal (PV/T) cells which concentrate large solar radiation on a small solar cell with a view to producing higher electricity and increased efficiency. Such systems are usually cooled by cooling technologies that extract thermal energy produced by the effect of solar concentration. They can be applied where both electric and thermal energy production are required.

Over three decades now, solar thermal electric power plants (STEPPs) and PV systems have been operating in areas with suitable solar resource to support these technologies. There is a worldwide rapid growth in solar power installations except for solar chimney.

1.1.1. Solar photovoltaic

Solar PV owes its origin to the discovery of photoelectric effect by Alexander-Edmund Becquerel in 1839 when he observed that electric currents were produced from some light induced chemical reactions and were further observed by scientists some decades later [1–3]. About the late 1940s, the development of the first solid state materials paved way for the first industrial production of solar cell of 6% efficiency [1,3]. This gave rise to solar cells whose physics and research over the years have given rise to the manufacturing of electricity-generating solar modules and panels. The earliest solar cells are made from silicon while new materials such as: Cadmium telluride (CdTe), cadmium sulphide (CdS), indium, Gallium arsenide (GaAs), copper cadmium telluride (CuCdTe), copper indium diselenide ($CuInSe_2$) and titanium dioxide (TiO_2), organic and polymer materials, are being explored for high efficient and cost effective solar cells production [1,4–7]. Thin film technology is also widely applied nowadays alongside deposition techniques in the manufacture of hybrid solar cells [8].

PV generates direct current (DC), electric power measured in watts (W) or kilo Watts and has the potential of being assembled into large capacity electric power for grid connection. Compared to other solar power technologies such as CSP and solar chimney, PV can easily find applications in grid, off-grid-small-household and rural electricity projects. It is the most common approach to solar energy conversion to electricity. The systems are rated in peak kilowatts (kWp), being the expected amount of electrical power that a PV system should deliver when the sun is directly overhead on a clear day [4]. As shown in Fig. 2,

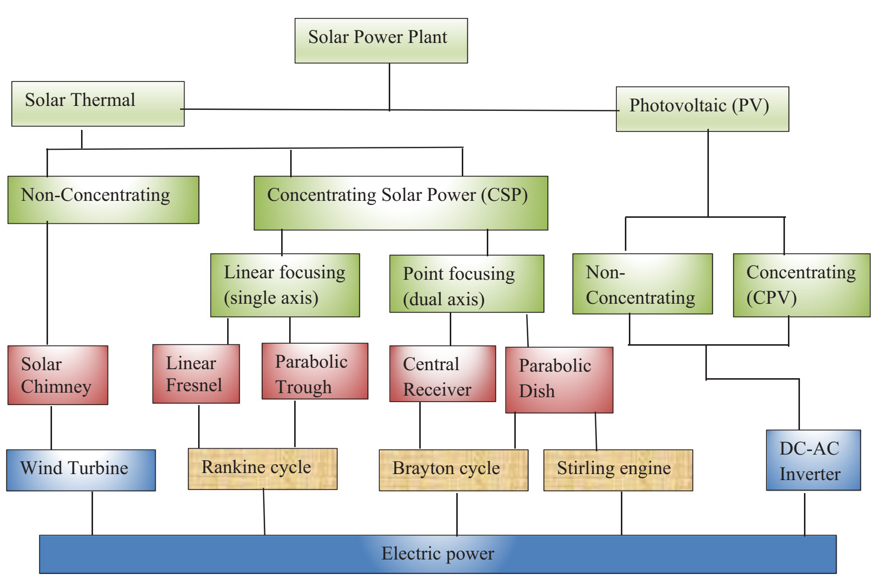

Fig. 1. Classification of solar power plant.