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# Integrated design and construction of a micro-central tower power plant

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A B S T R A C T

Concentrating solar power is considered as one of the promising ways for future sustainable electricity generation, especially in the Sahelian region, which is characterized by hot and sandy and high direct solar irradiation, but also a very low electricity access rate. This paper presents a design of a micro-central tower power plant of 10 $kW_e$ for Sahelian countries. The project reported here is specifically focused on a micro-concentrating solar and power project in Burkina Faso. It is designed to address energy access challenges in rural areas in the Sub-Saharan region, using central tower technology. The design of the power plant was thought in such a way to make locally possible the manufacturing of most of the components: local mankind and local materials are promoted and valued. We named after such a power plant CSP4Africa in this paper. The appropriate design, evaluation and selection methods are reported: solar field and its component design, solar receiver, conversion loop selection, thermal storage concept, storage tank design, heat transfer fluid, solar tower, etc. Some challenges faced during the design of CSP4Africa are also reported. Most of the components of the power plant have already been designed, built and under tests before their assembling for the pilot.


## Introduction

Electrification rate in Sub-Saharan Africa is about 32% (International Energy Agency (IEA), 2014) in average with high variation from one country to another. The situation is worse in rural areas (rural electrification rate: 16% (International Energy Agency (IEA), 2014)), where about 70% of the population actually lives. Recent studies indicate that, in this region of Africa, it is essential to make provision specifically for increasing rural electrification before embarking on large-scale privatization (Onyeji et al., 2012) in order to significantly facilitate the electricity access to the poor. In West Africa for instance, reforms in electricity sectors had, in best cases, no effects on the increase of electricity access to the poor; the main reason was the government's lack of commitment to support clearly rural electrification development (Onyeji et al., 2012). The strong links between energy access and millennium development goals, especially the connection between energy services and development, public health, gender empowerment, and the degradation of the natural environment and corresponding dramatic consequences of energy poverty as presented by Sovacool (2012), crucially evidence the need to address the challenge of the provision of energy services in Sub Saharan Africa (Adkins et al., 2012). Solar energy could contribute to increase the rural electrification rate with off-grid or micro-grid systems, which appears to be the future of sustainable electricity supply systems, especially in Sub-Saharan countries (Onyeji et al., 2012). Solar energy could allow reducing the energy dependency in many countries, especially Sahelian ones, which use diesel thermal plants and are therefore strongly depending on imports of petroleum products (up to 70% of GDP for Burkina Faso).

For electricity generation, solar energy may be converted via two main different ways: photovoltaic (PV) technologies and concentrating solar power[1] (CSP) technologies. Currently, PV manufactures could hardly be identified in Africa: only few PV manufactories could be identified in South Africa or Senegal where imported cells are assembled. So, from Africa, there is no large room to work on electricity generation cost via photovoltaic technologies.

CSP technology is considered as one of the promising ways for future sustainable electricity generation. Many African countries, especially in the Sahelian region, show high potential for CSP plants because of high direct solar irradiation (Azoumah et al., 2010): Africa is located in the

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[1] Solar thermal electric technology.

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heart of the solar belt (Fig. 1). However, to-date, CSP technologies have been shown to be economically viable only for large power plants (10–50 MWe (Py et al., 2013)), thus requiring high investment costs. The initial cost ranges from 2,500 to 12,500 US$·kW$^{-1}$ (Ziuku et al., 2014). This initial capital cost, combined to the technology is considered as the two main barriers to CSP development in developing countries (Amer and Daim, 2011; Ziuku et al., 2014). Therefore, many Sub-Saharan African countries could not invest in so high cost power plants. For instance, about US$600 millions (CSP World, 2015) were necessary for the construction of the Shams solar power station in Saudi Arabia: this is more than 15% of the State budget of a Sahelian country like Burkina Faso. Furthermore, there are a large number of remote areas requiring relatively small power plant capacity and decentralized energy systems are seen to be one of the most relevant future energy systems options (Onyeji et al., 2012). It is also worth noting that the skills required for the implementation for such power plants are not currently well spread throughout Africa. That is why we choose to investigate the feasibility of a micro-CSP (μ-CSP) plant in Sub-Saharan Africa by analyzing the system through various aspects such as capacity building, economical and technical issues. We aim at developing a cost-effective μ-CSP plant for decentralized micro-grid by designing and experimenting their components using local low cost materials.

In this paper, the design simplification of the power plant is reported. The design is thought in a way to make possible the manufacturing of most of the components by local mankind using locally available materials. Some challenges faced and options made in the curse of the project are also reported. All the main components of the power plant and related issues are addressed.

## Existing μ-CSP projects in the world

Five CSP technologies are available today: concentrating photovoltaic (CPV) and four common CSP technologies, which are parabolic trough, dish parabolic, linear Fresnel and central receiver system or solar power tower (Fig. 2). Concentrated solar thermo-electric technology is an emerging technology that is at an early stage of development (Barlev et al., 2011). Parabolic trough is so far the most mature technology and more than 95% of installed large scale CSP plants are built upon this technology. Solar tower technology is the second most matured technology and represents the next alternative to parabolic trough for the following advantages (Zhang et al., 2013):

- Low thermal energy storage costs due to the high temperature increase in the solar receiver compared with parabolic trough since the required mass and volume for the storage material and facilities are lower for a given amount of energy to be stored. Furthermore, the technology is foreseen to be the cheapest CSP technology by 2020.
- The position of the whole piping system and eventual thermal storage tanks next to the tower: this reduces the size and the length of the piping systems and therefore also energy losses, material and maintenance costs.

The number of μ-CSP projects, existing plants or projected plants for electricity generation, is very limited. We have conducted a literature survey on power plants with an electric power output of less than 500 kW. Only about ten projects have been identified worldwide as presented in Table 1. It appears that the maximum power output is actually 100 kW for small scale plants (Table 1).

Apart from SPS from EPFL (academic demonstration plant) and AORA Solar (commercial plant), all the identified projects are dealing with parabolic trough as it is the case for large scale CSP plants. Indeed, μ-CSP are mainly designed for low/medium grade temperature heat source (≤200 °C for all the identified projects) and point focus technologies are usually for high temperature heat output. In addition, only one-axis tracking is required for parabolic trough. For focus technologies, two-axis tracking is required. This tracking aspect leads to a more complex and eventually costly design and maintenance issues.

Almost all these μ-CSP use an organic Rankine cycle (ORC, Table 1) for the conversion loop since these conversion cycles are more relevant for low temperature heat sources. The listed projects are those involving electricity generation.

## General considerations and preliminary choices

Among the four CSP technologies, parabolic trough and dish technologies require curved mirrors while linear Fresnel and solar power tower technologies use flat mirrors. Because flat mirrors are easily available on

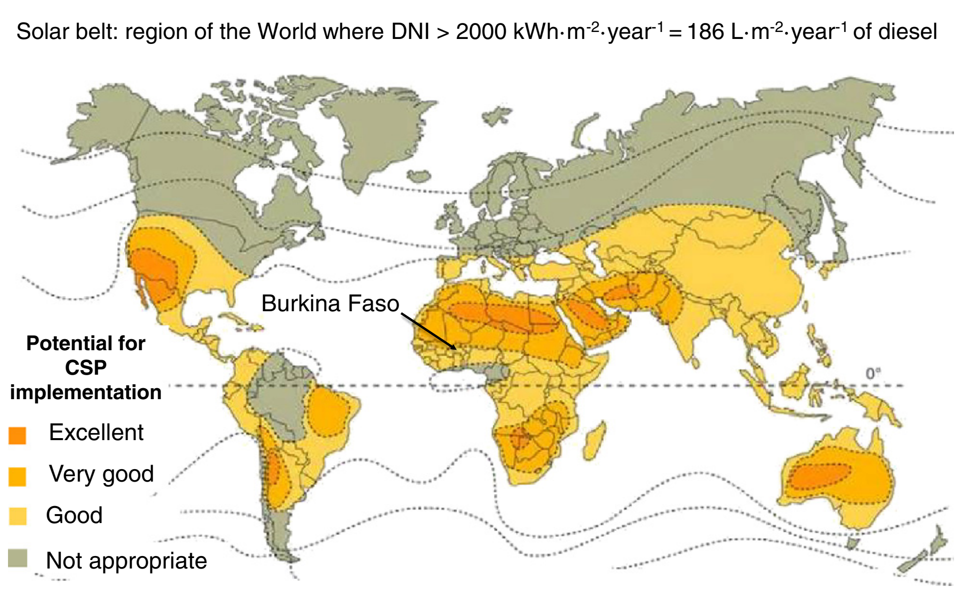


**Fig. 1.** Regions of the world appropriate for concentrating solar power.
Source: Solar Thermal Power, European Commission, Directorate General TREN cited in World Energy Council (2004).