Paving the Way for Energy Efficiency through Solar Power Projects in Zambia

Shadreck Mpanga[1], Mwansa Kaoma[2], Ackim Zulu[3]

[1,3]Department of Electrical and Electronic Engineering, University of Zambia, Lusaka
[2]Department of Agricultural Engineering, University of Zambia, Lusaka

Abstract— *At present, there is great pressure to meet the national electrical energy demand on the existing power system network in Zambia. The situation has been made worse due to reduced rainfall received in recent years as the country has mostly depended on hydroelectricity generation for many years. The 2015-2016 rain season saw little trickling of precipitation too due to the El Niño effect, with results of reduced rainfall over much of Southern Africa. In addition, the 2015 hot dry season turned out to be the hottest season Zambia had ever experienced, and led to high evaporation losses from open surface water bodies. This resulted in load shedding across the country thereby affecting households, business houses and the mining operations. All these are consequences of climate change. In harmony with the historic climate agreement adopted in Paris on December 12, 2015, this paper reviews how solar energy can help mitigate the effects of climate change and thus contribute to the national electricity mix in Zambia by increasing the power flow in the existing infrastructure as far as possible. By means of a comparative study, the merits and demerits of using photovoltaic technology for large scale electricity generation in Zambia are highlighted. In light of this, the potential of solar energy to contribute towards industrial energy efficiency in Zambia is assessed. The paper also advocates for increased research on renewable energy technologies.*

Keywords—Energy efficiency, climate change, households, industries, solar energy.

I. INTRODUCTION

At present, there is great pressure to meet the national electrical energy demand on the existing power system network in Zambia. As more than 95% of generated electricity in Zambia has been from hydro for many years, the reduced rainfall activity seen in recent years has led to low power outputs from the generation stations. Thus, the low water levels in the two major reservoirs used for hydroelectric generation at Kafue Gorge Power Station and Kariba North Bank Power Station have resulted in load shedding, the level of which has never been experienced before in the history of Zambia. For instance, as of December 2015, out of the installed capacity of about 2,300 MW, Zambia could produce only about 1,100 MW against a national demand of about 1,600 MW, with the peak demand being around 2,000 MW [1]. The 2015-2016 rain reason was worse due to the El Niño effect and this led to suppressed rainfall over much of Southern Africa [2]. In addition, the 2015 hot dry season proved to be the hottest season Zambia had ever experienced, which led to high evaporation losses from open surface water bodies. The status of Kariba dam as of March 2016 is depicted in fig. 1 where the sea floor close to the river bank in (a) is exposed and the water level dropping from the brick-wall fence is clearly seen in (b).

(a) Sea floor exposed *(b) Water level drop*

Fig. 1: Lowering water levels in Lake Kariba as of March 21, 2016 (Source: University of Zambia)

The picture in (a) above was taken at Bay Hill lodge whereas the one in (b) was taken at Manchinchi Bay lodge. These two lodges are only a few kilometers apart and are on the same side of the seashore. This is the time when the lake is supposed to show improvements in water levels since it was towards the end of a rainy season. As a result of little rainfall received in this period, load shedding still remained critical. It was anticipated that the lake would fill up a bit when flows from upstream come into the lake by May or June. In any case, the current water levels explain why the regulatory body, the Zambezi river authority, says it would take three good rain seasons to fill up the lake. The 2015-2016 rainy season was poor.

In fact, worldwide people have become concerned about the supply of energy available to man. Electric power cuts, black outs, long lines at gas stations have made "energy crisis" a household name. One may wonder, is

the earth's supply of energy running dangerously low? The answer is **NO**, because the **SUN** is the principal source of energy for the earth. The sun is an enormous clean and infinite source of solar energy. No wonder governments worldwide are turning their attention for new energy solutions to solar power. Just think of it, the sun's energy can be used to heat our homes, operate our home appliances, light our cities, drive our vehicles or fill any power need we may have. In Zambia, through the National Energy Policy (NEP) of 2008, the authorities have recognized solar energy as an important contributor to the energy mix.

Many water bodies, rivers and lakes, in Africa are affected by climate change, leading to droughts and increase in air temperatures that cause higher evaporation of water [3]. Countries like Zambia that mostly depend on hydropower get affected in such situations. Thus, this paper is a review on how households, business houses and industries can take advantage of the abundant sunlight in Southern Africa and use it to light our premises, operate our home appliances and drive our machines. Energy efficiency practices are emphasized throughout the paper.

II. OVERVIEW OF PV INSTALLATIONS AROUND THE WORLD

Concerning the shift to solar energy, one challenge in the Southern African Development Community (SADC) is to do with the change of the mind set. Many people still believe that it's the power utility company's responsibility to supply electricity to them. They don't want to generate their own electricity and be independent from the utility company. In the SADC region, only South Africa has more Photovoltaic (PV) power projects than any other country and a good number of people there are willing to be independent from the utility power companies. The situation is the same in western countries like United States of America (USA). Individual households are able to generate their own power from solar energy and feed the excess to the utility [7,9]. The electricity bill they get at the end of the month is then based on net metering. Net metering is a billing mechanism that credits solar energy system owners for the electricity they add to the grid. The SADC region has a lot to learn from these countries, especially when it comes to large scale PV installations. Zambia plans to generate a total of 600 MW of electricity from solar energy in the foreseeable future and feed it into the national utility network. Looking at large PV installations worldwide, this is possible since Zambia has good insolation per year pegged at about 2,200 kWh/m^2. Table 1 shows some selected installations from around the world.

Some of the installations, e.g. Solar star, in Table 1 are connected to the utility network and it's a good learning point for countries in Africa that have plans of integrating PV installations with the existing utility networks. So, Zambia has a lot to learn from these installations through consultancy and research [5]. For stand-alone systems, it can be learned that if battery storage is used, there is an advantage in that these systems reduce the cost of building and maintaining a distribution network. This approach in turn reduces the cost of a bill to be settled at the month end.

Table 1: Selected PV installations around the world [4]

No.	Name	Country	Capacity [MW]	Year completed
1.	Longyangxia solar park	China	850	2015
2.	Solar star	USA	579	2015
3.	Topaz solar farm	USA	550	2014
4.	Desert sunlight solar farm	USA	550	2015
5.	Huanghe solar park	China	500	2014
6.	Copper mountain solar facility	USA	458	2015

III. POTENTIAL FOR PV INSTALLATIONS IN ZAMBIA

Zambia has good insolation per year of about 2,200 kWh/m^2 and the situation is comparable in the SADC region. This gives a good opportunity for regional data sharing so as to learn from one another. The calculations below show approximately how much solar energy strikes the Zambian soil per year.

$$Hours/year \approx 8760$$
$$Daylight\ hours/year \approx 4383$$
$$Available\ sunlight\ hours/year \approx 2836$$
$$Insolation/year \approx 2200\ kWh/m^2$$
$$Area \approx 752618\ km^2$$
$$Total\ Power = 2200 \times 752618 \times 10^6 = 1{,}655{,}759{,}600\ \text{GWh}$$
$$Total\ Power = \frac{2200 \times 752618 \times 10^6}{2836} = 583{,}836.2482\ \text{GW}$$

Assuming we just manage to harness one percent of the total solar energy from the sun per year, then we

would have 16, 557,596 GWh. According to the WORLD FACTBOOK information as compiled by the CIA and shown in Table 2, Zambia produces about 8,000 GWh of electricity per year. One percent of the solar energy reaching Zambia's soil is about 2000 times higher than the energy from Zambia's conventional electricity. It is also about 3 times higher than what the world's most populous nation, China, produces per year.

Table 2: Yearly electrical energy production for selected countries [6,7]

Item	Country	Consumption [kWh]	Year
1.	China	5.523 trillion	2014
2.	USA	3.832 trillion	2012
3.	UK	319.1 billion	2012
4.	Zambia	8.327 billion	2012

3.1 PV Power for Individual Households

Assuming a home with the appliances shown in Table 3 and having a total load of 397 W, then 2×250 W solar panels, a 12 V, 150 AH battery and a 12/230 V, 500 W inverter should suffice to power these components. The stand-alone PV installation to be used in this case is as shown by the block diagram in Fig. 2. Energy efficient bulbs or motion detector bulbs should be used. Note that the components in the Table are AC loads and that incandescent bulbs are now banned in Zambia. For cooking, gas stoves are available on the market in Zambia and their price is competitive.

Table 3: Household electrical appliances

Item	Appliance	Wattage [W]
1.	PS4 Kit	90-150
2.	55" LED LG TV	67
3.	Home theatre	90
4.	Multi-Choice decoder	30-45
5.	3×15 W bulbs	45

One fact we have to keep in mind is that we may not need to use all these gadgets at the same time. For instance, when playing PS4 you may not need your decoder to be on since you will require the Television (TV) for your PS4, considering that there is one TV per average household in Zambia. In addition, old electrical apparatuses should be replaced with new ones. The energy saving could pay for the initial cost of replacement within a year or so. This exercise will also reduce the carbon footprint.

Given an economically rational household, investing in battery storage can be a profitable venture for small residential PV systems [8,9]. The only challenge will be that when integrated PV-storage-systems become profitable for many Zambians, then the electric utilities will likely require increased investments in technical infrastructure that will support distributed electricity generation systems.

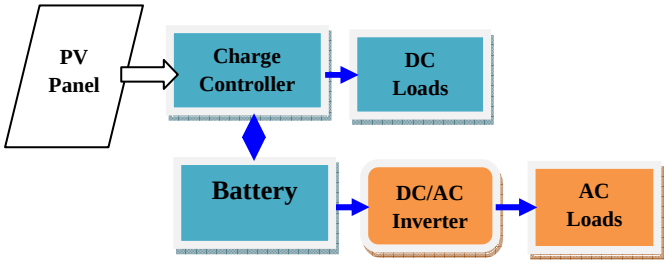

Fig. 2: Powering typical loads in a home from a solar panel

1.2 PV Power for small Communities

For small communities, it's important first to come up with the total load and then decide on the size of solar panels to install. The block diagram would still look like Fig. 2 but the realization may look as depicted in Fig. 3. The critical part is looking for energy saving appliances in all installations.

In establishments like Fig. 3, people are concerned more about entertainment. So, if their radios or Television sets are powered, that will make them content with life.

Fig. 3: Energy solutions for a small community in Namibia [10]

1.3 PV Power for Commercial Operations

Pumping of fluids is one of the common operations in many industries. Medium sized pumps for some industries can be powered by solar panels as long as there is good planning on the time when they are supposed to be in operation. Some common pumps are rated in the range of around 1 HP drawing power of about 1.2 kW for pumping operations. Industries with stable financial muscle can afford to install large PV panels to feed these pumps. The energy policy [11] now allows

interconnection with the existing utility network. So, during the night or when there is no sunshine, the utility power can continue to operate them. At the end of the month, net metering can be used for the bill that the energy consumer has to settle with the electric utility company. The concept is demonstrated in Fig. 4 where the maximum power point tracker is used to march the load to the power generated by the solar panels.

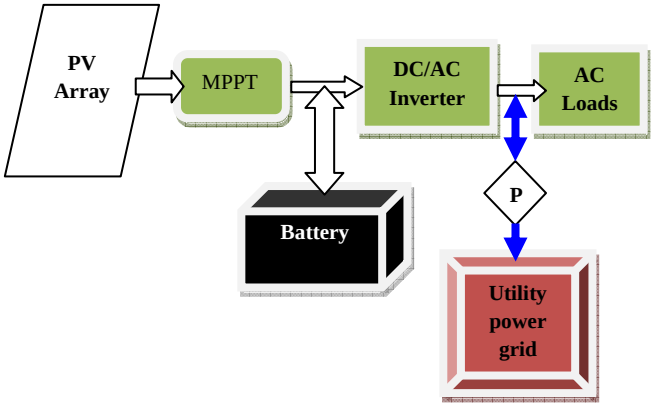

Fig. 4: Power conditioning, energy storage and integration with the utility (MPPT=Maximum power point tracker and P=Net metering)

In the event of grid blackouts, systems as in Fig. 4 will switch to "off-grid mode" and will draw power stored in the battery bank to power the apparatus and they will use solar panels to recharge the battery bank [8,9]. The other advantage of battery storage even for a grid-tied PV system is that electricity from the grid can be used to charge the battery bank in cases of heavy cloud cover or darkness. However, it must be noted that battery storage can significantly add to the cost of these installations. So, many consumers choose to bypass this component in their installations. The installation will still be profitable if it is planned that PV power will be used during sunshine hours and when there is cloud cover, utility power will be relied upon. This will still reduce the size of the electricity bill to be settled with the utility company.

1.4 Install now or Wait?

The truth of the matter is that many Chiefs' palaces around the country have been electrified with PV power already and many more will in future. Add to this list, some communities like Mpanta (connected to a 60-kW solar power plant) in Samfya district on the shores of Lake Bangweulu and many individual households already tapping into solar energy. Some households in Zambia do not experience the effects of load shedding because their homes, equipped with battery storage, have solar power throughout the day. Generating electricity using PV arrays is the most environmentally benign way of harnessing energy from the sun. This is one way of going green since climate change summits, the latest being the Paris conference held in December 2015, are intensifying ways of reducing pollution and global warming on our planet earth.

Solar energy falls on our roof tops, on the walls of our houses and in our backyards. All we need to do is go up the roof top or check the backyard for any obstructions and then make a plan for PV installations. The cost will be worthwhile especially in times of black outs. It's encouraging that the authorities [11,12] have also seen the need to go solar and according to Bloomberg news, those going solar will win big. In fact, high efficiency solar panels are now available on the market.

Studies [13] reveal that seasonal climate variability will continue to affect hydropower generation by reducing water run-off and reservoir storage capacity in dry years, and water overflow that can affect hydropower infrastructure in wet years. To mitigate such risks, they have recommended the integration of renewable energy sources other than hydro in the power generation plans in order to sustain future demand. Such an approach will require undertaking a thorough study on the renewable energy potential (including both technical and economic) in Zambia. Thus, increased research on renewable energy potential by both government and academic institutions is necessary to clearly understand all the technicalities related to PV power.

1.5 Demand Side Management

The government issued a communiqué banning the use of incandescent bulbs from 2016 onwards. This implied that only energy efficient bulbs would be allowed to be sold to customers in Zambian shops. Some of the bulbs which can be found now on the market have motion detectors, implying that they come on once they detect the presence of a person in the room. This is a very efficient way of utilizing electrical energy as it avoids wastage. The electricity utility company, ZESCO, carries adverts on national TV sensitizing people to switch off lights during the day and in the night when not needed. It also encourages the use of solar geysers as opposed to conventional electric geysers. For cooking purposes, gas stoves are now being preferred to electric stoves. Furthermore, the Government embarked on the installation of solar-powered milling plants across the country to avoid dependence on grid electricity. All these measures will reduce the burden on the national grid network.

Many shops across the country have ventured into selling many of the energy efficient electric appliances mentioned above and are at a reasonable price. High efficiency solar panels can also be readily found for those who want to set up stand-alone PV systems such as solar home systems. These come together with the necessary accessories like charge controllers, storage battery, DC or AC bulbs, DC/AC inverters, connecting cables, etc,

depending on one's preference. Suppliers like Muhanya Solar and Davis & Shirtliff Zambia are able to provide complete solar kits for water pumps. Many private and public premises have started opting for solar street lighting, just to avoid too much reliance on conventional electricity and thereby promote energy efficiency.

IV. CONCLUSION

This paper has reviewed a number of measures Zambia can take to mitigate the effects of climate change on the electricity supply industry. Due to reduced rainfall activity in recent years, the electrical energy supply has been severely affected. To combat the energy crisis, there are a number of projects embarked on such as bringing in a coal fired power plant for the first time in the history of Zambia, when the country has traditionally relied on hydro power generation. Since it has been recognized through the National Energy Policy that the use of renewable energy technologies can provide an alternative approach to combating the energy crisis, many people can take advantage of the sunlight that falls in their backyard to generate electricity. As of 2015, more than 200 households and 260 social infrastructures had been connected to stand-alone PV systems in Zambia. Energy efficient bulbs and high efficiency solar panels are available on the market and these should make it easy to light the premises. At the regional level there is a strong movement to embrace non-hydro renewable energy, as countries in the Southern African Power Pool (SAPP) have started to determine their grid capacity to accommodate renewable energy and policies to import renewable energy-based electricity, as can be seen in South Africa.

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ACRONYMS

[1] MW –Megawatt
[2] WFP –World Food Programme
[3] NEP –National Energy Policy
[4] SADC –Southern African Development Community
[5] PV –Photovoltaic
[6] USA –United States of America
[7] GWh –Giga-watt hour
[8] CIA –Central Intelligence Agency
[9] UK –United Kingdom
[10] AH –Amp-hour
[11] DC –Direct Current
[12] AC –Alternating Current
[13] PS4 –Play Station 4
[14] HP –Horsepower
[15] kW –Kilowatt
[16] SAPP –Southern African Power Pool