Solar Photovoltaic in Kenya

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PV technology has advanced significantly in the last decade and this has presented new opportunities in most economies but with attendant challenges. This topic review explores, from a renewable energy system implementation lens, the key barriers and solutions towards increasing the integration of solar PV in Kenya.

Keywords: technical ; economic ; institutional

1. Introduction

Currently, Kenya depends mainly on oil, geothermal energy and hydro resources for electricity production, however all three have associated issues. Oil-based electricity generation is environmentally harmful, expensive and a burden to the national trade balance. The rivers for hydropower and their tributaries are found in arid and semi-arid areas with erratic rainfall leading to problems of supply security, and geothermal exploitation has cost and risk issues amongst others.

2. Barriers to Increasing Integration of PV in Kenya

Barriers are categorized into four: technological, economic, institutional and political barriers.The advent of the PV technology in Kenya in the 1970s was mainly facilitated by donors and particularly in the 1980s, PV systems were donated to facilities such as health clinics that were off-grid [1]. During the implementation of PV in rural off-grid areas it was established that there was a market for PV technology beyond the scope of health clinics and off-grid missions [2]. Thus, within two years from 2000 to 2002, households increased the purchases of PV systems from 20% to 40% of total annual PV purchases. However, the benefits from the solar PV systems were mainly accrued by the rural middle class [3]. Consequentially, poorer rural households were sidestepped in terms of receiving subsidized PV systems [4].

With time, a focus on the rural affluent allowed the PV sector to be commercially viable without reliance on donors or subsidies. Specifically, in the 2000s, focus was on the middle-income segment, which was propelled by reduced costs of PV systems and a desire for the middle class to watch television [3]. These advances have led to the development of a considerable amount of PV systems being installed [5], however most of the development in Kenya has been in the form of stand-alone (i.e., off-grid) systems that are not connected to national grid. Thus, the PV market in Kenya has evidenced use of Solar Home Systems, which has been considered the most successful off-grid solar market in the developing economies [6].

2.1. Technological Barriers

Although PV technology has advanced significantly in the last decades, there are still several technical barriers to its adoption as highlighted in the literature. The quality of PV systems is of vital importance for its integration. Lack of adequate knowledge is a crucial barrier that may result in improper usage and inability to maintain the systems [7]. This may create a negative perception and prevent potential customers making a decision to adopt the systems.

A large technological challenge for PV in Kenya has been the lack of energy storage systems [8]. Meanwhile since Kenya relies largely on reservoir/dammed hydroelectric power supply, a PV-based pumped storage hydropower could offer an even more flexible solution to the variability of the residual production (demand minus non-dispatchable power production). Battery storage solutions also exist but the accompanying initial cost is high (though falling) for grid-connected systems hence research has pointed the need to look at development of hybrid systems combining solar PV with hydropower as a viable alternative option [9]. The storage requirement is of course dependent on both the composition of the rest of the electricity systems and on the share of PV. While a small share of PV can be integrated into the grid with no technical issues, large-scale integration of PV sets higher demands for the flexibility of energy systems.

Mathiesen at al. [10] identifies three phases of implementing RES. The first stage is the introduction phase where RES only marginally replaces production based on fossil fuels. The second stage is the large-scale integration phase where the integration of fluctuating renewables in the system becomes complex and where grid stability becomes an issue in the power system. The third stage is the full renewable energy phase with a complex system with suitable storage and conversion technologies to maintain the temporal balance of the energy system.

As the national Kenyan system is in the second phase—similar to most other countries in the world—the integration issues of large-scale integration are not faced yet, but a strong focus on PV will eventually bring the country there.

In this connection, the key technical issues that demand to be addressed when integrating solar PV on the grid include voltage level and point of common coupling, network voltage variations, power quality, voltage ride-through capability, reactive power compensation capability, frequency regulation capability and protection issues.

2.2. Economic Barriers

The main economic barrier for PV integration has been the high upfront cost and an unwillingness of banks to fund such investments [35]. The higher construction costs have previously made financial institutions more likely to perceive renewables as risky, lending money at higher rates and making it harder for utilities or developers to justify the investment. Perceptions of the (high) costs associated with solar PV can still be a barrier even if prices have come down considerably in recent years.

There have been efforts towards establishing the economic viability of solar PV in different regions of the world. A study focusing on the Middle East and North Africa regions concluded that rooftop PV systems were competitive with other energy producing plants in the region [9], however development has not followed suit. Nevertheless, a study in the Kenyan context confirms this. In [11] the authors used a levelised cost of energy evaluation and established that solar power in combination with other renewable energy generation technologies is competitive in relation to non-renewable energy. In spite of the high insolation levels, solar PV has mainly been used for off-grid application such as solar lanterns because of the high upfront investment costs of grid-connected solar PV systems [12]. However, currently, solar PV has been highly incentivized and prices have dropped significantly thus making it a viable option compared to diesel-fuel generators that are expensive to run [13].

Cost comparisons and competitiveness of solar PV with the conventional fossil fuels to electricity production are among the most significant barriers for adoption of solar PV in Kenya both for the utility company and for individual investors [1]. From the perspective of both the national utility company Kenya Power and Lighting Company (Nairobi, Kenya) and independent power producers, large-scale PV electricity generation without a well-functioning energy storage system maybe too expensive considering the fact these companies are also required to maintain the grid infrastructure and manage other running costs [6].

To mitigate these challenges, the incumbent could consider selling or leasing out PV energy storage systems, provide financing and grid connections or build a service relationship with individual investors. Once the domestic market grows, the installation costs will become cheaper; this could further be facilitated by training and certification of solar PV installers at the national level.

2.3. Institutional Barriers

The institutional barriers vary largely and are here grouped into four categories; (a) grid access, (b) research and development programmes, (c) university linkages and (d) policy experience from other African nations.

2.4. Political Barriers

Policy measures are of vital importance for large-scale introduction of PV. A lack of stability of incentives for the adoption of PV can be a significant barrier—for instance a sudden removal of existing subsidies or inconsistencies in policy measures.

Kenya has instituted policies meant to increase the integration of PV [14]. Particularly, among these policies is the Kenya Rural Electrification Master Plan [15], a Feed-in Tariff policy [16] and the Vision 2030 [17]. The government has also made a move towards ensuring that entrepreneurs willing to invest in solar PV are catered for [18].

As early as 2008, Kenya developed a feed-in tariff policy meant to ensure market stability for investors in PV. The feed-in tariff made it possible for independent power producers to deliver power from wind and hydro sources to the national grid. In 2012, the feed-in tariff policy was revised to also include solar power [12]. However, these policies have not translated to higher installed grid-connected PV capacity largely because the policies are not well coordinated during implementation or at worst, they are not implemented at all [14].

Under- or over-prioritization of investments in certain sectors in relation to others is usually not based on technical decisions but rather involves political choices and prioritizations. Large-scale PV projects are essentially large infrastructure projects that are typically highly political and that involve a multitude of actors with competing interests and negotiations across various levels. For example, [19] argue that the push for RE in Kenya is not necessarily being driven by environmental concerns, but rather by the need to provide access to electricity to the highest number of people within the shortest time possible. These authors highlight the tensions that come from pursuing the multiple objectives of 'growth', 'inclusiveness' and 'sustainability'.

3. Pumped Hydro Storage Solution

The shift from fossil fuel-fired power production to RES such as PV requires some form of storage or flexibility to cope with intermittency of the sources. A limitation with batteries is that they cannot offer multiple-hour storage capacity and discharge over a long time period. Moreover, batteries have a specific lifespan beyond which their performance is not guaranteed. Batteries also require ample housing space for large power output.

Pumped hydro storage (PHS) is a form of energy storage whereby gravitational potential energy of water is pumped from a lower reservoir to a higher one serve as a dispatchable reservoir to feed turbines on request [20]. PHS is the largest form of grid energy storage available; currently, PHS accounts for about 95% of all active and tracked storage [53]. The first PHS systems were commissioned in Alpine Switzerland, Austria and Italy in the 1890's. World-wide installed capacity stands at over 181 GW, of which about 29 GW are in the USA [20].

Modern PHS plants have a cycle efficiency of about 80% [21][22], and allow the utilization of excess electricity from base-load power sources (such as coal or nuclear) or fluctuating RES to be saved for use during periods of higher demand. Reservoirs used in these systems are generally smaller compared to conventional hydroelectric dams of similar power capacity and their generating periods are often less than half a day.

4. Modelling of Kenya's Future Electricity Grid

PV as a technology for electrification of rural Kenyan communities was modelled in [2]. The results showed that interconnecting a number of solar minigrids into one common grid leads to better technical performance. Moreover, the more minigrids connected, the better the performance and the more the power available for the national grid for supply to consumers.

A system-level model of Kenya was presented in [23]. This was used to assess the combination of PV and hydropower to displace diesel-based power generation. The research tested various generation mixes for the years 2012 to, and results obtained showed the value of high penetrations of PV exceeded expected feed-in-tariff payments.

In the work of [24], a spatially explicit supply model was developed to seek for a least-cost PV electrification model to connect consumers that are not served by the national electric grid. Information from individual consumer demand was used to develop this model. It was concluded from the results obtained that PV minigrids can serve up to 17% of the country's population. This includes due consideration for latent demands—i.e., demands currently unmet but which either grid expansion or access to PV electricity may stimulate.

In another study by [25] a rural electrification spatial model for Kenya was developed to identify various approaches to meet electricity needs for various places in the country. The analyses considered both diesel-based generators, various renewable energy sources and expansion of the national grid. Results obtained showed that renewable energy sources can play a key role in meeting energy demand for rural consumers.

Another study conducted in Morocco by [26], an energy management algorithm was modelled and simulated using MATLAB/SIMULINK to serve the load. The system is a grid-connected PV-battery which can manage its energy flows via an optimal management algorithm. Results of this modelling showed that the load was well served in all cases by instant solar production.

In Tunisia, research by [27], a grid connected PV system was modelled using a command approach to function under normal conditions and Symmetrical Grid Voltage Dips (SGVD). In normal operation mode, the command developed increased the low solar voltage to a suitable level corresponding to the Maximum Power Point Tracking. Under the SGVD, the control strategy should ensure stable connection as long as possible and inject more reactive power to support the grid faults. The modelled control scheme in the various operation modes presented high performances in transient and permanent phased. The system improved safety of the overall system and increased the connection time.

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