SASEC2015
Third Southern African Solar Energy Conference
11 – 13 May 2015
Kruger National Park, South Africa

DEMAND LOAD CURVES – AN IMPORTANT TOOL FOR ASSESSMENT OF PV DEPLOYMENT SUCCESS?

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ABSTRACT

The interaction of electricity supply and demand is important in the process of system optimization. There is never a perfect match but reduced mismatch benefits the functioning of the system. Too small supply relative to the demand increases the risk of collapse in terms of black-outs, and too large supply relative to the demand increases system cost. For small, isolated systems these supply-demand interactions grow in importance due to limitations in redundancy. Since photovoltaics (PV) has its major comparative advantages in off-grid systems and is often deployed in small, decentralized applications the supply-demand interactions are of large importance for successful PV deployment. Thus, knowledge of the electricity demand and its variations with various users and as a function of time at different time scales is a key for PV deployment success. In this paper, a range of issues relating to PV-supplied demands and loads are discussed.

INTRODUCTION

The interaction of electricity supply and demand is important in the process of system optimization due to the difficulties and large cost of electricity storage. In large-scale power systems the supply is following demand fluctuations through regulations of easily regulated power supply such as hydropower or gas turbines. In addition, these systems have a number of means to correct for mismatches between supply and demand at various time-scales. In less well-managed systems supply-demand mismatches leads to blackouts when the demand exceeds supply. Om the contrary, a too large supply relative to the demand increases system cost.

For small, isolated systems these supply-demand interactions grow in importance due to limitations is redundancy. Since PV has its major comparative advantages in off-grid systems and is often deployed in small, decentralized applications the supply-demand interactions are of large importance for successful PV deployment. Thus, knowledge of the electricity demand is a key for PV deployment success. In large systems with several demands, the resulting demand curve, as a function of time (daily or weekly) is smoothen out and demand peaks are usually less marked (still important though) while in small systems, or in systems with only one demand category, there are marked demand peaks leading to increased risk of technical collapse or a more costly supply.

This paper is focussing on solar energy for non-electrified areas of developing countries. In many of these areas there are obvious relative advantages of solar energy options due to high solar irradiation, high costs of grid extensions and low power demands. However, for the time being and due to reasons of scale and complexity, solar thermal plants are not an option for non-electrified areas in developing countries and, thus, solar energy can be applied through solar home systems (SHSs) or solar powered minigrids. Key characteristics of theses two solar electricity supply options are outlined below. The deployment of SHSs in the past has mainly been carried out in a large number of aid projects with mixed outcomes (a number of SHSs have been abandoned rather soon). However, recently, there are clear signs that in a number of countries SHSs have left the project support phase and are now being deployed through a rapidly expanding market. Solar power minigrids, on the contrary, are still few.

Advantages and disadvantages in general of decentralised generation, stand-alone options and minigrids compared to grid extensions have been addressed in number of publications (Kaundinya 2009, Mahapatra & Dasappa 2012, Blum et al 2013). Their general conclusion is that minigrids can be a cost-competitive option under a variety of conditions. Some studies have also focused specifically on PV supplied systems and compared the cost of PV supply to the cost of other electricity options (Nässén et al 2002, Chaurey & Kandpal 2010, Nfah et al 2007).

Kirubi et al (2009) addressed the benefits of a minigrid in terms of development, and .Millinger et al (2012) compared electrification through PV minigrids and SHS and assessed differences in development progress between the two options.

The issue of productive use, i.e. how electricity can contribute not only to human well-being, like the SHSs providing light and entertainment through the radio, but also contribute to income generation activities has been central in last years debate on rural electrification. It has been questioned that PV can contribute to productive use but actually the last years development has shown on a very rapid development of PV powered productive use. This has mainly happened through the deployment of PV for electricity generation for mobile phone charging. This business has almost exploded and many shop owners have started with a small PV array but soon added more capacity since the pay-off time is very short and thus the business highly profitable (Svensson & Farina 2010).

More recently, in some areas, possibly as a consequence of the rapid expansion of the use of PV for mobile phone charging, there are other business activities also increasingly being electrified through the use of PV. Examples are primarily low load businesses like bars, restaurants, shops, barbers etc. many of these seem also to be engaged in the seemingly highly lucrative mobile phone charging business.

OBJECTIVES

Based on the recent developments of productive use activities based on PV, it is the objective of the present paper to address some issues related to rural electrification through PV connected to the demand load and its variations at two different time scales, and to discuss how this could influence the adoption of PV for electrification.

The two time scales concerned are the daily time scale, i.e. the typical daily load variations, and a time scale of a decade, to address development of load with time. The paper is primarily a discussion paper but also presenting evidence and arguments based on a number of recent field studies.

DEMAND, LOAD AND TIME SCALES

An increasing amount of intermittent electricity supply (wind and solar power) requires a much stronger focus on the supply-demand match. The wind power supply is despite some by seasonal variation patters, very hard to predict. Thus easily varied back-up power as hydropower or gas turbines are necessary in the system.

PV generation on the other hand is characterised by some clear variation patters. The most obvious of these are of course the day-night variations but away from the tropics there are also marked seasonal supply variation patterns.

In most areas industrial countries with hot climates the peak electricity is due to cooling and thus is reasonably well matched with the possible peak PV generation. However, while the peak generation is around noon, the peak demand is often a few hours later. Thus, an adjustment of the orientation of the PV modules (if they are not sun-following) would give a better supply-demand match but would also lead to slightly reduced overall generation. The optimum orientation is system dependent and is ultimately a cost issue.

There is some recent work addressing supply-demand interactions for the case of PV generation in main grid systems. E.g. Richardson and Harvey (2015) are comparing various strategies of optimizing the capacity value (or capacity credit) of PV supply. They compared three different possible strategies; optimal orientation of PV modules, storage and site dispersion. The two first strategies involve energy losses and economic costs. However, the optimal solution is determined not only by the amount of energy losses and costs but also by the capacity value and depends on the amount of intermittent power in the system.

As mentioned above, in off-grid applications two different modes of PV generation are possible; SHSs and PV minigrids. SHSs are single household generation units consisting of a PV module, typically 50 Wpeak, charging a 12 volt battery and delivering a direct current (DC) output. Often a charge converter is included in the system to enable the use of alternating (AC) appliances. The SHS output is generally sufficient to drive low voltage appliances, such as a compact fluorescent lamp (CFL), a radio, a fan or a 12V television, for a few hours per day. A microgrid is composed of a small power plant and a power distribution network. A PV supplied plant has a number of PV panels charging a battery bank that is connected to a power conditioning unit (PCU), containing inverter and charge controllers. Both types of systems typically have an autonomy of one to two days to cover for cloudy days (Chaurey and Kandpal, 2010b).

Both types of systems offers advantages and disadvantages. Due to their centralized nature, microgrids facilitate maintenance compared to SHSs but due to the general lack of metering, unlimited electricity consumption can lead to excessive electricity use, resulting in faster battery degradation and system malfunctioning (Ulsrud et al., 2011). There are also management issues, which are not always easily resolved (Millinger et al 2012). Since SHSs are owned and operated by the households there is no possibility to increase electricity use other than investment in an additional and/or more battery capacity. Batteries have found to be a weak part of both micro-grid (Ulsrud et al., 2011) and SHS systems (Laufer and Schaefer, 2011).

Batteries provide the most simple, and normally necessary, option for load management for both SHSs and PV minigrids by storing sufficient energy to delay the demand load from the hours with day light to the evening when both light bulb and radios are used. Due to the abundance of solar home systems in some developing countries the optimal battery sizing based on most irradiation-demand profiles is today well-known, and the size of the batteries used for storage is optimized as to find a suitable optimum between cost and security of supply. However, when PV is used to cover other types of electricity demands, such as productive demands in small and micro enterprises, the demand picture is becoming more complex.

There is a considerable literature addressing supply side options in order to provide a better supply-demand match, including various kinds of hybrid systems, combining the PV supply with diesel generators. However, here, we will not address the supply but the demand and particularly the demand load characteristics at the daily time scale, i.e. the typical daily load variations, and a time scale of a few years, i.e. how the demand develops over time. The scientific literature is this field is very scarce (see e.g. Díaz et al 2011).

As mentioned above, the non-productive use related to most uses of SHSs results normally in a rather simple load curve, which now is well-known: there is almost no night load, a minor morning peak, hardly any load during the day, and a marked early evening peak when most of the electricity is consumed.

The new, productive use, on the other hand, results in very different load curve. Of course this depends directly on what kind of productive use that is causing the load.

Mobile phone ownership and use are spreading rapidly all over the world including the poorest areas of sub-Saharan Africa. Due to general the lack of electricity supply in this areas this has driven a rapid growth of use of PV for mobile phone charging. Typically village shops are offering the charging service and the profits results in very short payback times for the PV modules (order of months) (Svensson & Farina, 2010). Recent field work indicates that there are two load peaks related to the use of PVs for mobile phone charging, one morning and one late afternoon peak, corresponding to when people are leaving their homes in the morning and returning back home, respectively (Ho, 2025). Thus, this indicates a rather limited duration of the peak load, and it also indicates that the mobile phone charging peaks are not coinciding with the traditional SHS evening load.

Any broadening of the load peaks implies possibilities for a better utilisation of the system. As mentioned above, a too large capacity is costly, and any systems solution that could reduce the capacity requirement could contribute considerably to saved cost. Thus, this suggests the possibility that connections of different demands should grow in importance when the use of PV generated electricity is expanding form domestic to productive use. Further, this suggests that minigrids are to become relatively more attractive than SHSs, and the possibility of connections of SHSs into village minigrids.

However, so far this seems to be very rare (Ho, 2014).

Both the traditional domestic SHS demand loads and the new mobile phone charging loads are low load applications, and it is likely that the PV market will develop further based on other low load applications, rather than to include high load applications as milling and sawing. Low load applications in off-grid areas where PV is being increasingly used include various service establishments as restaurant, bars and barbershops (except for the traditionally donor targeted demands at schools and nursing clinics). With increasing PV deployment The variety of these various low load activities, indicates that this low load electrification would further contribute to the load levelling of the entire system (though not connected today in most instances). However, this also indicates strongly that connection of the various SHS distributed at village level would soon be a cost-efficient measure.

The connection of distributed SHS into minigrids also involves a number of non-technical issues such as ownership of the created minigrid, responsibilities for the operation, charging etc. These might seem as minor hurdles if sufficient cost savings are possible but hurdles of this kind have actually turned out to be the major obstacle to minigrid evolutions (e.g. Millinger et al, 2012).

A very different demand load issue is related to a longer time scale; the demand load development over time. Since the specific cost (per capacity unit) of supply additions are higher than initial installations, and in remote locations there are also a number hurdles and difficulties involved in supply additions, the initial load dimensioning is of great importance to avoid the risk of the supply system to be either over-dimensioned, and thus unnecessary costly, or soon becoming under-dimensioned, causing system collapse. Thus, knowledge of the development of the demand load over time is essential for an optimal system dimensioning. This knowledge is essential also since a widespread idea about an increasing demand in all types of applications is argument disfavouring PV installations since PV is often considered a first electrification measure to cover initial loads. However, there is very little knowledge of the development of the demand load with time reported in the scientific literature despite its obvious importance for off-grid electrification.

Díaz et al (2011) found an increase in demand for villages using a hybrid system including PV and diesel while demand of villages with only PV supply remained constant. However, it was not clear neither what was driving the development nor which other differences that existed between the villages in terms of economic activities. In a recent study, three different villages electrified over a time period of ten years but otherwise with similar conditions were studied in order to assess developments over time (Schmidt, 2014). It was obviously an increased demand over time in these villages but most of the differences between the villages could be ascribed to two factors; in the first electrified village traditional light bulbs were used for lighting while in the more recently electrified village modern light bulbs were used; and there was and increased used of fridges in the villages which have electrified for an extended time period. Despite these differences, it was concluded that there was only a very limited development of the load with time, and that this kind of time developments seems not to be a factor which should have a great impact on the choice of electricity supply option; it is likely that in most small villages without any major possibilities for a major demand increase such an increase is not going to occur. On the other hand, Ho (2014) reported that micro enterprises using PV for low voltage loads soon were planning to expand the PV supply due to increasing demand. While based on a very meagre data, this indicates a very different development of demand load with time depending on the use of PV, for domestic or productive use activities. Finally, this indicates the importance of another still unanswered question; if electricity supply is a prerequisite for economic growth or only supporting this growth.

CONCLUDING REMARKS

In this paper, by addressing evidence of recent developments of productive use, it is argued that good knowledge of demand curves and their development over time of various types of demand systems is imperative for commercial deployment of PV in productive use applications. Thus, research in the area should focus more on how demands and loads are developing as this might have a large impact on the cost-effectiveness of solar energy solutions with their high installation cost and low running costs compared to other electrification options. Due to this solar energy characteristic, minigrid solutions coupling various productive use demands may be attractive, and should be considered as a way of reducing costs.

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