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# Power availability and reliability of solar pico-grids in rural areas: A case study from northern India

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ABSTRACT

Solar micro-grids are receiving increasing interest in the electrification in emerging economies. On-site performance studies of these systems have become more important as the global market is being supplied with an ever-greater variety of solar power equipment with inconsistent quality. We studied the reliability of seven small identical low-power DC solar grids installed in real settings in villages in rural northern India. A detailed analysis of measurement data, interviews and field visits over a whole year showed that solar electricity was available to the households for 87% of the time. Along with technical problems, a share of the power shortages was an indirect cause of an illegal behaviour of users. The study draws attention to quality recommendations for energy access for consumers with modest energy needs.

## Introduction

Micro-grids are feasible options for electricity provision especially in developing countries with large populations without access to electricity [1]. India inhabits most of the people without electricity [2], or some 239 million persons, but this number is rapidly decreasing [3]. By definition, micro-grids involve small-scale electricity generation, which can function apart from the main grid and serve a limited number of customers [4]. Their capacity varies from small pico-scale systems below 1 kW up to several MW. Technically, micro-grids are able to use intermittent renewable sources such as photovoltaics in a way which does not jeopardize the reliability of local electricity supply [5,6]. In literature, micro-grids are considered as a reliable alternative to an erratic central power grid supply [7,8]. In the state of Uttar Pradesh (UP), which is the most populous state in India, centralized grid power in rural areas was available for 11 h per day in 2016 [9]. Power quality problems persist in the state, but the situation is improving [10]. Meanwhile, customers have reported notable satisfaction with micro-grid services in Uttar Pradesh [11,12].

The reliability of micro-grid services in low-income countries has received little attention in the past. A reason for this may be that micro-grids have been on the market for a short time, e.g. in Uttar Pradesh the first micro-grids were installed less than 10 years ago [13]. However, components with poor quality have been found e.g. in solar controllers, protection, and metering, but also the quality of installing work has sometimes been lacking [14,15]. Most of the technical literature on off-grid electricity actually focuses to the system planning phase [16,17], reporting on system simulations or on energy balance calculations. Ex-post analyses of off-grid energy projects mainly focus on the societal outcomes, but they rarely address real-life technical problems in detail, which would be important for improving such systems.

In this paper, we focus on investigating the reliability of small pico-scale micro-grids in rural Uttar Pradesh in India. Our study provides a unique analysis of real off-grid solar electricity systems, based on actual measurement data over a whole year. We assessed how well the engineering design managed in delivering uninterrupted electricity to the customers in the villages and analysed the technical and social reasons for the malfunctions and interruptions in electricity supply. We focus on the continuity of supply [18] and calculate the number and duration of the power outages. We also evaluate the reliability and availability of energy access of pico-grids according to the multi-tier matrix method of World Bank's Energy Sector Management Assistance Program (ESMAP) [19].

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## Smart low-voltage solar pico-grids

This study concerns seven solar pico-grids, which were installed in seven hamlets (small villages) in rural India near in the Unnao district in Uttar Pradesh. The installations were set up by Boond Engineering and Development, an Indian energy service company. The systems resemble a typical low voltage direct current (DC) distribution pico-grid, offering basic electricity services, mainly lighting and mobile phone charging, for households in villages without a grid electricity connection [20]. In 2017, some 1900 privately-run micro-grids could be found in Uttar Pradesh, most of which were of DC and pico-scale type [21]. Also NGOs and government institutions have installed DC pico-grids in Uttar Pradesh [13]. These systems served still only 0.1% of the people of this densely-populated state in 2017 [21]. Though the unit price of pico-grid electricity is several times higher than that of main grid electricity, the users save in their total monthly energy costs as they do not need to purchase kerosene for lanterns [20,22].

The seven rural hamlets selected in this study are small, inhabited by around 400–800 people each. Each grid connects 5–7 households, each with 7 persons on average. The hamlets are located in Safipur block, and 1–5 km from Chakal Wanshi village (26°41′16″ North, 80°24′12″ East, village code 141578) a distance long enough from other hamlets to make interaction between the people less probable (Fig. 1). Most hamlet villagers derive their main income from agriculture. Typical monthly earnings per household are 3000 INR per (46 dollars) [23]. The villagers have not had access to electricity in their homes before, but they have mainly used kerosene lamps for lighting and portable batteries or local service providers for their most urgent electricity needs, e.g. charging their mobile phones. The national power distribution lines have been extended to some of the hamlets in our study, but has not yet been available to the villagers.

The households connected to the pico-grids are provided with three LED light bulbs à 3 W, a fan, and a socket for connecting small electronic appliances (see Appendix A for the technical details and Fig. 2 for the grid configuration). In a typical pico-grid, the power would be available for 5–7 h in the evening [20], but in the pico-grids of this study, electricity is available 24/7, but limited to 30 Watts, which is controlled by an energy meter installed in each household (Fig. 3). The energy meters function in a pre-paid mode and the customers can buy energy credits from the operator, who puts the credits on the customer's 'energy stick', or dongle. The customer attaches the dongle to his/her meter and the credit is registered. The customers can monitor their instantaneous energy consumption and their remaining energy credits on the meter display. Lights on the meter indicate the currently valid electricity price, which varies dynamically according to the availability of the power in the battery bank. The electricity price is the same throughout the hamlet at all times and the price is sent to the households with a serial data cable. Further details of this dynamic pricing experiment and the effect of the changing prices on household energy consumption in presented in another publication [23].

The central charging station consists of PV panels with a capacity of 200 W and a battery bank of 120 Ah, which is centrally located in the house of the designated operator of the hamlet, who typically is a shopkeeper or another key person in the community. The operator is advised to clean the PV panels weekly. The general technical maintenance is handled by the system provider.

In order to ensure constant data recording, the energy meters were reconfigured to prevent the customers from turning them off. This reconfiguration was performed during a trial period of six months, and before the start of the actual experiments, as some customers were found to shut off the meters for the night because they thought the glowing light on the energy meter screen was consuming their energy credits.

## Methods

To test the power reliability in pico-grids, electricity production and consumption were measured in 7 hamlets with a total of 43 households. In addition, the customers were interviewed weekly for their satisfaction. Two field trips were made to observe the installations.

In the central charging station, the data logger recorded the following values over 5-minute intervals: date, time, solar panel voltage (in volts, V), battery bank voltage (V), charging current (in amperes, A), discharging current (A) to and from the battery bank and load current to the grid (A). In all 43 households, the energy meters measured and stored the date, time, power consumption (in watts, W), meter output voltage (V) and energy price range over 10-minute intervals. The values were measured both at the supply and the demand side in parallel.

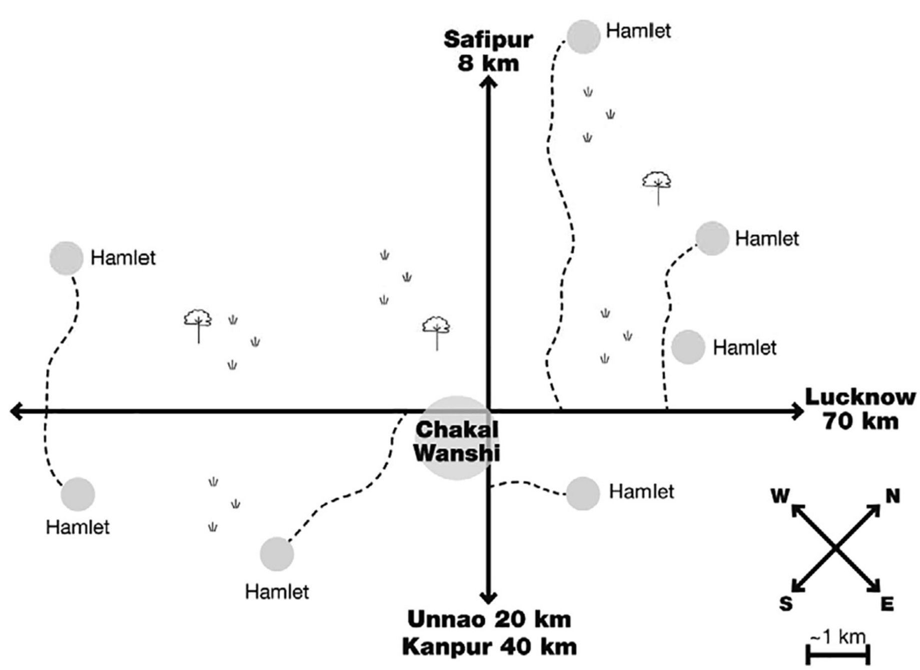


**Fig. 1.** Graphic showing the locations of the seven hamlets around Chakal Wanshi town in Uttar Pradesh.