

Jhunjhunwala, Ashok et al.

Conference Paper

Mobile Apps Making a Socio-Economic Impact for Managing Power at Underprivileged Homes

27th European Regional Conference of the International Telecommunications Society (ITS): "The Evolution of the North-South Telecommunications Divide: The Role for Europe", Cambridge, United Kingdom, 7th-9th September, 2016

Provided in Cooperation with:

International Telecommunications Society (ITS)

Suggested Citation: Jhunjhunwala, Ashok et al. (2016) : Mobile Apps Making a Socio-Economic Impact for Managing Power at Underprivileged Homes, 27th European Regional Conference of the International Telecommunications Society (ITS): "The Evolution of the North-South Telecommunications Divide: The Role for Europe", Cambridge, United Kingdom, 7th-9th September, 2016, International Telecommunications Society (ITS), Calgary

This Version is available at:

<https://hdl.handle.net/10419/148679>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

Mobile Apps Making a Socio-Economic Impact for Managing Power at Underprivileged Homes

Ashok Jhunjunwala, Prabhjot Kaur, Anusha Ramachandran, Sai Ram Mannar, Mrinalini Ramakrishnan, Sree Hari Nagarajan
Indian Institute of Technology, Madras India

Abstract: The paper presents how connectivity feature integrated into a roof-top solar power system, *Inverterless500*, designed and developed to electrify off-grid and near off-grid homes in an energy efficient manner, is critical in optimum service delivery, especially for lower income homes. It makes such products not only suitable for different categories of homes, but also economically viable, offering a promising business solution. Monitoring and manageability are unique features that help in maintaining the solution at remote areas of installation where manual intervention is not routinely feasible. The paper describes the technology and learnings gained from deployment of these systems that helped in improving the product and overall management process.

Keywords: BLE, cloud, data monitoring portal, Energy efficiency, Inverterless, mobile app, monitoring, power management, Solar-DC

I. Introduction

Almost half of India's 1.3 billion population has limited or no access to electricity due to myriad of reasons. Power shortages, that is imbalance between peak demand vs. supply, and challenges in extending grid connectivity were considered till recently as the primary reason for this. In the last three years, power-generation has outstripped demand-increase and considerable investment has been made to extend grid to homes. However, as brought out in a recent CEEW report [1], the main reason for limited and poor consumption amongst un-electrified homes could be affordability of power. The democratic compulsion drives state governments to impose below-cost tariff for domestic supply on Power distribution companies (DISCOM). DISCOM loses money as a result, and yet the low-tariff is still not low-enough to be affordable to the bottom 50% of the population. Hence, they just deny themselves even the minimum electricity usage.

Decentralized roof-top solar is often touted as a solution to the problems of power-shortages and lack of grid-connectivity. However, the conventional roof-top solar systems fail on the front of addressing affordability problem [2]. In fact, it accentuates the problem. The article suggests use of roof-top solar and DC power-line at home, coupled with DC appliances, greatly reducing the electricity cost to the consumer.

Inverterless500, a product designed to drive solar-DC in homes has been designed and commercialized. It has been deployed in about 4000 off-grid homes in desert areas of Rajasthan, India. It is important to note that the product, while deployed first in off-grid homes, is equally beneficial to homes with poor grid-connection (with hours of load-shedding each day) and reasonably good grid-connection. For the former, it will ensure that power is available even during load-shedding (known as 'black-outs' in India). For all homes, it enables bringing down of power-costs and making the homes green with efficient usage of power and solar-panel on the roof-rooftop. It is therefore likely that such solar-DC systems spread to most homes and replace poor-efficiency Inverters deployed today. One of the features of this product (and likely to be for all such products) is provision of a very-low cost indirect connectivity to the cloud. This

connectivity leverages the fact that mobile connectivity has surpassed the reach of the electricity grid in countries like India. The connectivity is crucial in enabling low-cost power especially using new and innovative technologies. It also enables the home-owners to better plan the power utilization and gets the DISCOM to understand the power-usage patterns in homes. With intelligence in the cloud, the connectivity would enable micro power-management, which could not have been envisaged till recently.

The paper will primarily focus on this connectivity feature of *Inverterless* and its enabling functionalities. The paper begins with an introduction to solar-DC system and the *Inverterless* product. Section 3 discusses how the low-cost connectivity is provided, enabling power-management even in the lowest-income homes. Section 4 discusses how this connectivity helps in power-management today and what its impact is likely to be in future. We finally conclude with some discussion on how much touted internet of things (IoT) needs to focus on problems like the ones described here to make a difference to the lives of disadvantaged people, rather than just focusing on problems of advanced countries.

II. Solar-DC System

With over 300 sunny-days in a year in most parts of the country, India appears to be in a unique position to leverage roof-top solar PV systems to overcome the challenges of power-access in its domestic sector, especially for its economically weaker half. However, inspite of a plethora of Government schemes and subsidies, such deployment has failed to take-off to any appreciable extent. A careful look shows that most low-income homes use very limited amount of power (less than 1 kilo-Watt hour or one unit of power per day). In a sunny country like India, a 200W solar panel would be sufficient to fulfill its daily needs. However, the solar panel produces DC power; even the battery used to store power uses DC power as its input and output. When connected to the AC grid in the home, such a solar-AC system has as much as 45% losses due to multiple AC to DC and DC to AC converters required as power flows from solar panel to AC grid and then to battery and finally back from battery to the loads on the AC grid [2]. This is in addition to the losses in the battery.

Further, the loads at homes are changing rapidly in recent times. All electronics uses only DC power. Lighting has changed to LED, which needs only DC power. With the advent of power-electronics Integrated Circuits, far more energy-efficient DC motors (like Brushless DC motors and Switched Reluctance DC motors) as compared to hitherto used AC motors have come into being. These motors use only DC power. This is changing fans (which now consume 30W instead of 72W), refrigerators, air-conditioners and all appliances which have motors. In other words, the appliances at home are quickly changing and would have preferred the home power-line to be DC. When powered on a AC line, they would each involve an AC to DC converter, which results into more losses besides the costs.

These multiple conversion losses imply that very little of solar power reaches the load, pushing up the cost of power heavily. Decentralized solar would never take off with such high costs.

A bold approach will be to use **DC power-line at home** powering the new-generation energy efficient DC appliances. The line would be powered by DC from solar panel and would directly connect to a battery. Only the power from the AC grid would have to be converted to DC. The problem with this approach is with legacy of 120 years, where AC power-lines have thrived. DC power-line would appear to be out of mind. However, with rapid changes in technologies, which promise to enable electricity-access to a large section of people who have been hitherto denied this, the leap has to be taken.

IIT Madras took this leap as it designed the solar-DC system, shown in Fig. 1. Inverterless500 drives the 48V DC Home Micro-grid and connects to a Solar Panel, a battery and to the power from the grid, converted to DC with minimal losses. This enables highly efficient usage of power as the DC Appliances and loads are directly powered by DC. These loads can be distributed among the Normal load and Emergency load by connecting these load types in different wiring loops through Inverterless500. The design was non-trivial as the solar MPPT voltage is not fixed but varies during the day, battery needs to be charged at voltages depending on its state of charge, and the load would need some fixed voltage. Using DC-DC converters to equalise these voltages will once again add to losses. Therefore, a careful design was carried out minimising losses and still maximising efficiency, even while keeping the cost low. 48V DC was chosen due to safety considerations (SELV voltages) and the fact that it would have lower cable losses as compared to the 12V or 24V DC systems.

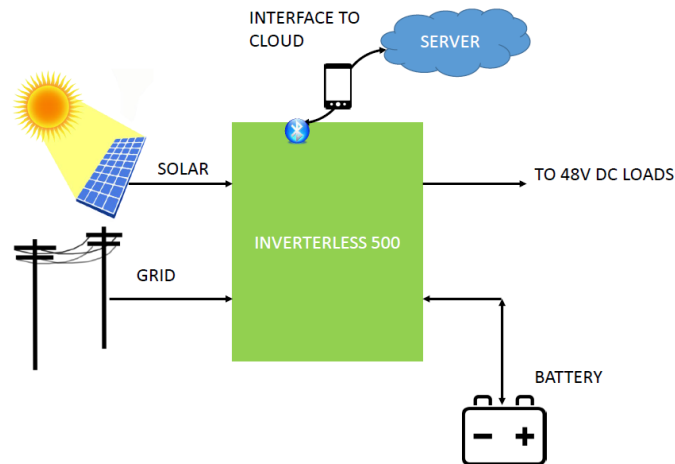


Fig 1: Block diagram of Solar DC system

These systems have now been widely deployed. 4000 off-grid homes in the desert regions of Rajasthan in India are powered using *Inverterless500*. Fig. 2 provides a glimpse of such deployments. Inverterless500 are also deployed in many on-grid systems, providing back-up power during load-shedding, reducing power-costs and making them green with highly energy-efficient appliances and roof-top solar panels.



Fig 2: Inverterless deployment snapshots from Rajasthan, India

III. Establishing Low-cost connection to the cloud

Inverterless500 uses a solar-panel as small as 125W, enabling it to become affordable to low-income homes. It monitors the input solar-power, the grid-power and power in and out of battery on a continuous basis. Similarly, it continuously monitors the power used on the main line and the emergency line. It also monitors State of Charge of the battery and voltage at each point of time. Such data could be extremely useful both for the customer as well as the service provider, if made available on the cloud. It would be a simple extension to add a data modem to *Inverterless500* to do this. However, the cost of this data modem would be comparable to that for Inverterless and would make it unaffordable to most low-income homes in India.

Instead a different approach is taken. The Inverterless is designed with a low-energy Bluetooth (BLE) interface. The additional cost is small. This enables Inverterless to talk to an external BLE device. Fortunately, most Indian homes have a mobile phone or at least access to it. Most of these phones have Bluetooth interface. An application on the mobile phone could have a two-way connectivity to the Inverterless. While the energy and related data from Inverterless can be periodically transferred to the mobile phone, the mobile phone in turn can transmit the control data to Inverterless obtained from the cloud, enabling it to be used in a whole variety of ways. The power consumption in BLE interface is small and does not take away much of the valuable solar power to operate. The only issue is that the bandwidth available may be small at remote areas (less probable that 3G/4G is available in scarcely populated areas), and therefore the monitoring/tracking/control application has to be designed to communicate only the essential. This also ensures least data usage, and hence lower data charges.

The mobile phone is equipped with GPRS and hence has data-connectivity to the cloud. Even if the mobile connectivity in a remote home is limited, the mobile gets connected to the cloud, as one moves with the mobile to areas with better mobile coverage. Thus the mobile phone acts as a relay device to establish either a real-time or a non-real-time connectivity between the cloud and the Inverterless. As the mobile comes within the vicinity of Inverterless, the application triggers a communication with it. Data from the Inverterless for the cloud is captured and data transmitted earlier by the cloud for Inverterless is delivered. Now as soon as the mobile phone comes into the coverage area of mobile data-connectivity, communication with cloud takes place, delivering to the cloud what Inverterless had sent and picking up from the cloud data for Inverterless. Fig. 3 shows this approach as the Inverterless and cloud gets connected using one hop.

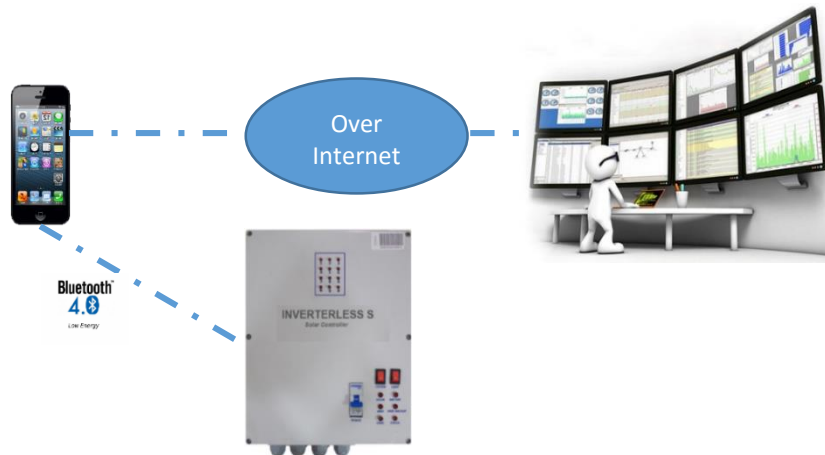


Figure 3: Inverterless to Cloud communication through mobile phone in one hop

IV. Leveraging Connectivity for Power Management

How does the data interface to Inverterless help? The data interface is used for two kinds of purposes. The first is for monitoring, while the second is for management or control / configuration setting.

Monitoring

The first role that monitoring plays is in determining health of the power systems and its components on a continuous basis. Fig 4, shows a working system with solar power being used to charge the battery and support the load during the day and battery supporting the load during non-availability of solar power. System data is continuously monitored and any inconsistent/anomalous data is indicative of system faults which are investigated and rectified. In early phase of product launch, the anomaly could be the result of a design deficiency. More commonly it could be due to specific behavior of a sub-system, which was not accounted for in the design. For example, the battery may be charging or discharging at a higher rate than envisaged in certain usage scenario. The time and duration of availability of sun varies from place to place. The usage pattern during different hours may vary from home to home and may also depend on geography. The power availability and blackouts would also vary from region to region. All this would impact battery charging and discharging. The design would take into account some of these patterns. Monitoring may show up new patterns, which may not have been taken care of in the design. The designs may have to be improved to take care of these new situations. Many a time, these changes can be made by a software upgrade. At other times, the power system may be forced into a limited operation state (for example the main line could be cut-off and only emergency line could be kept on) so as to prevent long-term damage to the system. At still other times, the configuration (for example, the size of solar panel or that of a battery) may have to be tweaked to provide desired service.

Another example of behaviour not captured in lab tests was brought out by monitoring field data from homes which lead the algorithms being modified. In some homes, it was observed that usage was very low and battery was almost always fully charged and the solar was repeatedly switching off/on. The algorithm was then suitably modified such that solar was turned on or off appropriately when usage was low/battery nearly 100% charged.

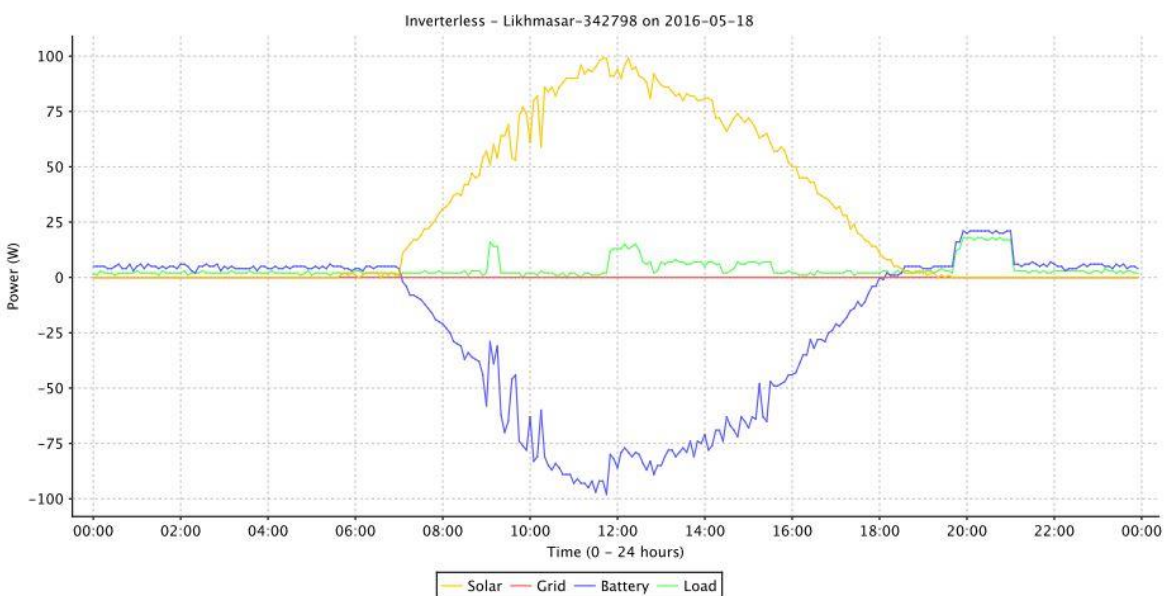


Figure 4: Monitored daya snapshot from a healthy system

Monitoring would also show that a subsystem is no longer behaving as per specifications or is simply reaching end of life (for example in case of a battery). Another aspect that comes out with monitoring is identification of tampered units. In such cases, replacement of the subsystem may restore the system health.

Another role that monitoring plays is that it gives to DISCOMs the power-usage behavior of customers. The behavior may vary from community to community or from one region to another. The usage statistics helps immensely in planning the power-network and generation-capacity required during different times.

So far we have talked about monitoring of system on the cloud by the service provider / designer of the system. Monitoring from Inverterless is done by individual customer using a mobile App.. It enables consumer to use own mobile device to track power consumption. The consumer then feels involved in tracking and monitoring of system. It allows consumer to plan and decide on usage of system so as to ensure continuous availability of power. It specifically helps user find out (i) her daily usage of power from different sources, (ii) extent to which solar power is being utilized and (iii) in case of grid outage, what would be the power availability to user from the battery storage. It could help user alter her usage behaviour, help them conserve power when needed and avoid wastage of power. For instance, if the grid power is not available, a user may dim the lights, or use limited power, so that the battery available could last much longer time.

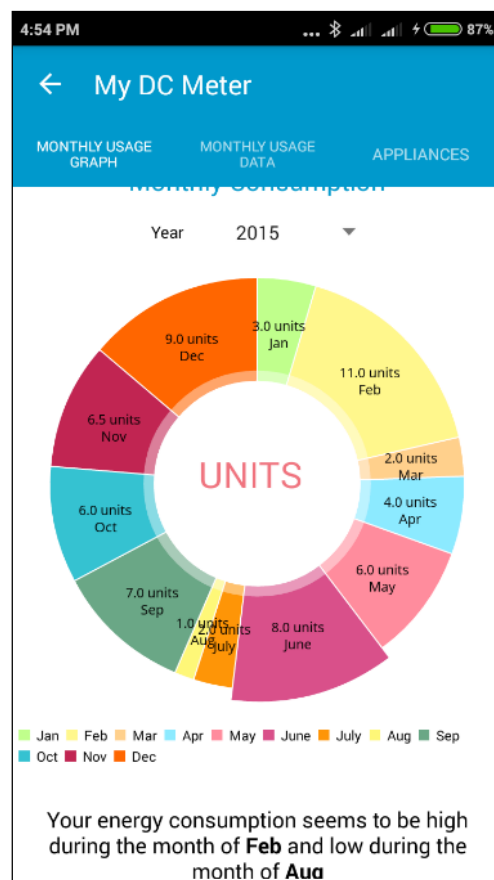


Figure 5: Energy consumed by a user, as shown on user's mobile App

Specifically, mobile app collects and sends data on energy available and energy consumed as shown in Fig. 5, which can be used to infer consumption patterns and size the system accordingly

1. The usage pattern of a system helps elicit the power requirement of that household and thus size the system accordingly. Observations show usage patterns in households where appliances are used minimally and 125W solar panel is sufficient, while in others, usage is high and requires larger solar panel and battery.
2. In some cases, it was seen from usage patterns that solar power was not fully utilized. Therefore, in homes that also had some grid power, the system is modified such that solar power is used to the maximum extent possible to charge the battery. In the evening, the battery is drained to a defined limit, so that solar power can be used the next morning to charge the battery. If battery charge falls below this specified limit during solar non-availability hours, only then, the grid is used to charge the battery. Since solar availability is dependent on the season, the limit can be set according to the month. These month-wise limits can be set using a BLE-based app, which also makes it easy to modify the limits as needed.

V. Management

Inverterless and its subsystems can be managed effectively through the cloud-mobile-app-Inverterless data interface. The Inverterless system has several configuration parameters like limits / thresholds for voltage, battery charging etc. Based on availability of grid power and solar power and usage patterns, among other things, the mobile application helps to set and modify these parameters to ensure efficient operation. For instance, the battery in Inverterless system operates only emergency loads when its state of charge (SoC) is low. Based on solar power availability at a location and load usage patterns in households, the SoC limit below which battery switches to emergency mode and the battery cut-off limit can be specified on the server and using the mobile application, these limits can be set/modified in the Inverterless system. The data interface can also help control the Inverterless system by determining the order of priority in utilising solar power, grid power and battery to operate the loads. At a location with abundant solar power, the mobile application can be used to accord it the highest priority such that loads are operated (and battery is charged) to the maximum extent possible using only solar power, and grid power is used only during solar non-availability or when battery SoC is nearing cut-off limit. This makes the Inverterless system highly adaptable.

The Inverterless system can also be shared by a cluster of homes which allows users easy access to power with limited OPEX. A number of households can share the fixed costs, including the most expensive elements, i.e. solar panels and battery pack. Since it is not likely that each home will use peak load at the same time [2], such a shared system is designed for average loads rather than peak loads. In this case, the mobile application facilitates effective and efficient management of Inverterless and subsystems by helping to monitor usage patterns and to implement usage limits and billing for individual homes. 'Pay as you go' models for Inverterless can be made available and easily administered using BLE application and mobile phones, such that households can easily select the most suitable option depending on affordability. A range of 'top-up' packages provides users flexibility in choosing how much power they pay for based on their requirements. The packages can also be designed such that users can choose to purchase credit for power only when they require it. Even if users do not purchase credit for a period of time, they can always resume it subsequently by just paying for a selected package without losing access

to power or by paying a re-connection fee. Therefore, the BLE application provides flexibility in managing power and power access for users.

VI. Conclusion

Nearly half of Indian population does not have access to quality power. Studies [1] reveal that lack of power and grid connectivity are not the only causes of this poor power access, but unaffordability is the biggest barrier. Even when power tariffs are subsidized, people are unable to afford electricity. An innovation is thus needed to develop an economically viable solution. Inverterless 500 Solar-DC solution offers a promising solution to overcome affordability issue to electricity access. The manageability and monitor-ability features of the system help in achieving the target. The system is packed with BLE for interacting with cloud through user's mobile App. We have seen the impact of the technology through our various deployments in Rajasthan, India. While the technology has enabled bringing a transform in lives of people, it has also paved way for adding more and more appliances as and when people can afford these. Exploiting the mobile app in monitoring these systems remotely has proved to be an interesting application of internet of things (IoT) which has helped in understanding the health of system and possible root cause of any error occurred in event of its failure. Remote management through this App has enabled in further improving the technology with no additional cost. Besides the technical achievements of this technology incorporation, the systems have empowered users through an opportunity to self-learn and control with ease in affordability.

The deployment of this technology has showcased the power of ICT in removing the dependency on manual intervention for sustaining such systems while making the access affordable.

References

- [1]. CEEW, "Access to clean cooking energy and electricity: Survey of States," Council on Energy, Environment and Water, New Delhi, 2015.
- [2]. Ashok Jhunjunwala, Aditya Lolla, Prabhjot Kaur, "Solar-DC Microgrid for Indian Homes: Transforming Power Scenario", *IEEE Electrification Magazine*, Vol 4, Issue 2, pp: 10-19. June 2016.