Enhancing Affordability of Roof-top Solar using Communications

Ashok Jhunjhunwala, Prabhjot Kaur
Department of Electrical Engineering, Indian Institute of Engineering, Madras, Chennai India-600036

1.0 Introduction

As high speed wireless communications reach every rural home and become more and more affordable, stage is set to unleash what communications, especially data communications promised all these years. The promise was that it would impact all sectors and transform lives, especially for the disadvantaged; it has yet to materialise [1]. One of the fundamental sectors it may impact is the energy sector, taking reliable power to each home. Electric power has become fundamental necessity of life; denial of lights, fans and electronics cannot be adequately understood unless one lives without these. Most low-income homes in many emerging markets get poor quality grid-power, with no power or power outage for large fraction of the day [2]. At same time, most of them cannot afford the cost of power, even with some subsidy [2]. This paper outlines an approach and associated technologies and concepts leveraging available communications, which can go a long way in overcoming such a situation.

The approach notes that most of the nations classified today as Emerging Markets, do not have much oil and gas [3]. They have coal, which is known to be polluting, or have renewables. Most such nations have significant solar incidence. This can be leveraged, especially as prices of solar panels fall rapidly and is less than that of conventional grid-power today [4]. Decentralized roof-top solar photovoltaic (PV) can become the most affordable solution, irrespective of whether grid is present or not. The affordability can be enhanced if it draws power from the grid, only when power is available at the lowest cost. This would require a communication link between electric utilities and homes. In fact, savings from such demand response system may pay for the communication expenses for low-income homes. Communication embedded to the systems also enables monitoring of roof-top solar system, while helping in optimal usage of power [5].

This paper presents possible early design approach and its cost-economics in section 2. Systems with such features have been deployed widely (about 10,000 homes) in states of Rajasthan and Assam in India as well as in several other states. The monitored data and the user-responses to such deployments are presented in section 3. The cost analysis for a small home is detailed in [6] and will be briefed in section 4. This will show that the cost savings for such deployments vary from 25% to 50%. The section also presents the approach to further reduce costs, by making the system grid-responsive, wherein it draws power from the grid, only when its costs lowest. Section 5 concludes the paper with a discussion on how this approach of using communications for decentralised solar deployment may lead to powering every home in not too distant a future.

2. Design Approach and cost-economics

Solar PV prices have fallen to as low as $0.25 per W for high volumes [7]. With some careful design, it should be possible to get balance of systems (systems required to install solar-roof-top and deliver power) at costs as low as $0.15 per W and keep the losses down to 10%, as discussed later in this section. Considering that the roof-top solar lasts for 25 years and balance of systems for 10 years, this amounts to about $0.04 per unit of electricity (kWh), assuming 10% interest rate as shown in Fig. 1. This is lower than grid-power, almost anywhere in the world. Besides, such solar roof-top system can be installed almost anywhere, where sun is available. This is indeed powerful.

TABLE 1: COST OF ROOF-TOP SOLAR PER UNIT OF ELECTRICITY (KWH) FROM ROOF-TOP SOLAR PV

Interest Rate	10%
Solar PV costs ($ per W)	0.25
Solar Life (years)	25
Solar Panels ($ per year per W)	0.028
BoS costs ($ costs per W)	0.15
BOS Life (years)	10
BOS costs ($ per year per W)	0.024
Total cost ($ per kW)	51.954
Solar Insolation (hours per year)	1500
Losses	10%
Cost per kWh	0.038

The problem comes from the fact that such power will be available only as long as sun shines and to the extent of its intensity. It cannot be used in the evenings and nights and power would be wasted if all of it is not consumed instantly. It helps if grid-power is available and roof-top solar is combined with it. Solar power can then be first used and the balance can come from grid. It is important that all the solar-power generated is used instantly and therefore solar should always be less than what is consumed. An alternative will be to feed excess solar power back to the grid, but this is difficult when solar used is small (most rural homes will need less than 500 W in countries like India).

The problem becomes more severe if the grid is unreliable, as is the case in most rural areas of countries like India. The only solution is to add a battery. But battery costs are humungous and can easily quadruple the per unit cost of electricity. The advantage of solar disappears. But when grid is unreliable and is cut-off, there is no other option (options like diesel generators, used at some places today, is even more expensive as compared to solar plus battery). So what should be the strategy? Use solar plus grid (to the extent available) plus battery as source of power. First consume solar power available and then use excess power to charge battery. Use grid to drive load, when solar power available is less than the load. Only when solar and grid are both not available, use battery. This will minimise the extent of use of battery and therefore the costs.

The approach may work. But when we start looking at the implementation deeply, we run into problems. Solar power generated is in form of direct current (DC) and it needs to be converted in the form of alternating current (AC) and combined with grid [6]. Again, an AC to DC converter is required when the solar and grid power is to be used to charge the battery as battery stores energy only in DC form, and yet another DC to AC converter when power is taken from the battery to feed the AC Loads. As losses in each of these converters is a minimum of 15% for small solar power (less than a kW), the total loss of the system would be nearly 45% excluding the losses due to battery. This queers the cost-economics of solar.

Noting that all appliance are also becoming DC and need to be powered by DC power-line or would use an AC to DC converter, which would further add to the inefficiency and costs, the answer, lies in moving to DC power-line at homes [6]. Solar, battery and loads would be directly connected to this DC power line and only a single AC to DC converter would be required for the grid. The approach, referred to as solar-DC, would minimise losses. The cost of solar power, when directly powering load will be comparable to what is given in Fig. 1. When powered through battery, costs would be closer to $0.16 per unit. But if the amount of power delivered through battery is only 25% of the total solar power, the average costs would still be closer to $0.07 per unit.

Now if we assume grid power costs to be $0.08 per unit, and power used is half from the roof-top solar and half from the grid, average price would be $0.075 per unit. This is not all. The solar-DC power line at home has assumed that one is using DC power appliances powered directly by DC power-line. Now such appliances save between 20% to 60% of power as compared to the conventional AC appliances. This would imply about 40% savings in energy used. Combining this with lowering of average costs, energy bill savings may be closer to 50%.

Thus Solar-DC system gives three benefits. It has potential of reducing power-bill to about 50% of the overall energy bill in lower-income rural homes. It provides power back-up for grid failure or load-shedding and enables 24 x 7 power. Further it enables decentralised solar to be used in every home, making every home green.

3. Deployments and lessons

A solar-DC system, called Inverterless, was developed by IIT Madras and commercialised by Cygni Private Limited. To date, over 10,000 systems have been deployed in off-grid and on-grid environment in India as shown in Fig. 3. The locations include deserts of Rajasthan in Jodhpur and Jaisalmer District, hills of Assam, villages of Tamil Nadu, Orissa, Telangana, Andhra Pradesh, Uttar Pradesh and Karnataka [8,9]. Most systems have been deployed with 125 or 200 Watts solar panel, 1 to 2 kWh batteries and include DC lights, fans and chargers for laptops. In select locations televisions, personal computers, air-coolers and mixers are deployed.

Monitoring is in-built in all these systems. Energy parameters including solar input, grid energy consumed, load energy and energy going in and out of batteries as well as state of charge of batteries every few minutes are stored in the memory of Inverteless. A general packet radio services (GPRS) port was to be installed in each system. But as this would have been expensive three years back, a Bluetooth modem was included. A mobile phone can read all energy data for the past 30 days using Bluetooth. This data is then relayed to a server [10] on the cloud. The data can then be analysed to figure out how the systems are working. This was found to be very useful at an early stage, as such complex systems do not often behave in the field as designed. The early analysis helped figure out all the faults and was used to improve the systems. Now, the communications and monitoring is being used to analyse the system behaviour and see if solar energy is being optimised in each location. It is possible to use the server – Internet - mobile-phone – Bluetooth – Inverterless500 link to also configure certain parameters in the solar-system, so as to optimise the energy usage depending on the load profile, solar-profile and the grid behaviour in each location. As GPRS prices fall, this indirect link via mobile phones will be replaced by a direct GPRS link.

Fig. 1 shows typical data obtained from a home in Belagwadi, Karnataka recently using the two hop Bluetooth – GPRS links. Here the grid was present but load-shedding extended to several hours a day. Inverterless with a few DC lights, a fan and a cell phone charger was added. The observed data shows that load usage is low. Fig.2 shows the data for a full week. Grid is virtually not used and solar power generation is less than what is possible. Power from solar panel does not get fully utilised, when usage is low and battery is full. A recent survey of the household revealed that most households are disconnecting the grid, as they do not want to pay any additional monthly charges. They appear to be happy with lights and fans and the fact that they now get 24X7 power. Fig. 3 shows some deployment pictures along with user comments about the system.

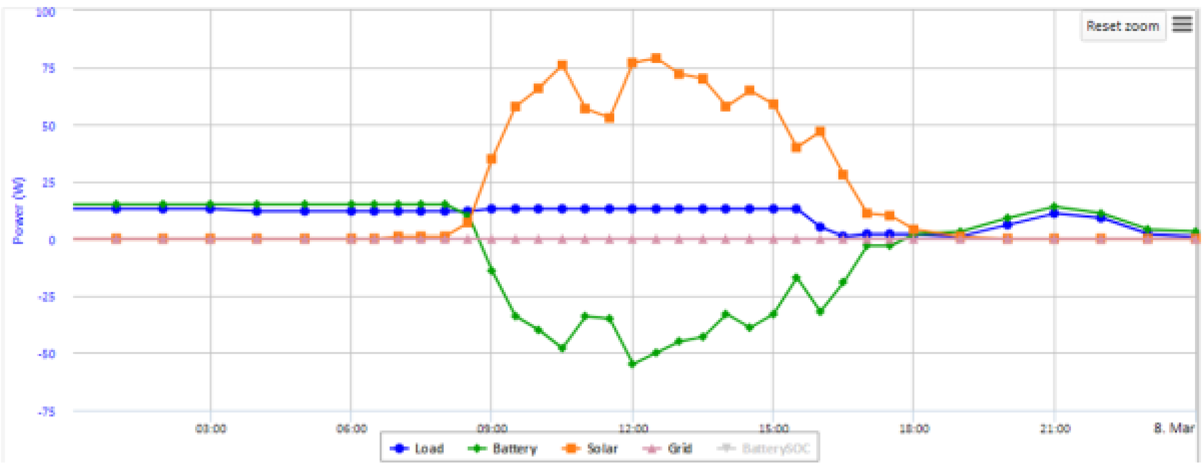

Figure 1: Power curve reflecting low solar withdrawal due to low load consumption

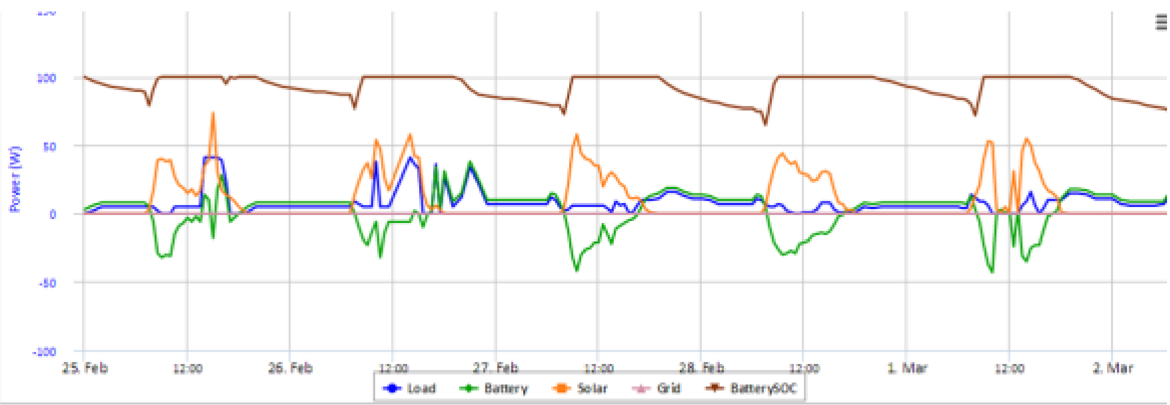

Figure 2: Typical power usage in Belagavadi along with battery SoC

"We do not have to worry about power cuts or kerosene lamps anymore. Because of this, life has become very comfortable"-Ramaih, a resident of Belagavadi

"This will make a huge difference to my children. They will now have a chance to study even in the nights and will have better lives" -Rema, Housewife in Belagavadi

"My family can now have the same quality of life as in the city with no power cut"
-Thimmaih, Resident of Belagavadi

Figure 3: Homes of the Beneficiaries of Inverterless system with their feedback

3.1 Study of deployments in Jodhpur, Rajasthan

Council of Energy, Environment and Water (CEEW) recently completed [11] a survey of 60 randomly households in Jodhpur Rajasthan, where Inverterless was installed about an year back. They carried out a baseline survey as well as survey after installation of system. The study reported marked shift from traditional sources (kerosene and wood) for lighting to Light emitting diode (LED) based bulbs and tuelights. Fans were considered as an important component of the service; about 30 per cent want to use them for 18 hours or longer, another 30 per cent for 9 – 15 hours, and rest of one-third for 5-8 hours daily. 75 per cent of the households stated that the system has led to a positive impact on their general day-to-day life, 80 per cent suggested a marked change in the ease of and the time of cooking, 70 per cent responded an improvement in their ability to carry out household activities and 76 per cent indicated a positive impact on children studying. "Over fifty percent of the sample households stated that they spent more time with family and others in the community. Almost all said that since the installation of the system, people would gather in the evenings or at night, to sit and talk or some men would play cards. One of the key aspects of any community intervention is its ability to build social capital. Prior to benefiting from the Inverterless system, most people would return to their homes post-sunset, as it was difficult to do anything without any light. With quality lighting, the social gatherings of people from the community could lead to an improvement in social capital and cohesiveness of the community, over time, increasing the probability of better development outcomes [11]."

4. Cost analysis

To analyse the cost benefits attained because of Solar-DC, a detailed case study was carried out using different use cases in Jhunjhunwala et all [6]. An efficient Solar-AC and solar-DC system were considered for a small home, each powering 2 fans, 2 tube lights, 2 bulbs, a TV and a phone, operated for 6, 10, 12, 4 and 10 hours per day. Other assumptions were made appropriately for the losses and efficiency for each subpart and energy route. Three separate scenarios were evaluated for each of the two types of systems considered, viz-a-viz: off grid homes, homes with 4-hour load shedding and homes with no power shedding at all. In all three scenarios, Solar-DC system clearly outperformed the solar-AC system.

For the off-grid home, the gains are huge. A comparison of the results obtained from these three scenarios for the two types of systems considered is given in Table 2[1]. The power is delivered to the loads with 91.4% efficiency for Solar-DC home as against the lower efficiency of 65.1% for Solar-AC home. Every day, one can save as much as 75% of the cost incurred on accessing power to operate the selected appliances by using Solar-DC as against solar-AC system. In the second case for home with four-hour load shedding, one lands up spending only 25% of the cost of a Solar-AC system. With the significant increase in the efficiency and much lower cost of electricity consumed, Solar-DC becomes an obvious choice for powering an off grid home as well as for the homes with power cuts. More power cuts bring in better alignment towards Solar-DC. Let us now discuss the case for homes with no power shedding. This is an ideal case for operating AC appliances with the Mains, attaining 100% efficiency (neglecting any wire losses for simplicity). However, this case typically highlights the benefit

[1] The prices quoted in this section is in Indian Rupees (₹) with $1 equal to about ₹65 in May 2017

of going towards DC appliances. The inherent property of improved efficiency or say lower power consumption with same or better performance of the DC appliances, helps in saving almost 60% electricity in the given case. An important point to observe is that the cost per day (₹12.6) for a Solar-DC off grid home is lesser in comparison to even the solar-AC home with No load shedding (₹16.3). This builds an understanding that an off grid home powered with a Solar-DC system is much more economically viable as compared to a home connected to an uninterrupted grid.

TABLE 2: COMPARISON OF A SOLAR-AC AND A SOLAR-DC HOME FOR DIFFERENT POWER SCENARIOS

Type of Home	Load/ day (Wh)	Off-Grid Homes		Homes with 4 Hour Load Shedding		Homes with No Load Shedding	
		Cost per day (₹)	Efficiency	Cost per day (₹)	Efficiency	Cost per day (₹)	Efficiency
AC Home	3266	50.6	65.1%	28.9	88%	16.3	100.00
DC Home	1212	12.6	91.4%	7.3	93.3%	6.45	94

While the cost-savings are indeed enormous, they may still fall below the affordability for a significant section of people in rural areas of countries like India. Communications can again be used to further reduce costs. As GPRS is likely to be included in future systems, this should be possible. The approach here would leverage the fact that power available on the grid varies throughout the day, especially as renewables (solar and wind power) become dominant. Further the demand varies in a day, with peaks around noon and in evening hours on most days. At nights power demand goes down considerably. In absence of storage on the grid, the generators have to back-off, so as to not generate excess power. As capital deployed for the generation plants contributes significantly to the power-costs, the backing off the generator increases overall costs of power. The operators would be willing to therefore give off power at much lower costs when grid power available is surplus, while they will charge high when grid-power is in deficit. This is often leverage by big industries today to reduce their total costs of power. With communications now available in low-income rural homes and solar-DC system deployment bringing in a battery (however small), it is possible to utilise this to the benefit of these homes. When the grid is surplus, the power can be drawn by these rural homes and used as well as used to charge the batteries. These systems can also avoid drawing grid power during its deficit state. In other words, the grid power used could be at lowest possible costs. This approach would bring down the costs of power in rural homes. As power supply on the grid becomes more and more reliable, the battery would be used less and less. It should be possible in years to come to reduce the overall costs of power in rural homes to as low as $0.04 per unit of electricity. Today the better off rural homes, who can afford to pay for 24 x 7 power use grid and diesel generator and spend as much as $0.25 per unit of electricity. The gains could therefore be enormous.

5. Conclusion

Time has come for communications to play a role in empowering lower-income and rural people of the world who have been hitherto left behind. Communication and internet of things need to be leveraged to provide education, energy, water, health and employment. This paper has focused on how communications, coupled with decentralised solar deployment can be leveraged to ensure affordable 24 x 7 electricity to each of these homes. Use of energy required for cooking has not been discussed here. In next few years, one would be able to innovate and come up with affordable solutions for cooking using electricity, with electricity being provided by solar-DC solutions assisted by communications. For newer deployments of these systems, the research group is working with the Government for bringing in special data packages to monitor the health of these systems, at rates much lower than what are offered by service providers for other services. In a very similar manner, one should be able to use communications to provide affordable and green power for irrigation and rural industries. Everywhere communications would play a major role taking us closer to the original promise.

6. Sources/references

1. Arturo Muente- Kunigami Juan Navas- Sabater. Options to Increase Access to Telecommunications Services in Rural and Low- Income Areas. WORLD BANK WORKING PAPER NO. 178. 2010.
2. CEEW, "Access to clean cooking energy and electricity: Survey of States," Council on Energy, Environment and Water, New Delhi, 2015.
3. U.S. Energy Information Administration (EIA) – U.S. Government – U.S. Dept. of Energy, September, 2011 EIA - International Energy Statistics. Available at : https://www.eia.gov/beta/international/. Accessed May 9,2017.
4. Sophie Weiner. Solar power is now the cheapest Power. http://www.popularmechanics.com/science/green-tech/a24357/solar-power-cheapest-energy/. December, 2016.
5. Michael Stadler2, Afzal Siddiqui3, Chris Marnay4, Hirohisa Aki5, and Judy Lai, "Control of Greenhouse Gas Emissions by Optimal DER Technology Investment and Energy Management in Zero-Net-Energy Buildings," European Transactions on Electrical Power 2009.
6. Ashok Jhunjhunwala, 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. http://ieeexplore.ieee.org/document/7480918/
7. Why Indian solar process will fall further, by how much and when. Available online: http://www.greenworldinvestor.com/2017/03/14/why-indian-solar-prices-will-fall-further-by-how-much-and-when/
8. Ashok Jhunjhunwala, "The People's Grid," IEEE Spectrum, Feb. 2017, pp: 45-50.
9. Krishna Shenai, Ashok Jhunjhunwala, Prabhjot Kaur, "Electrifying India with Solar DC Microgrids," *IEEE Power Electronics Magazine*. Volume: 3, Issue: 4, Dec. 2016.
10. Ashok Jhunjhunwala, Prabhjot Kaur, Anusha Ramachandran, Sai Ram Mannar, Mrinalini Ramakrishnan, Sree Hari Nagarajan, "Mobile Apps Making a Socio-Economic Impact for Managing Power at Underprivileged Homes," presented at *27th European Regional Conference of the International Telecommunications Society*, Cambridge, UK. 7th-9th September 2016.
11. Abhishek Jain, Aditya Ramji, Sarah Ashraf "Innovations for the Last Mile: Evaluating Prices, Performance and Perceptions for Decentralised Solar DC Electrification", New Delhi: Council on Energy, Environment and Water (forthcoming), May 2017.