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GUEST EDITORIAL

Solar-DC: India towards energy independence

Over the last few years, India has focused considerably on solar power. A vision of having 50% of electrical power from renewable technologies by 2030 is being put forward. But the focus is primarily on centralized power generation from solar photovoltaics (PV). There is talk about decentralized rooftop solar PV deployments. However, they are all subsidy-driven and so far have failed to make significant inroads into homes. To understand the reasons, let us take up a tangential issue first.

In 1880s, there was a fierce debate between Thomas Edison and Nikola Tesla, whether DC or AC power should be used for powering homes and offices. Edison, the proponent of DC, lost primarily because of the advent of transformers, which allowed easy voltage conversion for AC power, enabling transmission at higher voltages, thereby reducing ohmic losses, and then distribution at homes at lower voltage. From thereon, AC power-lines and AC-powered product development have dominated the world, with very little R&D on DC.

It took 100 years for DC to re-emerge. First with long distance high-voltage DC (HVDC) transmission lines, as DC current transmission did not suffer from skin effect and could use the full cross-section of wires, thus reducing losses.

What is less talked about is the arrival of DC power at homes and offices. Since 1980s, electronics started making a big entry into homes. All electronics systems use DC internally, and use AC-to-DC converters for powering. The losses in converters were paid little attention due to the low power consumption in electronics systems. However, as the presence of electronics grew in homes and offices, these losses started accumulating. This has been followed by the advent of LEDs for lighting. While they are far more energy efficient as compared to CFL lights, LEDs use only DC power. One can power LED lights using AC–DC converters, but these converters are lossy, will add to the costs and are more prone to failure. The converters could also impact the power factor of AC lines, unless sophisticated and expensive designs are used.

The final blow to the use of AC in the domestic sector has come with the advent of high-power integrated circuits, which heralds a potential for low-cost brushless DC motors (BLDC) and switched reluctance motors (SRM). These motors consume much less power compared to AC induction motors, especially for low-power and variable-speed applications. As an example, a BLDC ceiling fan consumes 40% power compared to a similar AC induction-motor fan. DC motor-based mixers, grinders, refrigerators, coolers and air-conditioners are far-more energy-efficient compared to their AC counterparts, and are already in the market. Even the pumps, lifts and chillers used in large buildings are now DC-motor based. Of course, today they are all powered by AC and use suitable converters. The converter losses, cost and reliability demand that all these appliances be powered using a DC power-line instead. However, one has history and the established base to contend with.

The case for DC powering of homes does not end here. Solar PV produces only DC power. Losses due to conversion to AC could be as high as 15% at the low power levels of 100–500 W used by most Indian homes, unless much higher costs are acceptable. Further, decentralized solar PV systems with varying power have batteries associated with them. Now these batteries are charged using DC power and also output only DC power. Once again, AC to DC for charging and DC to AC conversion for supplying to loads are involved, leading to further conversion losses. All these losses add up to a significant total. A solar-DC system with DC power lines and DC-powered appliances is a better option in terms of efficiency, cost and reliability. But how does one contend with 100 years of history and established practice?

Such a dilemma was witnessed not long ago in telephony, when India added only a million telephones a year to its 8 million lines, and one had to wait for 8 years to get a telephone connection. When some of us proposed wireless telephony to break this deadlock, it was considered preposterous. Was wireless not much more expensive? No one in the world had done it. We argued that we were replacing copper with electronics, and Moore's law and software-driven radios would help get wireless telephony at lower costs. We were laughed at or at best humoured. History tells us that India is a large enough market for us to take the lead and solve our problems.

The country has similar problems with power today. About 50 million homes are still off-grid. In spite of power surplus, there is load-shedding for many hours in several parts of the country. Affordability is a far bigger problem, with almost 50% of Indian homes unable to afford electricity even at subsidized tariff of INR 5 per kWh (unit), a tariff level at which the power distribution companies still lose money. It is in such a situation

that solar-DC with DC power lines at homes/offices and DC appliances could break the log-jam. Decentralized rooftop solar DC PV systems, with the benefit of avoiding all the losses discussed, as well as transmission and distribution losses, could in fact cut down costs and make power more affordable. The issue is whether India is willing to leapfrog and lead.

Should we choose to do this, there would be many problems that we will need to attend. Work would be needed on:

(1) DC appliances.
(2) DC standards and plugs/sockets/wiring. One has to consider safety, deal with arcing and devise switches and protection mechanisms.
(3) DC-based solar PV system technology, which is not so straightforward as solar PV works at varying maximum power-point voltages during the day, and batteries would need different voltages at different states of charge, whereas the appliances would be designed for fixed voltage. Use of DC–DC converters to make them all work at the same voltage would be lossy, like that in case of AC–DC converters. One has to come up with smart circuit implementations. At the same time, we have to deal with inrush of DC current due to capacitance of appliances when switched on. One has to also worry about protection when batteries are directly connected without a converter.

These are technical challenges. More complex will be the change management as affordability in India is low and everything has to be made affordable on day one. Commercialization of a whole host of systems together would be a challenge. The existing mindset of technical people as well as public will be against such changes.

India is going to build more homes and offices in the next 15 years than it has today. It would benefit immensely due to these changes. All it needs is the will and courage to travel on uncharted territory.

The acute power shortage faced in Chennai a few years ago, propelled a few scientists at the Center for Decentralised Power Systems, IIT Madras to look at solar power; soon they were able to understand the challenges as well as sense the great opportunity. They took the challenge head-on, with a determination that India would lead in solar-DC. Focusing on low-power appliances at homes and offices, like lights, fans, TVs, cell-phones, computers, laptops, tablets, displays, refrigerators, mixers, grinders, air-coolers, water-filters and all the sensors used today in large buildings, they came up with low-power low-voltage DC power-line at 48 V DC. The current would be limited to 5 A in any circuit. Heavy appliances consuming power of 1 kW or more, such as air-conditioners, pumps, geysers and induction cookers were excluded and were to be powered by either AC power-lines or higher-voltage DC power-lines like 380 V DC.

In the case of DC, there is no need for basic protection against electric shock if the voltage is below 60 V DC in dry conditions, according to IEC 60364-4-41 Sec 414.4.5. However, lower voltage implies higher current for the same power and wiring losses increase as the square of current. Thus, the highest safe voltage would be 48 V DC, as a battery nominally at 48 V would not reach 60 V, even when fully charged. Also, 48 V DC is already a standard for telecom all over the world. This could be a standard for low-power low-voltage DC at homes and offices as well.

The IIT Madras team therefore designed an Inverterless500 which could connect to solar panels up to 500 W, can draw up to 500 W from the grid, connect to a battery of 5 kWh and drive 48 V DC circuits within homes/offices up to 500 W. The maximum losses, apart from battery losses, are 6%, even when consuming power as low as 100 W (Jhunjhunwala, A. *et. al*., *IEEE Electrification Mag.*, 2016, **4**(2), 10–19). This is far from the nearly 50% losses, common in solar-AC systems at similar power levels. But this system by itself would go nowhere. The team therefore is driving 48 V DC as a standard in India and has defined and commercialized plugs and sockets. It helped develop and commercialize DC-powered lights, fans, cell-phones and laptops chargers, TVs, air-coolers and mixers, at costs only slightly higher than that for comparable AC-powered appliances, but saving 30–50% energy. The team has also driven scale in deployments.

Last December, Chennai saw one of the worst floods in recent times. While the whole IIT Madras campus had no power for 75 h, one home was always lit. With only 125 W solar panel and a battery with hardly half a kilowatt hour of usable power, an Inverterless500 deployed at the home provided power for a couple of tube-lights, a fan, a TV (for a short while) and charging of laptops and cell-phones from zero to full power some 20 times each. The strength of solar-DC technology could not be better demonstrated.

Now close to 4000 off-grid homes in desert areas of Jodhpur and Jaisalmar districts, Rajasthan are powered by Inverterless500, synched using bluetooth on cell-phones and remotely monitored at the IIT Madras server. Rural Electrification Corporation (REC), Government of India, is now going full-fledged in deploying such systems (see https://youtu.be/dIQZncaodpQ) in several states including, Assam, Jharkhand, Kerala and Bihar. The systems would soon be available in the open market as well.

This is the beginning. Much more needs to be done if every home in India is to proactively choose to use rooftop solar PV. Only then can the country hope to get 50% of its electrical power from renewable technologies. In the process, India could become a technology leader in DC power in the world.

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