Technological and Deployment Challenges and User-Response to Uninterrupted DC (UDC) deployment in Indian homes

Ashok Jhunjhunwala[1], Krishna Vasudevan, Lakshmi Narasamma & Bhaskar Ramamurthi
Indian Institute of Technology Madras, Chennai India
[1]ashok@tenet.res.in, krishna@ee.iitm.ac.in, lakshmin@ee.iitm.ac.in, bhaskar@tenet.res.in

Abstract—**This paper presents a load-management innovation to provide a limited but uninterrupted DC power supply to homes in India. In a typically power deficient situation, load shedding becomes unavoidable. The duration and areas where load is shed are typically cycled. In worst situation, power outages last for a greater part of the day. To enable every home to get at least a limited amount of power 24x7, an innovative approach that combines use of DC power and load management has been proposed and implemented in several hundred homes in various locations. In order to make best use of limited power, a DC power line and energy efficient DC appliances are introduced and installed at homes. The approach also enables addition of solar power directly to the DC power line and use of battery, without any converter; the power-limit on DC line can thus be overcome. The paper describes the rationale, implementation and user feedback of the approach. Further improvements and plan for future are indicated.**

Keywords—24 X 7 Power supply, DC devices, UDC, UDPM

I. Introduction

India is a country set for rapid economic growth. The growth is however likely to be stemmed by limited availability of electrical power. The power situation in India is grim [1] with peak demand exceeding available supply on most days. Industries and businesses are turning to captive power (like that produced by Diesel Generator) to take care of their needs. Households on the other hand do not have the advantage of power being treated as a working capital and find the alternatives too expensive. In areas where power shortage is severe, load shedding is resorted to for several hours, sometimes for the greater part of the day. This throws households completely off-course as essential activities become difficult. Those who can afford the cost, install inverters at home; these use battery storage to power the essential loads during the outage. Battery is charged when power supply is restored. While this solution works, this is quite inefficient. Power in the ac form is converted to dc and the energy is stored; it is then re-converted to ac form. The cycle efficiency is not high and the process involving several conversions is inefficient. Cost of cycling the power through the battery is high [2]. Further, the use of inverter causes problems for the grid, as when the power is restored, it needs to supply homes both for its appliance load as well as for charging the batteries. The sudden spike exaggerate the supply-demand mismatch. Also at times, severe shortages of power results into massive power-cuts in urban as well as rural areas, ranging for several hours a day during which batteries cannot be fully charged. Households are therefore severely affected.

India's electricity usage constitutes of domestic sector (about 27%), commercial spaces (about 10%) and agriculture & irrigation (about 22%) and others (about 7%) [3]. Reliable power supply to residences is the need of the hour, along with affordability of the solution. There are efforts in the country to install more generation plants to improve the situation. India has one of the largest reserves of coal in the world and coal forms the major source of energy in the country, followed by hydro-power. However, environmental calls are becoming more strident and tend to delay the process if not stall it. A different approach is needed to address the problem – it is necessary to provide uninterrupted power to the homes from the grid to provide affordability. It is in this context that the innovation proposed and briefly outlined here assumes significance.

II. The Innovation

The supply-demand mismatch is handled by the DISCOM (power distribution companies) by resorting to load-shedding in select areas. In these areas, the power is cut resulting into a "black-out," while in other localities, the power supply continues unconstrained. Load-shed localities are rotated every few hours, so that no one suffers more than the others and the shortage is distributed.

An alternative approach would be to not carry out 100% load-shedding in any area, but allow part of the power to continue to flow on the distribution line. If the load-shedding is carried out to the extent of 90% power, while 10% power continues to be fed from the grid (use of brown-out instead of black-out), the demand-supply mismatch can as easily be handled. The approach, referred to as Uninterrupted DC (UDC), would continue to supply a LIMITED amount of power to each home during brown-out. This would however pose two problems. The first is that 10% of normal power would be possibly too

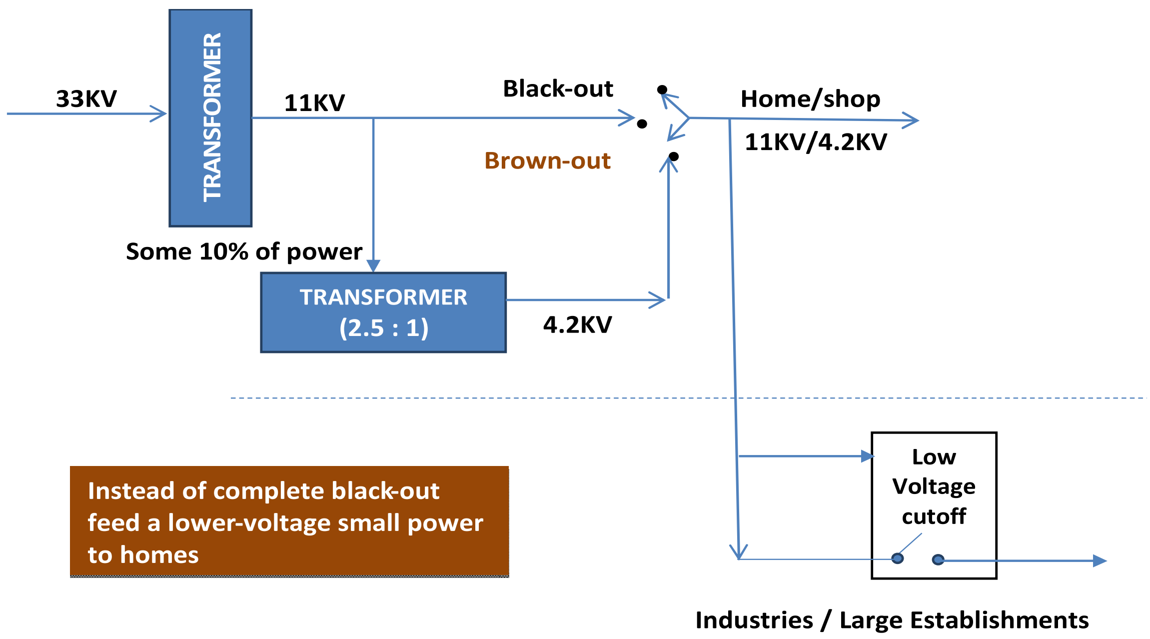

Fig. 1: Brown-out mechanism at substation

small to be useful to homes. The second problem will be how to ensure that no home draws higher power, bring down the distribution grid [4].

The answer to the first dilemma leverages the fact that DC appliances at homes consume far less power than the corresponding AC ones. Thus if the 10% of NORMAL power is supplied to homes in DC form rather than in AC form, it does not amount to be as small. More on it later. The only additional point is that this 10% of Normal power would now be supplied in DC form not just during brown-out, but also during normal operation, where no load-shedding is carried out. This would create a market pull for use of DC appliances at homes.

The second dilemma is handled by restricting each home from drawing no more than 10% of its NORMAL supply during brown-out. A converter-meter arrangement (known as Uninterrupted DC Power Module or UDPM) has been designed which enables the conversion of utility supply to DC with power-factor correction and with the 10% limit, to power DC appliances. This module also provides an AC output to power conventional home equipment, so that the home can continue to use the investment already made. This ac line is however cut-off during brown-out. The UDPM also meters DC power usage.

The module however needs to be signaled about the times of brown-out. One could conceive use of communication systems (like cellular-data communication and power-line communication) to enable this signaling. However, these communication methods had issues like reliability, delays and jamming. The approach has to be reliable and tamper proof and the signaling must be almost instantaneous, so that the grid is not disturbed. A simple but radical approach involving dropping the voltage level by a factor of 2.5 on the distribution grid, has been implemented for this purpose – a brown-out intentionally done on the line acts as a signal for cutting out the ac line. Since this is done on the regular power line itself, it is reliable and does not need any extra lines to the households. The UDPM installed at homes detects this dip and cuts out the ac line. The dc line remains energized, but at all times curtails power drawn to about 10% of the nominal value of household consumption. On restoration of the grid to normal voltage level signaling Normal supply, the UDPM restores the ac at the home.

III. The Case for DC Power distribution Line and DC appliances at Homes

As discussed earlier, the DC appliances today consume far less power than their equivalent AC appliances. Technology evolution has brought in LED lighting today, which is known to be two to three times more energy-efficient as compared to the florescent-tube based lighting such as CFL (the CFL themselves are several times more energy-efficient as compared to tungsten lighting bulbs, used widely till recently). LED lighting is DC-powered; one can use AC powered LED lights, but it involves conversion of AC power to DC at each light, which is inefficient. Similarly, DC-powered BLDC fans reduce power consumption by a factor of 2.5 as compared to induction motor based AC fans. Such BLDC motors are also generally at the heart of what are advertised as “Inverter based refrigerators and air-conditioners,” and are far more energy efficient as compared to their AC counterparts. All electronic appliances, like TVs (LED and LCD TVs), laptops, mobile phones, tablets and audio-systems anyway use DC power;

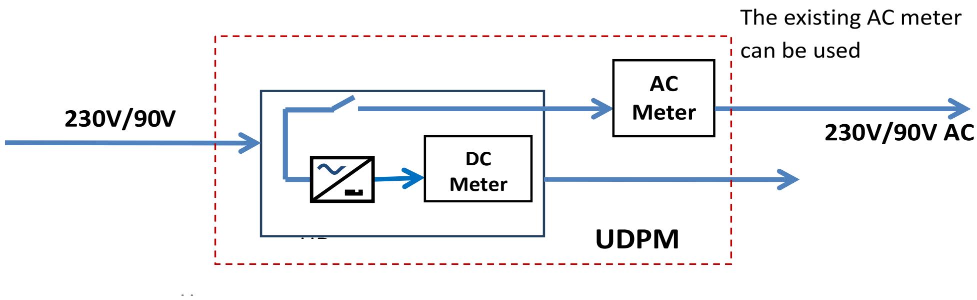

Fig. 2: Functional Block diagram for UDPM

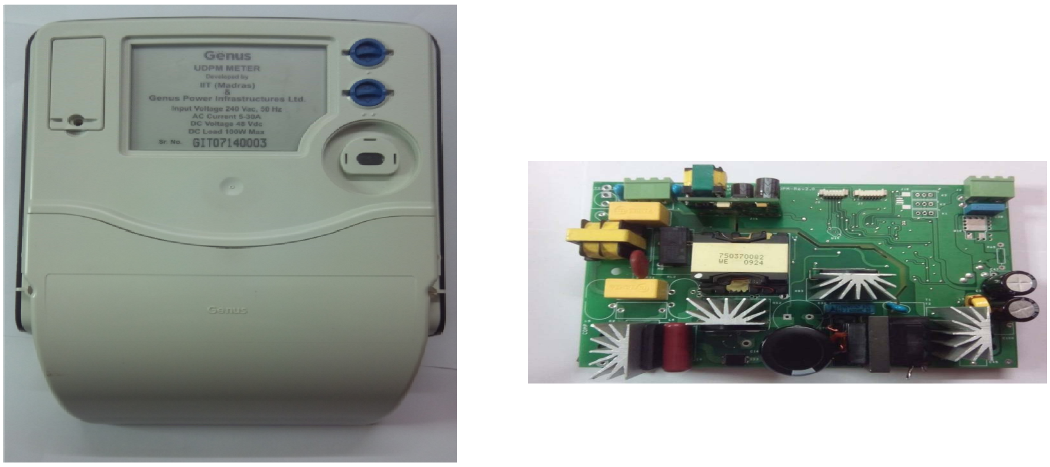

Fig. 3: UDPM a) As finished Product b) PCB

today they use AC-DC converters (either built-in or external adaptors), which not only adds to the cost, but are often energy inefficient (typically the losses could be 20% to 50%). Therefore a DC power line at homes and use of energy-efficient DC-powered appliances would significantly reduce the power-requirements. In other words, wide-scale adoption of DC-appliances (lights, fans and electronics) is a strong demand-side intervention in favor of bridging the supply-demand gap. The only problem is that to get people started, as people are unfamiliar with DC-grid and DC-powered appliances.

The UDC approach of providing a DC power-line (as an uninterrupted line) would provide a strong attraction for customers to start using DC appliances. Once they get used to it and see the advantages (like savings in power-bill), they would see more and more DC power-line and appliances.

A typical Indian home uses about 1 kW of peak power. So the limited but uninterrupted DC power that UDC plans to provide on the DC line is only 100W. Normally this may be considered too small. It is indeed so if 100W of AC power was used. One would barely be able to use one AC fan and one CFL tube-light. But using 100W DC, a home may be able to use two LED tube-lights, one LED bulb, two BLDC fans and one cell-phone charger. Further one can use one 24 inch LED / LCD TV with only one fan ON. For most lower-middle class homes, this would be reasonably adequate.

A. *The Solar / Battery Addition*

However a middle and upper-middle class home in India would want to add more appliances on DC line. This can be easily done by simply adding a solar panel. The UDPM has been designed to directly add solar-panels and batteries directly on the DC line [5]. For example, addition of one 500W solar panel and 2 kWh battery to the UDPM output would enable 24 x 7 powering of 8 LED tube-lights and bulbs, 4 BLDC fans, two televisions, one laptops and multiple cell-phone chargers on the DC line even when grid-power is available less than 12 hours a day.

B. *The Sub-Station Implementation*

To implement UDC, three things are required to be done at the substation:

1. Carry out load shedding by cutting of 90% of power (instead of 100%)
2. Provide power within homes from grid in two circuits
3. Ensure that instant cut-off of the AC line takes place, when load shedding is implemented

This requires that an instant signaling from the sub-station (where the load shedding is carried out) to each home, reliably, so that AC power is cut off during BO. Similarly, when normal

Fig. 4: The deployment in Madurthakam: Substation Deployment (left); UDPM and metering (bottom-right) and Household turning on DC devices (top-right)

power is restored, the signal should enable restoration of AC power. A reliable and guaranteed instant signaling is achieved by dropping the voltage level of the 10% power transmitted during load shedding by 2.5 times. This is achieved at the sub-station by using a tap on the 33kV/11kV transformer, or adding a 2.5:1 transformer at 11kV output, as shown in the Figure 1. This transformer/ tap is also limited to 10% of the power that the 11kV line would carry during normal operation. The brown-out then switches the 11kV output to 4.2KV (with 10% power level). The 4.2KV now goes through the distribution transformer where the voltage for each phase goes down to 90V. As the supply is at 90 volts, implying a current increase by 2.5 times for the constant power. However, as no more than 10% of normal power is used during brown out, the current will go down by a factor of 4, when voltage goes down by a factor of 2.5. This means loss goes down by 16 times. With power going down by 10% and losses going down by 16 times, even the relative loss goes down by at least 1.6 times.

Another major problem in countries like India is stealing of power, tapping it illegally from the power grid. Even though UDC scheme is not designed as an anti-theft system, the proposed UDC scheme would help in reducing power-theft. Power-stealing could be done during normal load operations also and even if SMART Meters are used to manage load at homes. The use of UDC makes it more difficult to steal to steal power. As during brown-out, the line voltage is only 90V, a voltage booster transformer would be required to connect the stolen power to loads. However, as soon as line changes from Brown-out to NORMAL, the 90V AC would change to 230V AC. The boost transformer would now increase the load voltage to about 575V, damaging the load. So, one needs to have a sophisticated system to steal power as compared to when only 230V is used.

C. *The UDPM Implementation*

At homes, the 230V / 90V AC line now feeds UDPM (Uninterrupted DC Power Module), shown in Fig. 2 and 3. The output from this box would drive 2 circuits (power-lines):

- A 48V DC line on which will be allowed a maximum of 100 W and services DC devices
- A 230 V AC line, fed through existing AC meter, to service all the AC devices.

The UDPM is designed to cut-off the AC line, when the input voltage 90V AC (implying brown-out). However, during normal power situation, with input being close to 230V AC, both lines are ON.

IV. THE PROOF-OF-CONCEPT

With utilities seeing the benefit of this approach, implementation of the scheme has started in four Indian states. In one locality at the town of Madurantakam in the state of Tamilnadu (India), the scheme is operational since December 2014 and the residents (as shown in Fig. 4) are experiencing the benefit of uninterrupted power even as power in other areas of the town is cut completely. The metering capabilities of the converter module are used for billing the dc power consumed by the households along with the regular utility meter for the ac power. Implementation at Hyderabad (Telangana) and in Orissa was completed in February, 2015.

TABLE 1: UDC DEPLOYMENT

Location	Name of the Feeder	Total Consumers in the DT	Status
Maduranthakam Town, Madurantakam, Chennai, Tamil Nadu, India	Maduranthakam Town Feeder	241	Commissioned on 02-Dec-2014
Moinabad Town, Moinabad, Hyderabad, Telangana, India	Moinabad Town Feeder, DTR-1	203	Commissioned on 04-Mar-2015
Thirumala Sub-Station, Poojapura, Thiruvananthapuram, Kerala, India	Poorjapura Feeder	407	Installation in Progress
Tirimalla Sub-Station, Khorda Circle, Bhubaneswar, Odisha, India	Bhoisahi Feeder	550	Consumer consent form collection in progress
Tirimalla Sub-Station, Khorda Circle, Bhubaneswar, Odisha, India	IDCO Feeder	81	Commissioned on 07-Mar-2015

Two further are locations in other states are in the pipeline (as shown in Table 1).

V. FEEDBACK AND CONCLUSIONS

Most families using DC power at Madhuranthakam are happy with the uninterrupted power. They appreciate the DC fans and lights powered by the system. "*We use them all day long*," they said. Lately, the neighboring areas have taken an interest in the project and have requested that the service be extended to them. Some of the residents at Hyderabad, who are using DC appliances commented that "our power bill has come down substantially."

The approach to provide limited but uninterrupted power in the form of dc is seen to have potentially large benefits in terms of:

1. No Blackout
2. Encouraging energy-efficient DC appliances
3. Creating a pull for decentralized Solar-DC deployment

As more and more use of energy-efficient DC appliances increase, the demand for grid power reduces. Similarly, as more and more decentralized solar power is deployed, it augments total power supply. As a result, the large Supply-demand gap that exists today would reduce. This would be easier to bridge with conventional power. Even when the gap is fully bridged, the latter two benefits would remain. UDC would have served the purpose. At the same time, if enough homes deploy DC appliances and decentralized solar power, India could become one of leading GREEN nation.

Currently, the Ministry of Power (Government of India) is planning a large deployment of UDC and DC appliances in a city of 100,000 homes.

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