GOGLA

The Voice of the Off-Grid Solar Energy Industry

Opportunities for Hybrid AC-DC Infrastructure in India

Discussion Paper, November 2020

PMANIFOLD

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About GOGLA

GOGLA is the global association for the off-grid solar energy industry. Established in 2012, GOGLA now represents over 180 members as a neutral, independent, not-for-profit industry association. Its mission is to help its members build sustainable markets, delivering quality, affordable products, and services to as many households, businesses and communities as possible across the developing world. The products and solutions that GOGLA members sell transform lives. They improve health and education, create jobs and income opportunities, and help consumers save money. To find out more, go to www.gogla.org.

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pManifold is a new Energy & Utilities focused Strategic Research and Consulting company. It enables Smart and Clean Tech Markets development and growth in Energy, E-Mobility, Low Voltage DC, Solar, Enviro and Urban sectors. It helps industries and organisations innovate and transform their solutions, services and business model, for faster reforms, higher customer experience and profitable market growth

Abbreviations

AC	Alternating Current
BIA	Battery Integrated Appliance
BMS	Battery Management System
CREDA	Chhattisgarh Renewable Energy Development Agency
DC	Direct Current
DDUGJY	Deen Dayal Upadhyaya Gram Jyoti Yojana
DRE	Distributed Renewable Energy
EE	Energy Efficient
ESMI	Electricity Supply Monitoring Initiative
FMCG	Fast Moving Consumer Goods
HAD	Hybrid AC-DC
HH	Household
LVDC	Low Voltage DC
MLS	Multi-Light Systems
NBFC	Non-Banking Financial Company
PULSE	Productive Use Leveraging Solar Energy
PV	Photovoltaic
RMS	Remote Monitoring System
ROI	Return on Investment
SARAL	State Rooftop Solar Attractiveness Index
SHS	Solar Home System
SRT	Solar Rooftop
UPS	Uninterrupted Power Supply
Wp	Watt-peak

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Executive Summary

India stands strong in achieving universal access to electricity with almost 100% electrification coverage by 2019. The national grid has played a very important role in improving this access, but its reliability continues to pose a challenge, and more so in semi-urban, rural and remote areas. Distributed Renewable Energy (DRE) in the form of solar roof tops (SRT) and solar home systems (SHS) tied with efficient appliances help improve reliability of service and are seeing increased adoption. By some estimates, there are approximately 4 million HHs (1.4% of the total 277 million HHs in India) with some form of SRTs or SHSs in India.

Many of the previously used SHSs were standalone systems powering AC and/or DC Appliances with energy storage. Today, there is a new class of DRE solutions commonly termed Hybrid Solar Systems, which integrates solar with AC grid power (uni or bi-directional) and can power AC and/or DC appliances. Such new Hybrid AC-DC (HAD) power solutions can help users to take advantage of solar power - improving supply hours and reducing their Power Distribution Company (Discom) energy bills. India saw estimated annual sales of some 0.8 million units of solar hybrid inverters or uninterruptible power supply (UPS) systems in 2019 (compared to some 8 million unit sales of conventional inverters) and there is an expected increasing trend.

More and more power systems and appliances OEMs and System Integrators are joining this fast-growing HAD market in India. There is a new class of efficient appliances (including lights, bulbs, fans, TVs, refrigerators, washing machines, pumps, etc.) that use fundamental DC-run LED or BLDC motors, and can be run on AC supply and/or DC supply. Some further innovations in appliances include embedding energy storage inside the appliance to avoid the need for costly centralised power back-up solutions. These innovations on the appliances side will further push for increased need of enabling HAD infrastructure for the synergistic co-existence of AC and DC.

In this discussion paper, the HAD infrastructure has been analysed in detail from two perspectives: a) Supply-side: power back-up solution side through combining grid, solar and battery storage, and b) Consumption-side: appliance side by enabling appliances to work with both AC and DC supplies. The following customer segments are expected to drive the demand for HAD solutions from the supply perspective.

- **HHs with no power back-up solutions:** Around 218 million HHs (out of approximately 277 million HHs) do not have any solar or conventional UPS power back-up solutions. On average, 8.8 million HHs (3.2% of all HHs) per year opt for either a conventional UPS (8 million/year) or a hybrid solar inverter UPS (0.8 million/year). The share of hybrid solar inverter UPS is only 9% of total inverter UPS market. By industry estimate, the market share for this category is expected to rise to 15% by 2023.
- **Potential grid-connected customers:** The market potential for grid-tied solar rooftop solutions (with a minimum capacity of 1kW capacity) in the residential segment is 1.37 million HHs. Currently, only 0.23 million HHs have installed grid-tied SRTs in India. These HHs may consider opting for hybrid grid-tied rooftop solutions under gross/net-metering schemes.
- **Existing HHs using conventional UPS systems:** As many as 55 million HHs have already installed conventional UPS. They can be targeted to convert their conventional UPS systems to hybrid solar UPS systems to save on their electricity bills. The conversion will involve an upgrade, but larger volumes could be achieved with government support and dedicated efforts by other players.
- **Existing AC Mini/Microgrids:** Some AC Mini/micro grid inverters can be replaced with hybrid grid-tied inverters with export facility (future compatibility)

There are approximately 4 million HHs (1.4% of the total 277 million HHs in India) with some form of SRTs or SHSs in India.

According to industry experts, the demand for small (<0.5 kW) and medium (0.5 kW–3 kW) hybrid solar inverter UPS systems is high. Small hybrid solar inverter UPS systems would be more suitable for HHs with power availability of less than 8 hours while medium-sized systems would be more suitable for HHs with power availability of 8 to 23 hours.

- **Existing Standalone SHS customers:** Customers using standalone SHS (like 0.35 million HHs provided with standalone SHS under Saubhagya) can also be upgraded to hybrid solar inverter UPS when they have access to main AC grid.

On the other hand, hybrid grid-tied inverters are new in the Indian market but are anticipated to see growth with increasing SRT installations. Initially, this demand can be expected to come from cities and government institutions. However, the high upfront costs and lack of consumer awareness of new technologies may be a limiting factor in achieving high volumes.

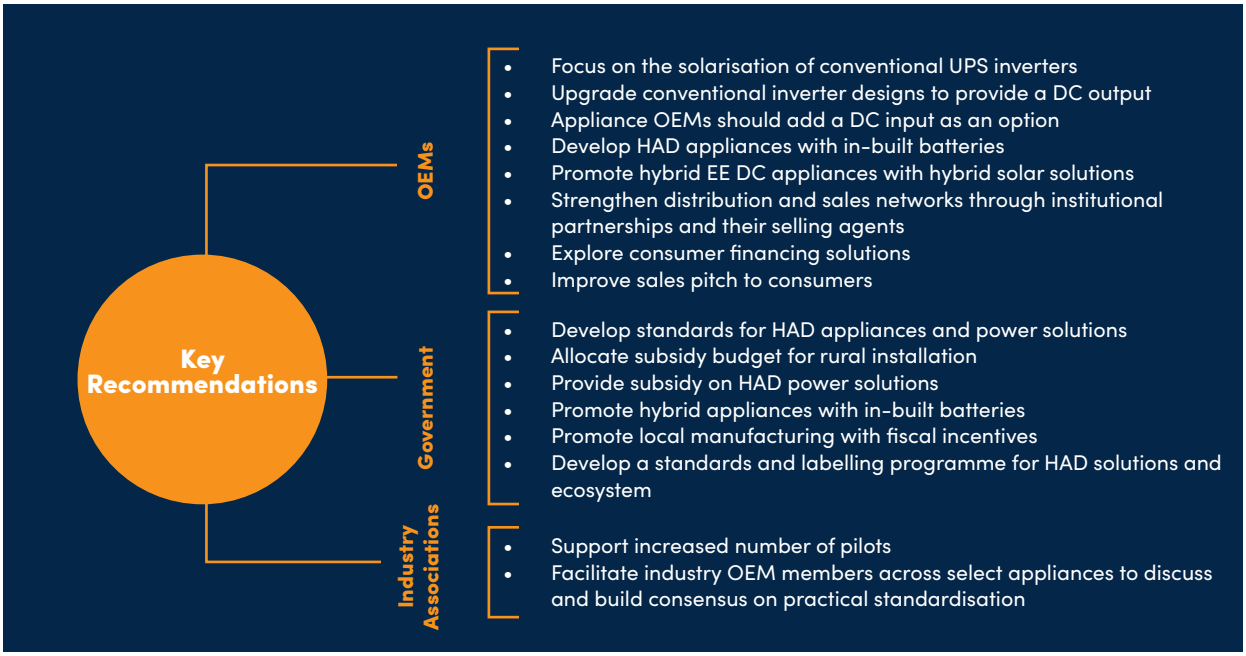
From the appliance perspective, two new categories of energy-efficient (EE) HAD appliances are emerging in the market, one with dual inputs and another with an integrated battery.

Most EE appliances in market today are fundamentally DC. They are more reliable and use up to 80% less energy compared to their conventional (AC) counterparts. Despite DC appliances presenting a good value proposition, their adoption is limited. This is because the AC appliance market is mature and affordable, with a better post-sales network, an established financing network, and post-grid electrification. In addition, the AC main grid is accessible to nearly all HHs. Hence, most consumers prefer AC-powered appliances over DC-powered ones.

Today, hybrid appliances are priced two to four times higher than conventional AC appliances. However, as the technology gains more popular among both original equipment manufacturers (OEMs) and consumers, they may become more affordable. Hybrid light bulbs and fans are expected to be the first set of appliances to become cost-effective.

Currently, a few OEMs are promoting hybrid appliances with dual input in the market (such as fans, refrigerators, TVs and air conditioners), but their adoption is limited. This is due to the lack of power systems that support both AC and DC power lines. However, these appliances provide OEMs and customers with the flexibility to operate within an ecosystem that supports both AC and DC.

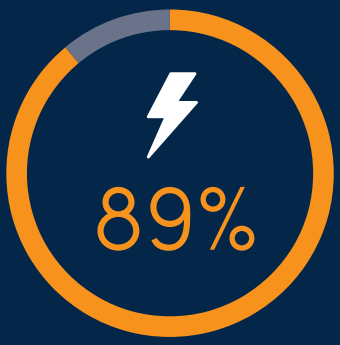
The market for hybrid appliances with a single input (mainly AC) and integrated battery is in its nascent stages. Due to grid electrification, there exists an untapped potential for such appliances, especially in areas where the



power supply from the grid is unreliable. As the price of battery storage falls further and new technologies emerge, hybrid appliances can become an alternative to conventional UPS systems, especially among lower-income groups or below the poverty line (BPL) consumers. However, the uptake of hybrid appliances with an integrated battery may be limited among HHs that are already using conventional or solar UPS solutions.

To further strengthen the HAD infrastructure in India, below are some key recommendations to the OEMs, Government and Industry Associations.

Evidently, the market is heading towards hybridisation, i.e. integration of AC-DC power supply and appliances that support these systems. However, challenges like high upfront equipment cost, high sales effort, low customer awareness, and lack of standardisation are an acknowledged reality. Yet, these factors should not deter off-grid players from diversifying and offering HAD solutions to customers. The key industry stakeholders like OEMs, Government and Industry Associations will play a vital role towards mitigating these challenges and enabling growth of HAD infrastructure in India.



The global population having electricity access have risen from 83% in 2010 to 87% in 2015, then accelerating to 89% in 2017

More than 9 million solar products being sold between 2014 and 2018

Almost 26.3 million HHs were electrified under the Saubhagya scheme

1. Background

1.1. The Energy Access Landscape in India

The world is gradually making progress towards achieving universal access to electricity. The global population with access to electricity has risen from 83% in 2010 to 87% in 2015, and accelerated to 89% in 2017[1]. India, Bangladesh, Kenya and Myanmar are among the countries that have made the most progress towards this goal since 2010. However, even at the current rate of advancement, it is unlikely that 100% electrification globally will be realised and the SDG 7 goal (affordable & clean energy) met by 2030.

Worldwide, the number of people accessing solar power has risen significantly in recent years with increased market penetration of solar off-grid products. In India, the distributed standalone solar market has shown tremendous growth over the last decade, with more than 9 million products being sold between 2014 and 2018. India has displayed global leadership in the sector by contributing to almost one-third of the global distributed standalone sales volume.[2]

The Government of India (GOI) has established various schemes and programmes to accomplish universal electrification in the country. In 2015, the Government of India launched the Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY), which focused on 100% village electrification. As per the official definition, a village was considered electrified when at least 10% of the total households (HHs) of the village were electrified. On 28 April 2018, the milestone of 100% village electrification in India was achieved, electrifying 0.59 million[3] census villages.

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Acknowledging that the grid alone may not be able to provide access to all households, and that it may take a long time to reach un-electrified households in inaccessible areas, the central government made complementary efforts to support these households through standalone mini-grids or solar home systems. For instance, an amendment was made in the DDUGJY guidelines that if the cost of electrification per HH in a village is more than INR 1 lakh (100,000), or the number of HHs in the village is less than 15, the village may be electrified using standalone solar home systems (SHS) consisting of a PV module (200 Wp), 5 LEDs, a 25 W DC power plug, a DC Fan (25 W), and a solar TV (optional).[4] State governments also contributed to the electrification effort through various off-grid energy access schemes and mini-grid policies to promote distributed renewable energy (DRE) solutions.

Similarly, in September 2017, the government launched the Saubhagya scheme, budgeted at INR 16,320 Crore (160 billion) which propelled India to achieve 100% HH electrification in 2019, up from 43% in 2000 and 82% in 2016. Almost 26.3 million HHs were electrified under the Saubhagya scheme. Out of these, 0.35 million[5] HHs were electrified using standalone SHS. To improve energy access, and optimise system design and the total cost, energy-efficient (EE) DC appliances were bundled with SHS for HH electrification. The most common SHS package included a PV module (100–300 Wp), a battery, a DC fan, a LED bulb and a mobile charging point. As per the Saubhagya portal, 18,734 HHs are yet to be electrified in the state of Chhattisgarh as of March 2019.

By 2019, under the Off-grid and Decentralised Solar Photovoltaic (PV) Applications Programme, more than 1.72 million solar home lighting systems were distributed. This push from the government also helped the private market increase sales of off-grid solar products due to a greater awareness among consumers.

1 https://unstats.un.org/sdgs/report/2019/goal-07/
2 GOGLA's semi-annual sales and market trends report 2018
3 https://www.financialexpress.com/economy/modis-village-electrification-is-among-worlds-biggest-successes-this-year-says-this-report/1380269/
4 http://www.ddugjy.gov.in/assets/uploads/15501452432byd8.pdf
5 https://www.gogla.org/sites/default/files/resource_docs/report_india_and_the_solar_standalone_market_sizing_in_india_web_opt.pdf

Microgrid is primarily led by private players, who hold a market share of 60–70%. In India, it is estimated that micro-grids have electrified approximately 0.175 million HHs

In 2018, 51,824 SHS units were reportedly sold. This figure is expected to have grown by 30% since then. It is estimated that 0.3 million HHs are currently using SHS, which were provided by private players.

In line with the government's electrification strategy, micro-grids have also played a vital role in improving energy access in India. This sector is primarily led by private players, who hold a market share of 60–70%. In India, it is estimated that micro-grids have electrified approximately 0.175 million HHs. Out of this number, 40% are powered by AC micro-grids while the remainder are powered by DC micro-grids. Half of these HHs are connected to both the main grid and the micro-grid.

The grid extension efforts have not necessarily translated into reliable electricity. Prayas Electricity Supply Monitoring Initiative (ESMI) data across 23 states shows that half of the locations experienced outages of more than 15 hours per month, and between two and four interruptions per day in rural areas.[6] The growing aspiration and consumer demand for uninterrupted power has led to an increased use of additional power back-up solutions and also energy efficient appliances.

1.2. The Emergence of Hybrid AC-DC Infrastructure in India

There are approximately 4 million HHs (1.4% of the total 277 million estimated HHs) with some form of Solar Rooftop (SRT) or SHS in India. These DRE systems primarily solar home lights, micro-grids and SHS bundled with EE appliances have helped improve energy access and quality. So far most of these DRE solutions are standalone solar systems with battery storage and run either AC or DC appliances.

As almost all HHs in India today have access to the main AC grid, a new category of DRE solutions is emerging in the market commonly called hybrid solar systems, which integrate DC solar with AC grid power and can power AC and DC appliances. They can have either unidirectional interaction for only receiving AC power from the grid or bidirectional to also supply solar generated and converted from DC-to-AC power to the grid. Such new Hybrid AC-DC (HAD) power solutions are helping users take advantage of solar power to improve supply hours and also reduce electricity bills.

Both the existing and new players in the market are serving this growing need by providing hybrid power solutions. These hybrid power solutions using solar with grid can be bundled with EE DC appliances as a value-added proposition. The combination of plain SHS and grid integration is creating an ecosystem for the emergence of new hybrid AC-DC infrastructure in India. Therefore, this is the best time for solar and low voltage DC (LVDC) industry stakeholders to promote solar-based power solutions and efficient appliances that integrate both AC and DC power to meet changing consumer needs and leverage almost universal grid access in India. The demand for HAD solutions is expected to increase across different system sizes, as illustrated in the below use cases.

a. **Small systems (<0.5 kW):** The demand for small HAD systems is expected to come from users who have recently gained access to the grid through government electrification programmes, but struggle with intermittent power supply. They have aspirations to use more appliances and for longer durations. This need can be supported with HAD power back-up solutions with EE DC appliances.

   The demand for such small systems can also emerge from HHs that wish to install conventional inverters for the first time. For example, the Chhattisgarh Renewable Energy Development Agency (CREDA) provides a subsidy of INR 10,000 to 25,000

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6 https://www.thehindubusinessline.com/opinion/100-rural-electrification-is-not-enough/article26645721.ece

per unit for the installation of a solar power back-up system with a capacity between 150 and 500 watts.

b. **Medium systems (0.5 kW–3 kW):** The HAD solution can tap the conventional UPS system market. Currently, the most commonly used conventional inverter ranges from 700 VA to 2 kVA. Therefore, a potential consumer who is planning to buy a power back-up solution has two purchase options: i) a conventional (non-solar) UPS system, and ii) a hybrid solar inverter UPS system. The advantages of the latter over the former are:

- Flexibility to augment solar in phases and hence reduce grid energy consumption and create savings on the HH's monthly electricity bill
- With both the AC and DC outputs, the system can run EE DC appliances directly from solar DC and save on conversion losses. Usage of EE DC appliances will also optimise the overall power back-up requirements and reduce the system size and hence upfront capex.

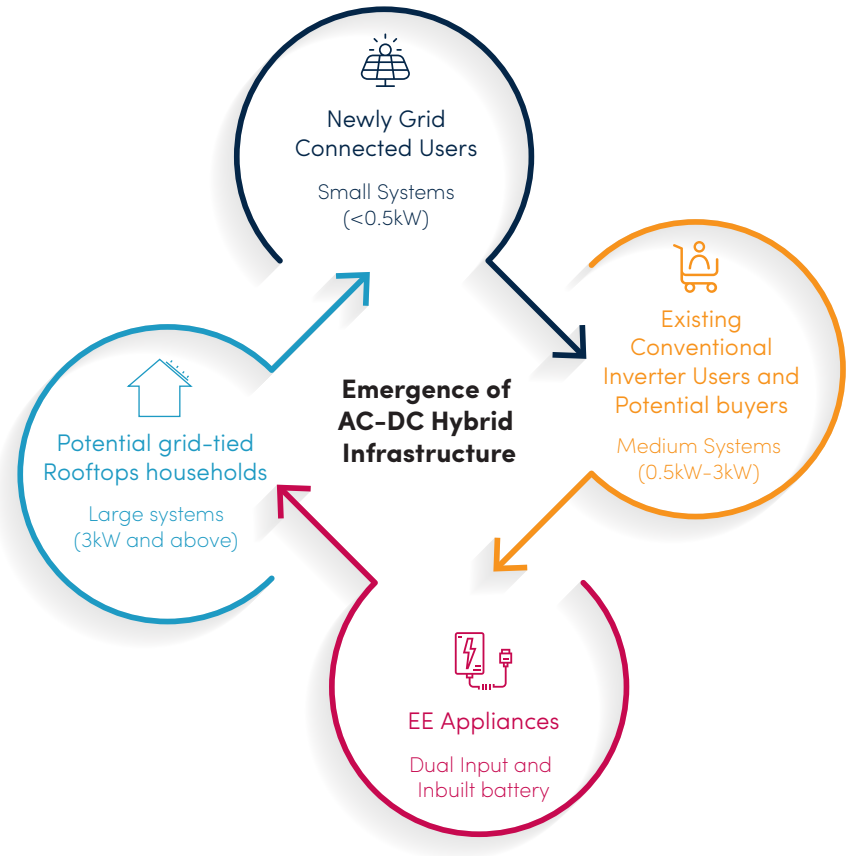
The other opportunity for hybrid systems is to tap the existing base of conventional UPS inverter users. Players can offer to retrofit a conventional UPS into a solar UPS system using a hybrid solar charge controller to customers. (for example, Luminous provides a retrofit solution converting conventional UPS into solar UPS system using a charge controller)

c. **Big systems (>3 kW SRTs):** Generally, these larger solar systems are installed as grid-connected SRT systems under gross or net-metering policies. They employ grid-tied inverters with no battery storage capabilities. These inverters have an in-built anti-islanding feature that stop the inverter from generating solar power during a main grid failure, leading to the loss of generated solar power.

This issue can be addressed by using hybrid grid-tied inverters with battery storage, which is advantageous for customers who face frequent power cuts. During a power cut, the system will work as an off-grid system, and solar will supply power to captive loads. When power is available, the solar system will supply it to the captive load on priority. In case of an excess of solar power, the battery will be charged after which power will be exported back to the grid.

In many states, there is a long process, delay and uncertainty to get Discom approval for gross or net-metering connections. If customers install hybrid grid-tied inverters with battery storage, they can run the solar system as an off-grid system until approval from the Discom is received. After approval,

Figure 1. Demand of HAD Solutions across different system sizes



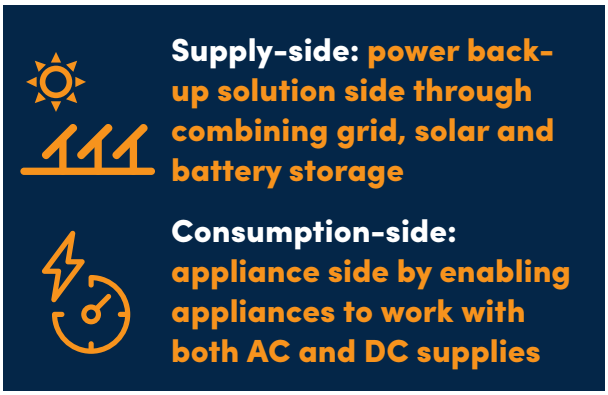
the system can be connected to the main grid, to which it can then start exporting excess power. Hence, such HAD systems can function as both an off-grid and on-grid bidirectional system. They also provide better options for risk mitigation against changing rooftop policies by Discoms.

d. **Energy Efficient appliances:** Most EE appliances in the market today are fundamentally DC (e.g. LEDs or appliances with BLDC motors) but use an AC power supply because it is the dominant supply source. The resulting AC to DC conversions has losses associated, in the order of 10% for one conversion. If hybrid solar systems can provide both AC and DC power outputs, then DC appliances can be run directly on DC, without conversion loss.

   Hybrid appliances that have both AC and DC interactions can be classified into two types:

   - Dual input: an appliance with both AC and DC supply options
   - Battery-integrated appliance: an appliance with a single input (AC) and in-built decentralised battery storage (DC)

The above potential use cases indicate that there is a good business case for AC-DC hybridisation on both sides, as below:



This is illustrated in the following HAD architecture section. The hybrid solutions space is gaining attention from established OEMs as well as many new startups. Some of the key OEMs that are already offering hybrid controller-based solar UPS solutions include Luminous, Microtek, Cygni, Intellizon, Simpa Networks and others. OEMs providing hybrid appliances include Philips, Syska, Sinox, Rico, Eveready and others. There are many more existing and new players that are joining, demonstrating that the HAD industry is on the rise in India.

2. The Architecture of Hybrid AC-DC Infrastructure

Several HAD system configurations can be designed based on customer needs. Figure 2 shows a schematic diagram to understand the architecture of HAD infrastructure with different possible configurations. There exists multiple definitions of HAD, and they vary depending on the application and understanding of the stakeholder. For this discussion paper, the definition of HAD infrastructure is considered from two perspectives:

1. **Power supply side (grid + solar + storage)**
2. **Appliance side (AC + DC)**

a. **Power supply side:** A (back-up) power supply solution is referred to as a hybrid AC-DC (HAD) solution if its controller can accept both AC and DC as inputs or give both AC and DC as outputs. The AC input will be from the main grid and DC input from solar. The battery as a DC input is optional.

For example:

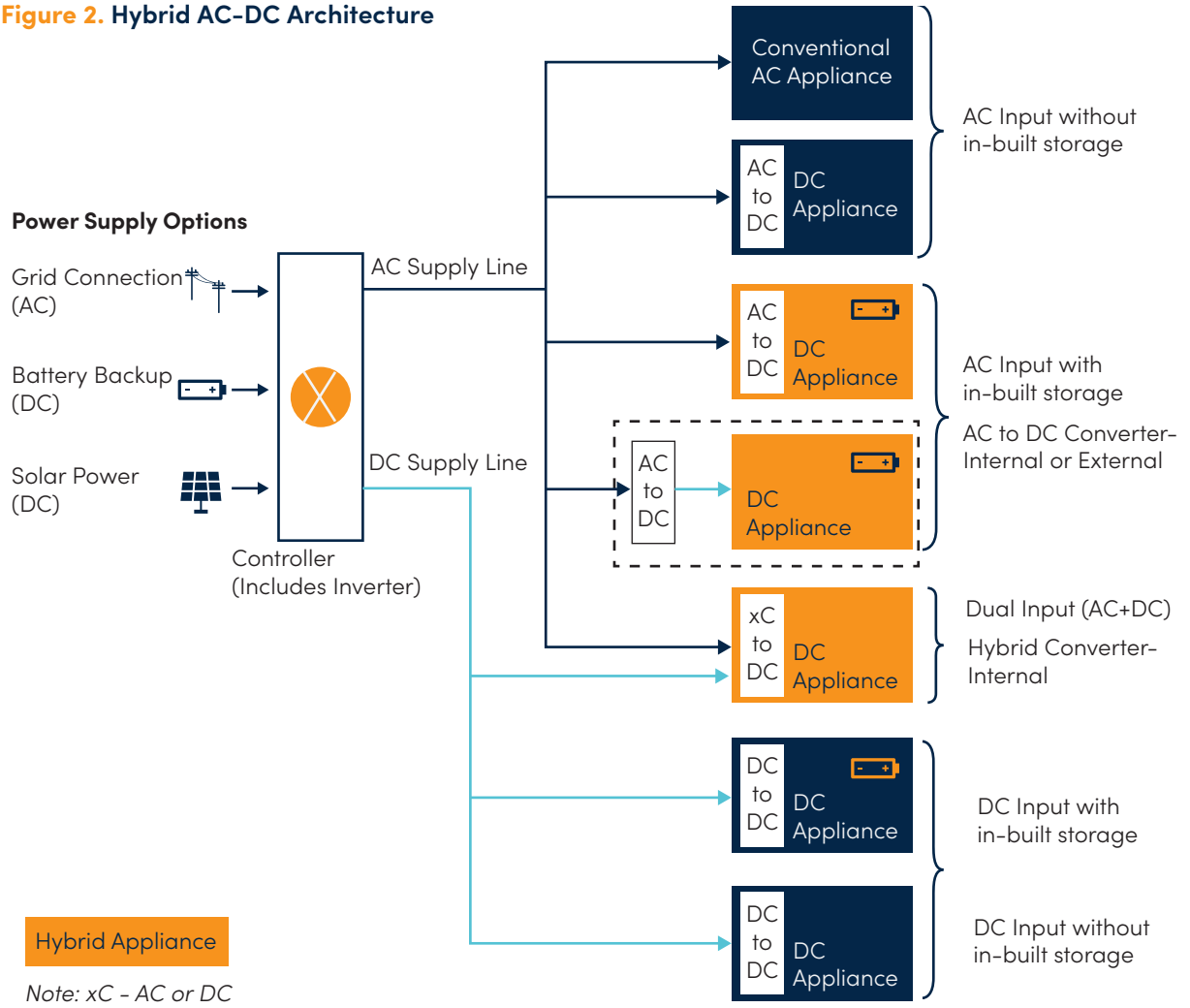
- 2 IN 1 OUT (AC + DC IN, AC **or** DC OUT)
- 2 IN 2 OUT (AC + DC IN, AC + DC OUT)
- 1 IN 2 OUT (AC IN, AC + DC OUT)

b. **Appliance side:** An appliance can be referred to as an AC-DC appliance or hybrid appliance if the appliance can operate in both AC and DC environments. This can be primarily achieved with the controller or converter circuit of the appliance. The controller or converter can be housed outside or inside the appliance.

For example:

- Dual input (AC+DC)
- Battery-integrated appliance (BIA) with single-input (AC) and in-built battery storage

Figure 2. Hybrid AC-DC Architecture



India has a population of 1.38 billion people and an estimated total of 277 million HHs, of which 60% are rural HHs

3. Customer Segmentation by Power Source and Solution Types

India has a population of 1.38 billion people and an estimated total of 277 million HHs, of which 60% are rural HHs. The HHs can be broadly classified into eight electrification categories based on the power source (grid, solar and battery) and mapped to the existing power solution used by them. Figure 3 shows an electrification below the tree diagram.

Based on the diagram, a household can be primarily classified into two types based on-grid connection status.

a. HHs with no grid connection (categories 0, 1a and 1b)

b. HHs with grid connection (categories 2 to 7)

i. HHs with both grid connection and in-house solar generation facility (categories 2a 3, and 4)

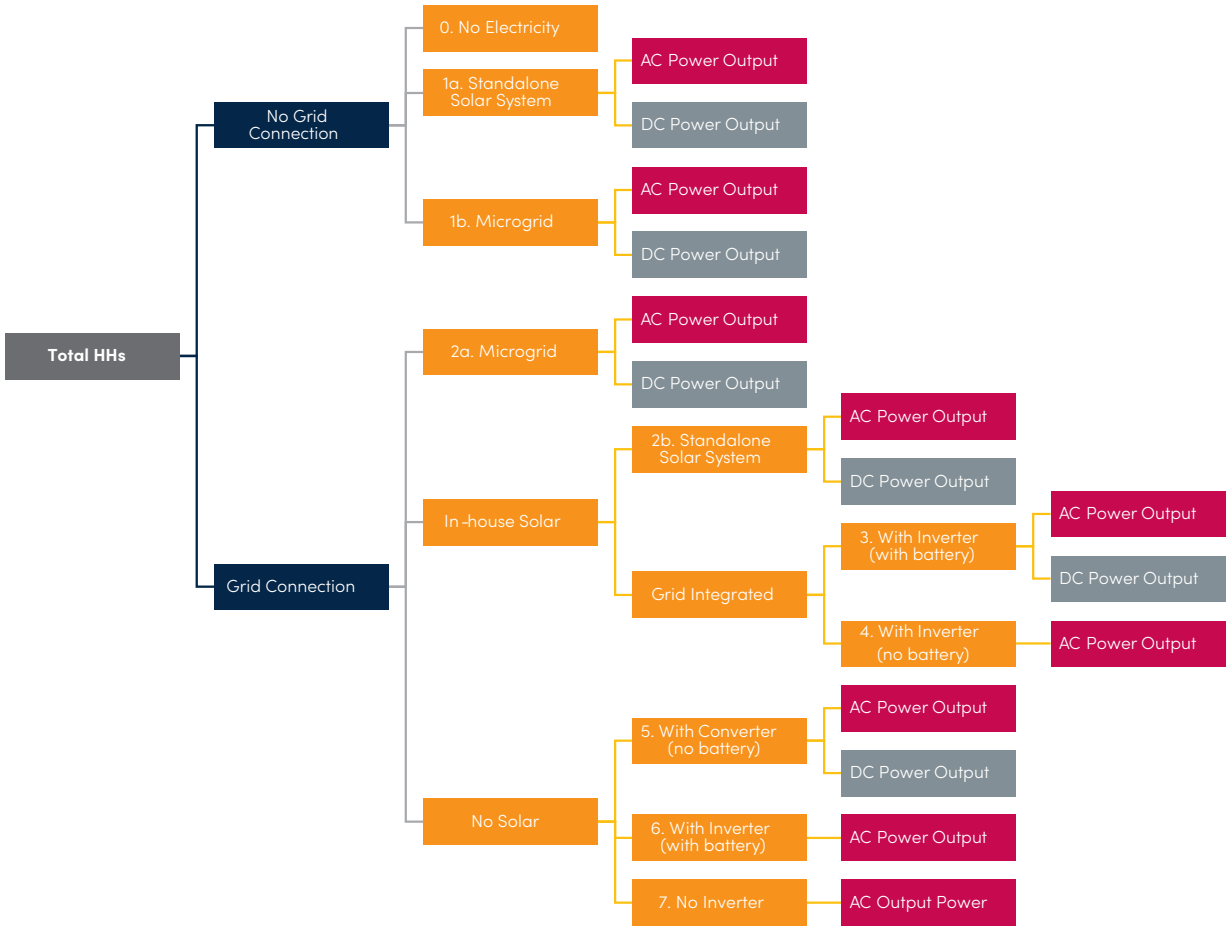
ii. HHs with grid connection but no in-house solar generation facility (categories 5, 6, and 7)

iii. HHs with both grid and micro-grid connection (category 2b)

Category description: The definition of the different electrification categories is given below. The estimations of number of HHs in each category was done with multiple rounds of stakeholder consultations in addition to triangulating multiple data points from various secondary sources.

Category 0: These HHs do not have access to electricity. They are completely off-grid. As per the Saubhagya portal, India has a total of 18,734 such HHs.

Figure 3. Household Electrification Tree Diagram



Category 1: These HHs are off-grid receiving electricity either through standalone SHS (category 1a) or micro-grids (category 1b). It is estimated that 1.7 million off-grid HHs have received access to energy via standalone SHS or multi-light systems through various government off-grid schemes. About 0.087 million off-grid HHs have received power only through micro-grids.

Category 2: These HHs are connected to the main grid while they also receive power from standalone SHS (category 2a) or micro-grids (category 2b).

HHs under the category 2a are primarily served by private DRE players. It is estimated that in the last five years approximately 0.3 million main grid HHs have been connected using standalone SHS. Similarly, around 0.087 million main grid HHs have been connected to micro-grids.

Category 3: These HHs are predominantly connected to the main grid and supported by a solar off-grid inverter system with battery storage. These systems allow the battery to be charged from either the solar or main grid, but do not feed back excess solar power main grid. It is estimated that 1.92 million units were installed in India over the last three years.

Category 4: These HHs are connected to the main grid and generate solar power through grid-tied systems for captive purposes and have no battery storage. They stop generating solar power when there is a power failure due to the anti-islanding feature incorporated in inverters. It is estimated that 0.23 million HHs have such rooftop systems, the average size being 4.1 kW and totaling some 940 MW in the residential segment.

Category 5: These HHs are connected to the main grid and have a central AC-DC converter. The converter gives both AC and DC as output power. It is estimated that 30,000 HHs have such converters. However, the central converter has to be installed after the Discom meter.

Category 6: These HHs are connected to the main grid and use conventional inverters with battery for power back-up. Such power solutions are highly popular in India. Currently, an estimated 55 million HHs use conventional inverter power back-up in India.

Category 7: These HHs are connected to the main grid but do not use any conventional inverter back-up systems or solar power solutions. The number of such HHs is estimated to be more than 218 million.

Based on the above description, below is a summary of the estimated number of HHs under each category.

Table 1. Summary of Estimated HHs across Electrification Categories

Electrification Category		Est. No. of HHs	Grid	Solar	Battery	Existing Power Solution	Controller Configuration
0	No electricity	18,734	No	No	No	No power solution	No
1a	Access through ONLY solar	87,500	No	Centralised	Yes	Mini/micro-grid	1 IN 1 OUT
1b		17,00,000	No	Decentralised	Yes	SHS	1 IN 1 OUT
2a	Access through an independent grid and solar	87,500	Yes	Centralised	Yes	Mini/micro-grid	1 IN 1 OUT
2b		3,07,000	Yes	Decentralised	Yes	SHS / SHL	1 IN 1 OUT

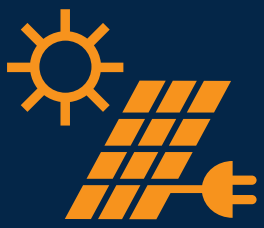
Electrification Category		Est. No. of HHs	Grid	Solar	Battery	Existing Power Solution	Controller Configuration
3	Access through the main grid and supported by solar	19,20,000	Yes	Decentralised	Yes	Grid-integrated SHS (solar hybrid inverter UPS and hybrid grid-tied inverter)	2 IN 1 OUT
			Yes	Decentralised	Yes	Hybrid solar inverter UPS system	2 IN 2 OUT
4		2,30,000	Yes	Decentralised	No	String/micro-inverters	1 In 1 OUT
5	Access through only the grid	30,000	Yes	No	No	Central converter	1 IN 2 OUT
6		5,50,00,000	Yes	No	Yes	Conventional inverters	2 IN 1 OUT
7		21,80,00,000	Yes	No	No	No power back-up	-

The Rationale for the Above HHs Estimation

Listed below are key insights gathered from discussions with industry experts and desk research.

- **Micro-grid (categories 1b and 2a):** It is estimated that India has more than 3,000 AC micro-grids and more than 10,000 DC micro-grids. The size of AC micro-grids ranges from 6 kW to 70 kW, each serving approximately 25 to 30 HHs. The smaller DC (2-4 kW) micro-grids serve 5 to 10 HHs each. It is estimated that 0.175 million HHs are connected through micro-grids. Out of which, approximately 50% (0.087 million) are powered by AC micro-grids while the others by DC micro-grids. About half the HHs connected to micro-grids are also connected to the main grid (category 2a). The remaining half are completely off-grid, i.e., connected **only** through micro-grids (category 1b).
- **SHS and solar home lights (category 1a):** As per the MNRE Annual Report 2019, the government has supplied more than 1.7 million units of solar home lights under various solar off-grid programmes.
- **SHS (category 2b):** In 2018, approximately 51,834 units of SHS were sold by DRE players to main grid HHs. The industry growth was estimated to be 30% year-on-year, but the actual growth might be less. As per estimates, cumulative 0.3 million main grid HHs have adopted standalone SHS systems as a power back-up solution.
- **Hybrid solar inverter UPS system (category 3):** As per discussions with leading solar off-grid inverter players, 0.8 million to 1 million inverters are sold in India annually, with a 25% growth rate. These UPS systems are sold individually or as a package that includes PV modules, batteries and inverters. However, EE appliances are not generally included in the package. Refer to section 4 for more details.
- **Grid-tied rooftop system:** In India, it is estimated that the rooftop size installation base is 940 MW in the residential segment. Assuming that the average installation size is 4.1kW, approximately 0.23 million HHs have grid-tied rooftop systems.
- **Conventional inverter UPS system:** According to industry experts, approximately 8 million conventional inverters are sold annually in India. Assuming that the average life of inverter is six years, approximately 55 million to 56 million HHs are estimated to be using conventional inverters across the country.
- **No power back-up:** As discussed earlier, India has approximately 277 million HHs. Out of these, it is estimated that 59 million are either using conventional inverters or solar systems such as SHS, micro-grids, multi-lights, hybrid solar UPS systems, or grid-connected rooftops. Therefore, approximately 218 million HHs still do not have access to a reliable power back-up solution.

Although grid access has been achieved the reliability of service remains a challenge



In 2019, 0.8 million hybrid solar inverter UPS systems were sold in India. In addition to this, around 8 million conventional inverters are sold in India every year

4. Opportunities and Potential for Hybrid AC-DC Solutions

4.1. Overview of Hybrid AC-DC Power Solutions

Government efforts to improve energy access in India have resulted in increased power supply hours in many regions, including rural areas. However, the supply is still unreliable and staggered through the day as evident from the 0.5% power supply deficit and 0.7% peak power deficit at the end of the financial year 2019–20[7]. Therefore, the demand for power back-up systems is expected to continue to grow. One of the technology trends in power back-up systems is a shift towards solar-based solutions. With increased consumer awareness of solar benefits, there is greater demand for solar integrated power back-up grid-inverter solutions.

One HAD power solution that can cater to this growing demand is the hybrid solar inverter UPS system. These systems allow the load to run directly on solar and charge the battery when it is not fully charged. This feature enables consumers to save on grid electricity bills for regular consumption. Additionally, it provides power back-up during a blackout, similar to a conventional UPS system. Its higher variant hybrid grid-tied inverter additionally supports grid-export and is expected to become popular in residential rooftops and also in micro-grids. One company Tata Renewables, that is targeting 10,000 micro-grids in India in the next five years, has installed hybrid grid-tied solar inverters in its existing micro-grid sites. The micro-grid inverters are operating in purely off-grid mode currently but in future may integrate with the main grid.

In India, many of the established UPS players, such as Luminous, Microtek, and V-guard, have already launched hybrid solar inverter UPS solutions while the hybrid grid-tied inverter market is in its nascent stages, with only a few players, such as Enertech, Statcon Energia, Sofar, Solax and others.

Benefits of HAD power solutions: Hybrid power solutions have a higher upfront cost but have more advantages compared to i) standalone solar systems, ii) conventional plain inverters/ UPS, and iii) conventional grid-tied inverters used in rooftop systems. Some of the benefits are listed below:

- Unlike standalone SHS, the grid-integration facility in solar UPS solutions or hybrid grid-tied systems allows the battery to be charged through the grid, if solar is not available or insufficient to charge the battery.
- Unlike conventional inverters, solar is used to charge batteries, which is mostly cheaper than grid tariffs. Hence, the consumer saves money.
- Unlike grid-tied inverters, solar power is not wasted in case of a power cut. It can be used to run a load directly (using charge controller) or charge the battery.
- In the case of hybrid grid-tied inverters, the extra solar units can be exported to the grid, which is not possible with solar UPS systems.

4.2. HAD Power Solution-1: Hybrid Solar Inverter UPS Systems

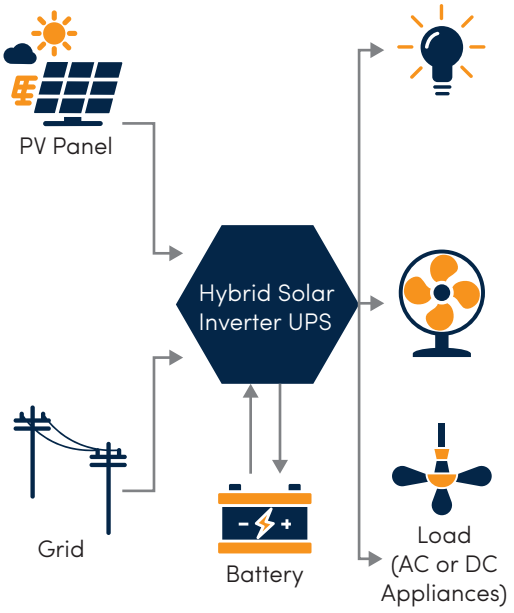
1. Technical Configuration and Usage

Hybrid solar inverter UPS systems combine grid, battery, and solar as an input, as shown in the figure-4. The excess solar power **cannot be** exported to the grid.

Some variants available in the market, based on the output are:

- Only AC output
- Only DC output (generally packaged with DC appliances)
- Both AC and DC outputs (example: Luminous and others)

Figure 4. Technical Configuration of Hybrid Solar Inverter UPS



7 Central Electricity Authority, Load Generation Balance Report 2020 (Annexure VI-A).

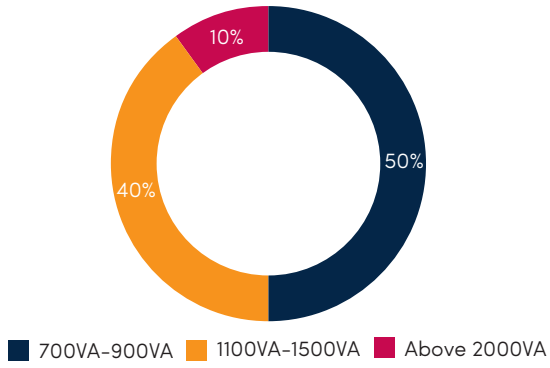
In India, many of the established UPS players, such as Luminous, Microtek, and V-guard, have already launched hybrid solar inverter

There are also retrofit solutions available in the market (example: Luminous and others) that adds a solar charge controller to conventional UPS and convert it into a hybrid solar inverter UPS.

2. Existing Penetration

In 2019, 0.8 million hybrid solar inverter UPS systems were sold in India. In addition to this, around 8 million conventional inverters are sold in India every year. The current hybrid solar inverter UPS systems market is 10% of the size of the conventional inverter market. The hybrid solar UPS industry is growing at 25% annually, whereas the conventional inverter market is growing at 10% annually. The industry is expected to see a similar growth rate in volumes over the next three years as per the interviewed industry stakeholders.

Figure 5. Conventional Inverter Sales by Capacity



For residential use, the general size of conventional inverters varies between 700-2000 VA, with 700-900 VA having the highest market share of 50%, as shown in Figure-5. The trend is similar for hybrid solar UPS systems, with 700-900 VA being most popular.

Some established players in the conventional inverter segment, like Luminous and Microtek, are already offering hybrid solar UPS solutions. These are either sold as a single product or packaged as a SHS together with PV modules and batteries. With lead-acid batteries and no remote monitoring system, the cost of a typical hybrid solar inverter UPS system is 20 to 30% higher than that of conventional inverters. As battery storage is becoming more affordable, a few players have launched lithium-ion battery variants as well.

3. Potential

The product will be a better fit for consumers who have access to power for more than 8 hours per day(preferably 12 hours or more). For customers with less than 8 hours power supply per day from the main grid, hybrid solar inverter UPS will require a relatively higher size of PV modules to compensate for lower grid power. This increases the product cost and can be a difficult proposition for this user segment, limiting its adoption.

According to the experts consulted, approximately 220 million HHs can afford conventional inverters in India (the addressable market). On average, 60% of the overall demand is from rural areas and the remaining 40% is from urban areas. Currently, 55 million HHs have already installed conventional inverters. The remaining **165 million** make up the potential customers for hybrid solar inverter UPS systems. Further, the 55 million HHs that already have conventional inverters can be targeted to convert their existing back-up solutions to a hybrid solar UPS solution.

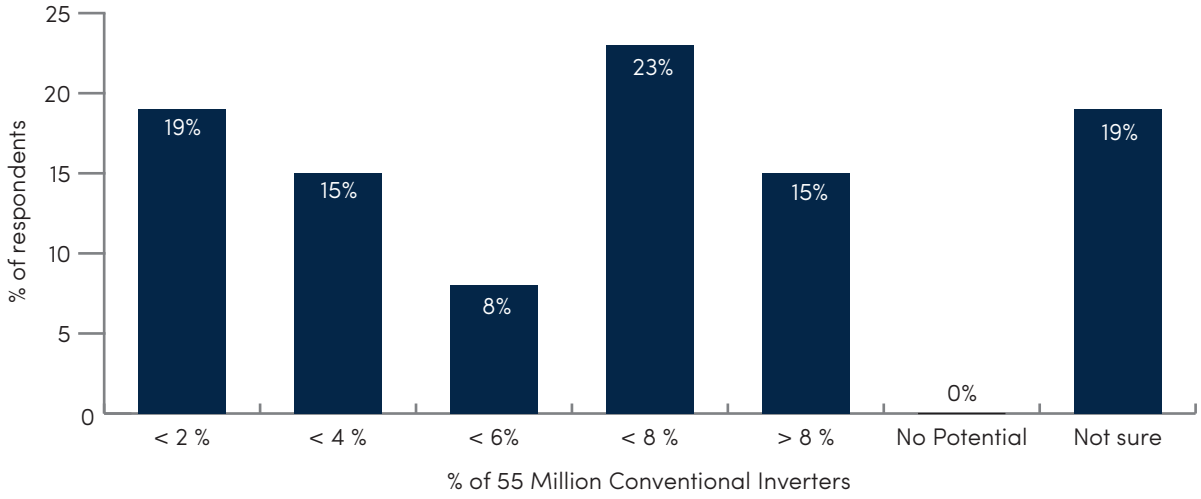
Considering current sales and growth figures of both conventional and hybrid inverters, it may take some 15 years to attain the addressable market size, with an annual sales rate of 9-10 million units (combining both conventional and hybrid solar inverters).

According to the GOGLA-pManifold India Industry Outlook Survey 2020 on Hybrid AC-DC infrastructure (IIOS-HAD 2020)8, all respondents see a potential for solarisation of existing conventional UPS systems to become hybrid solar inverter UPS solutions (i.e. retrofitting). 38% of respondents believe that solarisation can capture more than 6% of the market share of the total 55 million conventional inverter installations over the next three years.

It is expected that hybrid solar UPS systems with AC output will account for the majority of the sales. Due to grid electrification, the

8 The survey was organized with an objective to capture views on the potential of Hybrid AC-DC infrastructure in India from LVDC and solar industry. The survey queried about outlook on government's electrification efforts, adoption of solar rooftop systems, hybrid power solutions and hybrid appliances. The total sample size of 36 respondents spanned across categories of manufacturer, system integrator, consultant, discom and institution.

Figure 6. Potential for Retrofitting 55 Million Conventional Inverters



demand for AC appliances has further increased. The consumer shift from AC to DC appliances faces steep challenges as it requires high sales efforts and adoption volumes are limited. As per the advice of industry experts, it may take a decade for a noticeable jump in the adoption of DC systems and appliances to appear in the market. The supply chain and high prices are some of the larger barriers in scaling up adoption.

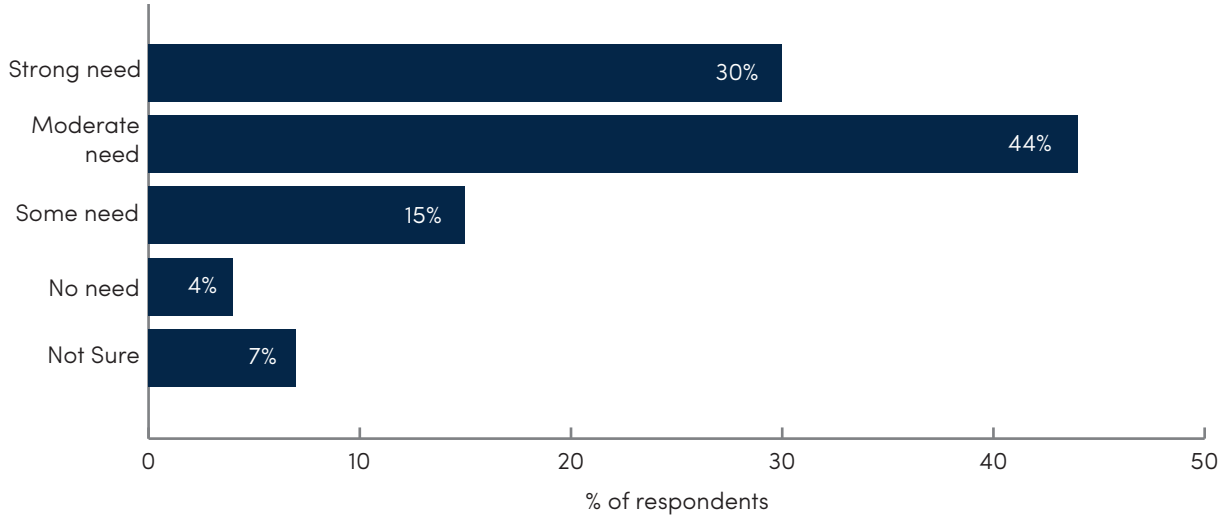
As per survey results, 89% of the total respondents believe that there will be a need for power back-up solutions to have two separate AC and DC outputs to allow efficient and direct supply to DC appliances.

Despite this, some OEMs have launched hybrid solar inverter UPS solutions that provide both AC and DC outputs to cater to both AC and DC markets. Recognising the market potential and changing consumer preferences, some GOGLA India members (OEMs) have shifted from standalone solar systems to hybrid solar systems over the last two years.

Similarly, productive use leveraging solar energy (PULSE) appliance manufacturers are also attempting to upgrade product models by offering solutions that can be powered by both solar systems and grid connections. For example, Alto Precision has a rice huller machine, a 'Made in India' product that uses a hybrid solar inverter that outputs both 48V DC and 220V AC power.

PULSE appliance like power looms can be upgraded to interoperate with AC-DC power supply using hybrid solar inverter UPS. There are nearly 27 lakh registered power looms in India, out of which 35,000 looms are in decentralized sector. The main clusters of power loom are in the states of Maharashtra (Ichalkarnaji, Solapur,

Figure 7. Need of Power Solutions & Energy Efficient DC Appliances to Have Both AC and DC Lines Support



Bhiwandi and Malegaon), Gujarat and Tamil Nadu (Erode, Salem, Madurai). The government (like Tamilnadu) provides a subsidy component of 50% on the equipment cost.

According to the experts, the demand for small systems (<0.5 kW) and medium systems (0.5 kW–3 kW) is expected to be higher among HHs that receive power supply for less than 8 hours and 8-23 hours, respectively. Some states like Chhattisgarh offer capital subsidies of up to INR 25,000 for a small solar pack system, which would result in sales for small systems being higher across all energy tier consumer categories.

3.1. Growth Rate

The price of hybrid inverters is generally 20-30% higher than that of conventional inverters. Today, the majority of sales are of inverters are compatible with lead-acid batteries and do not have a remote monitoring system. Typically, for a small system (1–2 kW), the remote monitoring system and a battery management system for lithium-ion batteries increases the bill of material cost by INR 4,000-5,000. The sample cost breakdown is below.

- Battery management system (BMS): INR 2,500-3,000
- Remote monitoring system (RMS): INR 1,500-2,000

The adoption of hybrid solar UPS with lithium-ion batteries may see relative slower adoption in next 2-3 years because of higher energy storage cost. However, the continuing fall in lithium-ion battery prices ($73/kWh by end of 2030) will eventually drive hybrid inverters with lithium-ion battery storage that are more efficient and economical. The variant with bundling of (in-built) lithium-ion batteries is also expected to grow.

According to industry experts, the hybrid solar inverter UPS market growth rate is expected to be 25% over the next five years. However, due to COVID-19, the sales volume in year 2020 is expected to remain flat or even 75% of the last year sales.

3.2. Regions with the Highest Potential

The power supply deficit and average power supply in hours per day are useful indicators to assess key potential states for solar hybrid back-up solutions. Some of the top power deficit states in India are Jammu & Kashmir, Jharkhand, Bihar, Telangana, Odisha, Kerala, Uttarakhand, and Uttar Pradesh.

Similarly, major demand is expected from areas with power cuts of more than 3 to 4 hours. Jammu & Kashmir, Jharkhand, Uttar Pradesh, Bihar, Odisha, and Karnataka could be the states to focus on. Refer to Annexure-3: Average hours of supply in a day in rural areas across different states.

Sales (2019)

0.8 million units

Estimated Sales (2023)

1.6 million units

As per discussions with leading OEMs, conventional inverter sales are primarily distributed between energy tier 3 and 5 customers (having more than 8 hours power availability). The top potential regions/states in order of priority are eastern Uttar Pradesh (18-20 hours.), Bihar (16-18 hours), central Uttar Pradesh, Haryana, Punjab, western Uttar Pradesh, and Maharashtra.

4. Challenges for Scaling Up

Some challenges discussed by industry players and experts are listed below:

- **Lack of product innovation**: The production innovation around hybrid solar inverter UPS inverters has been limited. They are generally compatible only with lead-acid batteries. Very few manufacturers of hybrid solar inverter UPS solutions integrate both solar and lithium-ion batteries, and their products are priced high. Product innovations are required to drive performance improvement, cost reduction and hence higher adoption.
- **Lack of local service centers:** Only a few players have pan-India service support. The presence of a local service team is an important factor to increase sales.
- **Lack of enforcement of standardisation:** BIS has adopted a 48V DC standard, but still many DC appliances are using different DC input voltages – for example DC fans use 12 V/ 24 V DC; TVs uses 12 V/ 19 V/ 24 V DC, etc. This makes it difficult to agree on one common DC voltage output from hybrid solar inverter UPS. Additionally, the limited supplies and service associated with external DC-DC converters and other DC components

Case Study:

Hybrid Solar Inverter UPS Solution uptake in Chhattisgarh

As per a brief assessment in Chhattisgarh, there is strong demand for hybrid solar UPS systems, particularly 300W systems subsidised by CREDA. One interviewed Dealer sells approximately 15 units a month, mostly in small cities and rural areas. The tentative cost breakdown is given below:

Component	Specification	Retail Price with GST (INR)
PV Module	12V / 150 W – 2 Nos.	7,900
Hybrid Inverter UPS	700VA	6,000
Structure for 2 PV Modules	As per the requirement	2,000
Solar Battery	12 V / 150 AH	14,100
Balance of System	As per the requirement	1,000
Total Cost		**31,000**

Adding other costs like transportation, installation, post-installation service, and other miscellaneous expenses, the total price for the system come to INR 40,000. After subtracting the subsidy amount of INR 20,000, the net price is INR 20,000. Hence, hybrid solar systems with subsidy are more cost-effective (approximately INR 20,000 with battery) than conventional inverters (approximately INR 30,000) which do not receive any subsidy.

There is growing awareness amongst customers on the benefits of solar, and subsidies supporting price parity of HAD power back-up solutions which has positively impacted sales in Chhattisgarh. Similar policy measures can be taken up by other states.

Case Study:

Energy-Efficient Solar Rice Huller employing a Hybrid Inverter

Rice hulling machinery require substantial energy that may be expensive or inaccessible to farmers, causing them to opt for manual hulling or rice mills. These increased costs and lower time productivity reduce the income potential of the farmer.

Alto Precision offers a solar rice huller machine using a hybrid solar inverter to tackle this challenge. The inverter can use either a 48 V DC or a 220 V AC input power supply and provide a regulated DC output (48 V or 180 V DC). This rice huller improves hulling efficiency up to 95% from 80-85%, typical of local available machines. There is also a 35% increase in the rice hulled when compared to manual hulling. Moreover, it takes significantly less time (1 hour) to husk 100 kg of rice, when compared to manual hulling (14 hours). Such innovative hybrid solar power solutions employing a BLDC motor helps reduce market incidental costs incurred by farmers like transportation costs, in addition to the loss of wages and electricity bills.

Figure 8. Solar Rice Huller

Figure 9. Technical Specifications of Solar Rice Huller

Technical Details	Units	Value
Capacity	kg/hour	100
Motor (BLDC)	HP	0.5
Power Supply	V	48V DC, 220V AC
Hulling efficiency @max capacity	%	90-95
Solar Modules	Wp	250 Wp x 2 to 4 modules
Usability	Hours/day	8
Cost (including installation)	INR	65,000

If the grid-export (of excess power generated) feature is further added to this solution, it can further add to the income of the farmer even when the machine is not in use.

and appliances, including hassles with home wiring changes, further adds to DC adoption barriers.

4.3. HAD Power Solution 2: Hybrid Grid-tied System

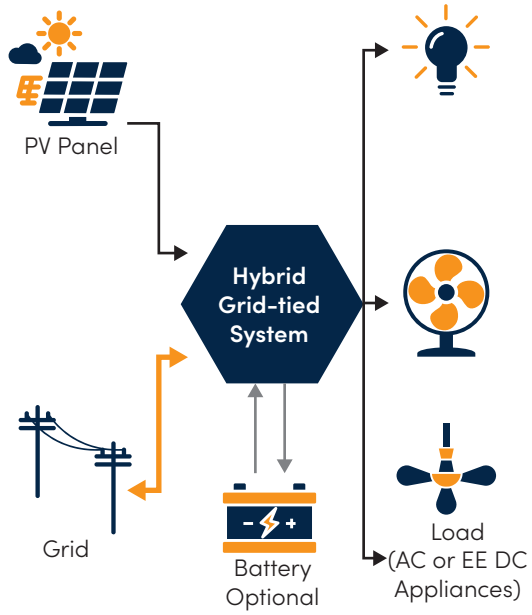
1. Technical Configuration and Usage

The hybrid grid-tied inverter is an upcoming technology in the market. It combines grid and solar (battery is optional) as input power and allows export of power to the main grid. The USP of these inverters is that they can operate in both the on-grid and off-grid (only if battery is available) modes depending on grid power availability. At the same time, the customer can opt for a net-metering facility, if applicable, from the Discom.

2. Existing Penetration

The government target for rooftop solar in India is 40,000 MW by 2022. By March 2020, approximately 15.7% of that target was achieved. The commercial and industrial (C&I) customer segment accounted for 73% of the market share. The remaining installed capacity was distributed between the government (13%) and residential segment (14%). In the last financial year (2019), an estimated 0.1 million HHs have installed conventional grid-tied inverters. This is 37% of the total estimated residential installation (approximately 0.23 million HHs).

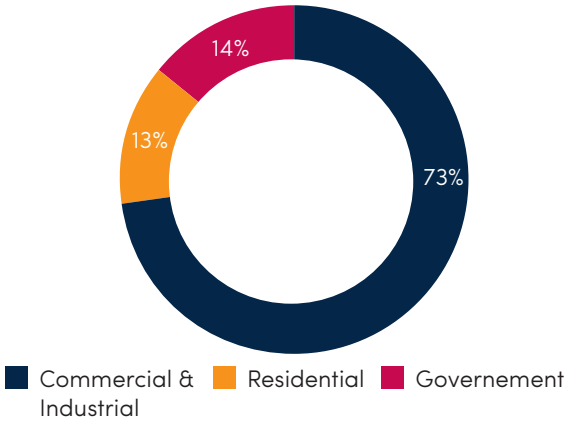
Figure 10. Technical Configuration of Hybrid Grid-tied system



Today, most rooftop installations in India use a conventional grid-tied inverter without a battery, while the penetration of hybrid grid-tied inverter power solutions remains very low. The smallest size available for hybrid grid-tied inverters is rated for an output of 3 kVA AC / 48 V DC, single phase. When there is a power failure, conventional grid-tied systems stop generating solar power. Therefore, hybrid power solutions are most suitable for where power back-up is a primary need and the system is installed as an SRT under gross or net-metering policies.

Micro-inverter-based[9] solutions are another growing grid-tied option. It is estimated that less than 2,000 HHs have installed micro-inverter based SRT solutions. However, these solutions are two or three times more expensive than conventional grid-tied inverters and a battery integration feature is not available in the Indian market as yet.

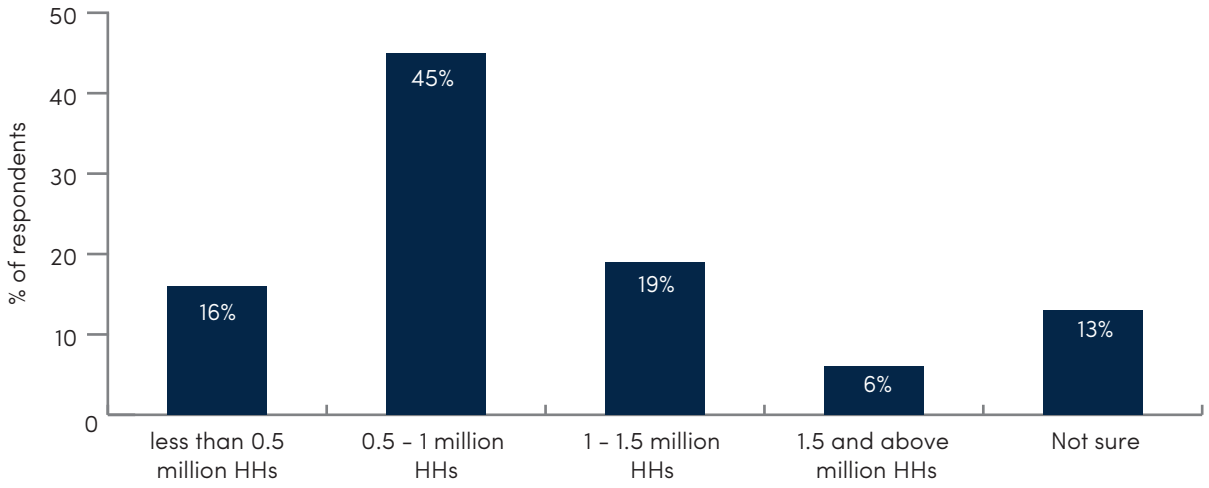
Figure 11. Solar Rooftop Installations till 2019



Note: A common misconception about solar is that the system will always generate power even during outages. This is not true as traditional grid-tied solar inverters automatically shut off during power outages due to a feature known as anti-islanding. This is to protect line workers repairing faults in the grid. Thus, a hybrid grid-tied inverter system is recommended for customer looking for back-up power due to frequent power cuts. Hybrid inverters running EE appliances during a grid outage are a great solution. They have both on-grid and off-grid capabilities, allowing them to continue running on solar power even if the grid failure.

9 Micro-inverter: A device used with solar arrays to convert the energy that is generated (Direct Current) to usable electricity for a home (Alternating Current). Each micro-inverter is connected to a single solar module for maximum control and reliability.

Figure 12. Potential HH Solar Rooftop Adoption in next 3 years



3. Potential

Assuming the residential segment continues to account for 14% of the total SRT potential market (i.e., 40,000 MW) and that the average size of the installation is 4.1 kW10, the market potential of grid-connected rooftop solutions in terms of number of HHs is approximately 1.37 million. Out of this, only 0.23 million HHs have currently installed solar rooftop systems in India.

Potential users include new SRT customers who have frequent power cuts, or those who live in the states where obtaining gross or net-metering approval from Discoms is a challenge. Potential users will also emerge from states with favourable off-grid SRT policies. As per IIOS-HAD 2020, 45% of the respondents expects that another 0.5-1 million HHs will opt for grid-connected solar rooftop systems over the next three years.

3.1. Growth Rate

The cost of a 5kW hybrid grid-tied inverter (approximately INR 65,000, excluding battery and PV module cost) is twice the cost of a conventional grid-tied inverter (approximately INR 30,000) and one-and-a-half times the cost of a hybrid solar inverter UPS system (approximately INR 40,000). However, the hybrid grid-tied inverter combines features of both the grid-tied and hybrid inverter UPS solutions but is less than their combined costs by about 7%.

Many OEMs have plans to launch their hybrid grid-tied inverter models in India by next year. It may be too soon to predict the market size and growth for such solutions, but sales are likely to be driven by government support initially.

Sales (in 2019)

< 1,000

Estimated Sales (2023)

0.03-0.04 million

(assuming 10% of grid-connected rooftop installations use hybrid grid-inverter-based)

3.2. Regions to Focus On

The limitation of hybrid grid-tied inverters is that they are generally available in larger sizes (3 kVA and above) and are expensive, restricting their adoption to bigger cities.

Hybrid grid-tied inverters are more likely to be popular in states with high penetrations of residential and government rooftop installations. Based on the SARAL (State Rooftop Solar Attractiveness Index) launched by the MNRE, some potential states are Karnataka, Telangana, Gujarat and Andhra Pradesh (see Annexure-4: State-wise SARAL score).

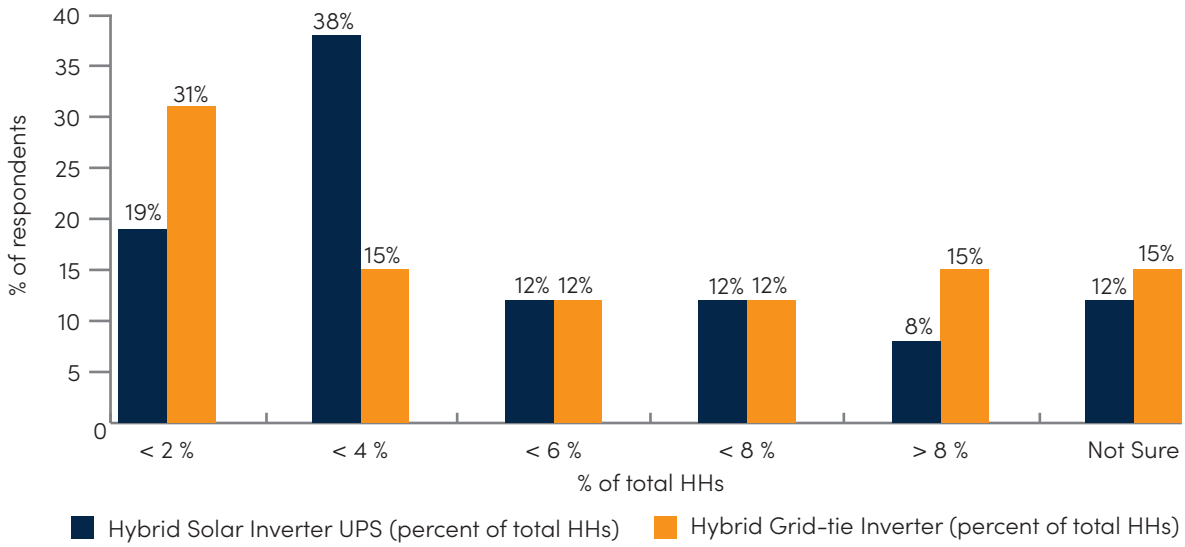
4. Challenges for Scaling Up

Though the grid-connected rooftop market has grown by over 50% over the years, it has underperformed compared to government and market expectations. Some challenges associated with big (>3 kW) systems using hybrid grid-tied inverters are:

- Capital subsidies for residential grid-connected solar rooftop installations are applicable only for conventional solar grid-tied inverters

10 As per interviewed industry experts

Figure 13. Potential for Adoption of Hybrid Power Solutions



- The high payback period for residential customers (seven years) due to higher inverter costs
- Limited financing for the residential rooftop segment
- Very few players focus on promoting SRT in rural areas under the MNRE subsidy programme. Hence, a major subsidy outlay goes to urban consumers.
- Lack of roof or space for PV module installation
- Big players focus more on the commercial and industrial segments

As per IIOS-HAD 2020 survey results, 38% respondents believe <4% of total HHs will adopt hybrid solar inverter UPSs while 31% respondents believe <2% of total HHs will adopt hybrid grid-tied inverters over the next three years.

4.4. Overview of Hybrid Appliances

Hybrid solutions are becoming popular in the market due to both AC and DC ecosystems evolving in parallel. Much of the credit goes to the off-grid solar industry. Now, there is a possibility that customers can have access to both AC and DC supplies. This can open up opportunities for OEMs in the emerging appliance or hybrid appliance market.

For this study, two types of hybrid appliances were considered:

- Dual AC and DC input appliances
- Battery-integrated appliances with a single AC input and in-built battery storage

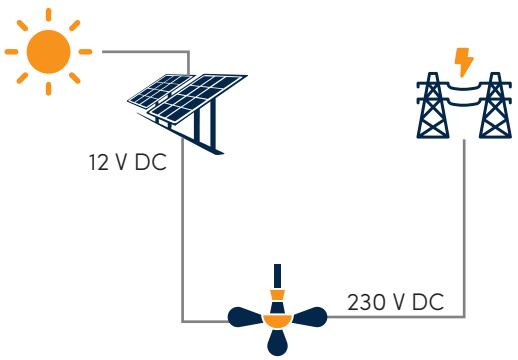
Dual inputs: These appliances can run on both AC and DC power. Various OEMs have produced dual input versions of common HH appliances, including TVs, fans, air conditioners, and deep freezers. The appliances have input voltage levels of 220V AC and 12V/ 24V/ 48V DC according to their power consumption. In general, dual inputs are most suitable for BLDC/ PMDC motor-based productive applications.

Some examples of appliances with the dual-input feature options are discussed below.

a. **Fans (Sinox Power):** Sinox Power's hybrid BLDC ceiling fan is a dual input 220V AC / 12V DC appliance that can be operated using a remote. It is relatively expensive due to the hybrid controller used.

Table 2. Technical specification of hybrid fan

Technical Details	Units	Value
Power Rating	W	35
Sweep	mm	1200
Nominal Operating Voltage	V	12V DC & 220V AC
RPM	rpm	350
Air Delivery	CMM	220
Warranty	years	2
Type of motor	-	BLDC
Cost	INR	~ 3,600



b. Air conditioners (Videocon and Solar AirWorld): These hybrid air conditioners runs on both AC and DC power with an intelligent power management technology that prioritises solar during daylight hours. The Solar AirWorld Hybrid AC product can also accept DC power directly from PV modules, without needing an inverter, controller, or batteries.

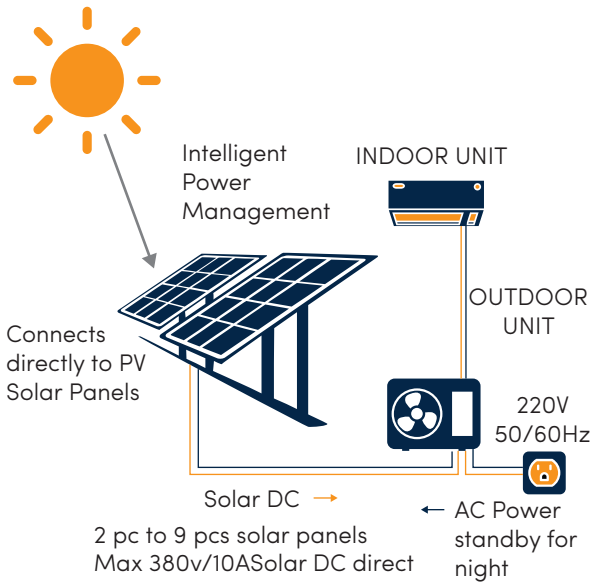
In 2017, Videocon launched its hybrid solar AC in two variants, 1.0 ton and 1.5 ton, priced at INR 99,000 and INR 1,39,000, respectively. These include a PV module, a solar inverter and complete accessories with the technical specifications below:

Table 3. Technical specification of hybrid air conditioner (Videocon)

Technical Details	Unit	Value
Capacity	ton	1.5
Solar PV	kW	2.5 kW
Solar Qty	Wp	250 Wp x 10 modules
Solar Inverter	kVA	4 (Off-rid mode)
Solar Battery (Optional)	AH	210 AH x 4 units
BEE Rating		5 Star
Refrigerant		R-410A
Power Supply Volt	V	220V AC and 50-300V DC
Warranty	Years	5 years for compressor and 25 years for solar PV module
Type of Motor		BLDC
Price	INR	1,39,000 (Included installation)

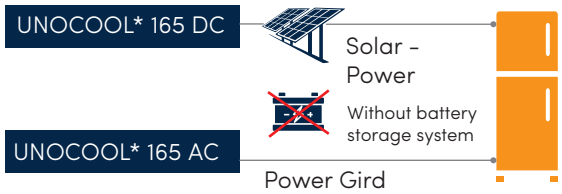
Solar AirWorld also launched the Solar World (SW) Hybrid Air Conditioner with intelligent power management. The air conditioner must be connected to a 220/240V AC power source and is capable of for off-grid operation. It runs on solar during the day and automatically switches to the grid when there is insufficient solar power.

Figure 14. Hybrid Air Conditioner (Solar AirWorld)



c. Refrigerators (Global Icetech): In the off-grid market, though there has been interest in PULSE appliance like solar off-grid deep freezers and refrigerators, the high price of DC appliances are a barrier for economies of scale. A PULSE appliance like dual input like refrigerator available in the market as shown in Figure 15.

Figure 15. Dual-input Refrigerator



Currently, the solar powered refrigeration market in India is nascent. The market size of solar off-grid refrigerators is only USD 21 billion[11] with a 10% adoption rate. The key players are Devidayal Solar, Cygni, Dulas, SureChill, Inficold, Ecozen, PLUSS, Promethean Power, Phocos, Sinfin, and Tan90. On the other hand, the annual demand for deep freezers in India is estimated to be between 0.7–0.8 million units. Demand is concentrated in the FMCG (Fast-moving consumer goods) industry. These appliances are generally provided on lease to retailers. Hence, energy efficiency is not a top priority for most of them as corporations are not willing to pay

Figure 16. Mitashi TV with dual input

11 Market Study on Solaar Off-grid Refrigeration

a premium price for EE technology (like inverter technology that uses BLDC motors). Therefore, end-users (retailers) are left with no choice but to use inefficient technology. Moreover, at present, there is no star-rating system for deep freezers in India. If the rating is implemented, it will increase competition among OEMs to adopt inverter technology.

d. **Televisions:** Televisions are also available with dual-input pins like the Mitashi TV shown below, with 100-240 V AC and 12 V DC inputs at the back.

Single-input (AC) appliance with in-built battery storage: These appliances come with in-built lithium-ion batteries and use AC input power. In case of a power cut, the in-built battery can power the appliance for up to four hours. The small battery can be charged even when power availability is limited (less than four hours). Such appliances may be particularly useful in weak-grid areas and can serve as an alternative to traditional power back-up solutions. However, there are some associated challenges:

- High appliance costs due to in-built battery
- Low awareness levels among consumers
- Product reliability and post-sales service support due to battery integration
- Battery design and integration can be a challenge for many appliance OEMs as they do not have any prior experience with batteries

> **The market price of a good quality hybrid fan is between INR 3,600-4,200**

Some reputed OEMs that are already manufacturing consumptive hybrid appliances are mentioned below:

a. **LED Bulbs (Philips, Syska)**

Since they can be used even during power cuts, hybrid bulbs, also known as emergency bulbs or inverter bulbs, are now immensely popular. There is no reported sales data for hybrid bulbs, but they are estimated to be in the range of a few millions.

These bulbs have received positive reviews, with an average 4-star rating, on e-commerce websites like Amazon and Flipkart. The bulbs are priced between INR 250-400, and their product warranty is between one and two years.

b. **Table fans (Rico, Eveready)**

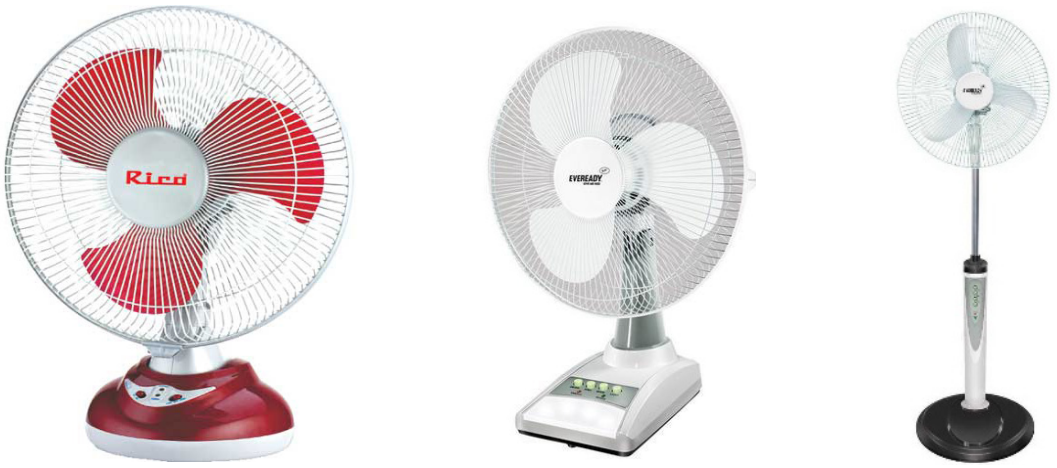
Many OEMs have attempted to develop rechargeable fans. Due to a lack of customer awareness and high prices, these fans are yet to become popular. The market price of a good quality hybrid fan is between INR 3,600-4,200. They come with a product warranty of one year and have received mixed reviews online. Local customer service support for repairs is a key ask from customers. Such a product has great potential, especially in rural areas, since it enables cooling during a power cut.

c. **Mixer grinder**

A leading manufacturer of BLDC fans plans to launch a BLDC-based mixer grinder next year. Currently, all mixer grinders available use universal motors. This EE mixer grinder is expected to be a high-power mixer grinder (750 W) and its market price is expected to be on par with products by leading OEMs. An OEM interviewed has also evaluated the option of including built-in lithium-ion batteries and estimates that the battery may increase the product price by 20%.

Figure 17. Battery-integrated Bulb

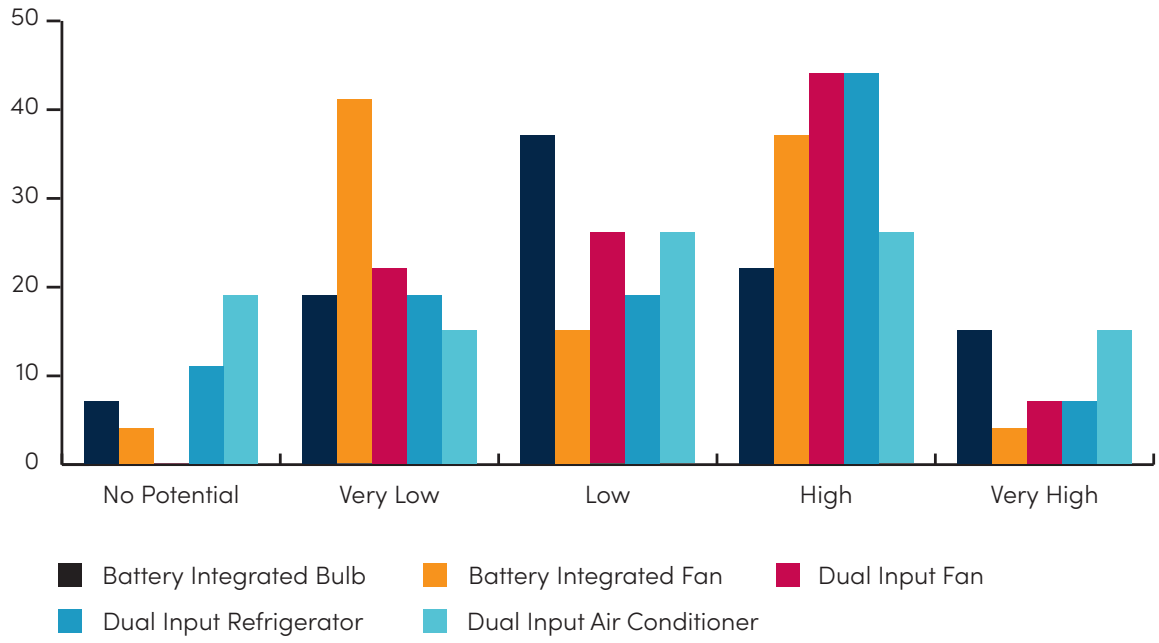
Figure 18. Battery-integrated fan



In conclusion, the price of hybrid appliances is two to four times more than that of conventional appliances. However, as the concept gains popularity among both OEMs and consumers, the price may fall and appeal more to the masses. Appliances like hybrid bulbs and fans with battery storage can be a good solution for consumers who cannot pay upfront for central power back-up solutions and for whom access to consumer finance is a challenge. Moreover, OEMs can look forward to upgrading the PULSE appliances like solar off-grid refrigerators to hybrid appliance with dual input. Certain other PULSE appliances like chillers and power looms can also be integrated with solar DC. As the price of lithium-ion batteries fall, these products may become more affordable. However, they may still may not match the price of traditional appliances because of the inclusion of a hybrid controller and an in-built battery.

As per IIOS-HAD 2020 survey results, the dual-input appliances are expected to have a higher potential than battery-integrated appliances, with dual-input refrigerators being more popular than the other appliances surveyed.

Figure 19. Potential of Hybrid AC-DC Appliance in next 3 years



Case Study:

Battery Integration in Smaller Appliances Like Bulbs and Fans to Improve Customer Affordability of Power Back-up Solutions

A conventional inverter back-up system costs between INR 10,000-15,000. The expected battery life of this system is two to three years. A normal HH, during a power cut, runs two or three lights and one or two fans. If the cost of the appliances is included, the conventional inverter UPS system packaged with appliances will generally cost between INR 13,000 and INR 18,000.

Now, assuming the customer cannot afford a power back-up solution, hybrid bulbs or hybrid table fans are a more affordable alternative. The following are the advantages to the customer:

- The customer has access to basic lighting and cooling even during a power cut without deploying a costly inverter solution.
- The appliances' in-built batteries are small compared to the central battery. This reduces the upfront cost.
- The customers do not have to depend on external financing and can purchase hybrid appliances in a phased manner as per their affordability (e.g. starting with one hybrid bulb, costing approximately INR 500, and later adding hybrid table fans).

4.5. The Overall Potential for HAD Solutions

The primary demand for HAD solutions is expected to come from the following customer segments:

- **HHs with no power back-up solutions:** Around 218 million HHs do not have either a solar or conventional UPS power back-up solution. On average, 8.8 million HHs per year opt for UPS (8 million/year for conventional UPS and 0.8 million/year for hybrid solar UPS solution). Assuming the trend continues, almost 3.2% of the total HHs will buy power back-up solutions every year. Out of this, only 9% are opting for hybrid solar inverter UPS solutions, which is expected to increase to 15%+ by 2023.
- **Potential grid-connected customers:** The market potential of grid-tied rooftop solutions in the residential segment is 1.37 million HHs (for a minimum of 1 kW capacity). Of this, only 0.23 million HHs have installed SRTs in India.
- **Existing HHs using conventional UPS systems:** About 55 million HHs have installed conventional UPS systems. These customers can be targeted to convert them into hybrid solar UPS systems to save on their electricity bills. The conversion of an existing inverter to a hybrid solar UPS solution will require an

Figure 20. HHs electrification categories mapping with potential HAD power solutions

Strategy-1: Upgrading existing power back-up solution; **Strategy-2:** Adding new HH that do not have any power backup solution; **Strategy-3:** Replacement at end of product life

upgrade but it is possible to implement. It may be possible to achieve larger volumes with dedicated efforts by private players and support from the government.

- **Existing Mini/Microgrids:** Some AC Mini/micro grid inverters can be replaced with hybrid grid-tied inverters with export facility (future compatibility)
- **Existing Standalone SHS customers:** Customers using standalone SHS (like 0.35 million HHs provided with standalone SHS under Saubhagya) can also be upgraded to hybrid solar inverter UPS when they have access to main AC grid.

Small (<0.5 kW) and medium (0.5 kW to 3 kW) hybrid solar inverter UPS solutions will see a higher demand. The small systems will be more appropriate for HHs with power availability upto 8 hours while the medium systems will be suitable for HHs with power availability of 8 to 23 hours.

Initially, big (>3 kW) hybrid grid-connected rooftop systems will be in demand in cities and for government hosted tenders. The high cost and new technology can be a limiting factor to achieve volume. However, key policy changes like improving the ease of processing net-metering applications and incentivising (financing) residential and small commercial segments will be important to drive SRT adoption.

The potential market for hybrid solar UPS solutions is expected to come from customers with power availability of 8 to 20 hours in states like Arunachal Pradesh, Jammu & Kashmir, Mizoram, Sikkim, Meghalaya, Jharkhand, Haryana, Uttar Pradesh, Karnataka, Assam, and Odisha. The potential market for hybrid grid-tied inverters is expected to come from states with favourable SRT policies, such as Telangana, Gujarat, Andhra Pradesh, and Rajasthan.

As per IIOS-HAD 2020 survey results, more than 50% of the respondents believe that Maharashtra, Rajasthan, and Andhra Pradesh are the top three states for hybrid solar potential.

There are hybrid appliances with dual input in the market, but their adoption is still limited. AC-powered appliances (even with inherent DC elements like LED or BLDC motor) will continue to be preferred over DC-powered ones. DC appliances with only a DC input can operate in an AC ecosystem through the addition of an external AC-DC converter at the input.

The market for hybrid appliances with a single input (mainly AC) and in-built battery is in its nascent stages. Due to grid electrification, there exists an untapped potential for such appliances, especially in weak grid areas. As the price of battery storage falls further and technology improves, these appliances can become an alternative to installing conventional UPS systems, especially for lower-income groups or BPL consumers, for whom affordability is a challenge. However, the uptake of hybrid appliances with built-in batteries may be limited for HHs already using conventional or solar UPS solutions.

Overall, there is clear evidence that the market is heading towards hybridisation, i.e. the integration of AC and DC power supply. Challenges like high upfront equipment costs, high sales effort, low customer awareness, and post-service support are acknowledged but these factors should not deter off-grid players to diversify and offer HAD solutions.

As per the IIOS-HAD 2020 survey results, the key drivers that will further grow HAD power back-up solutions and appliances market in India are: i) inadequate and unreliable grid supply, ii) reducing the cost of solar power and battery systems, and iii) increasing adoption of EE appliances. The increasing price of electricity and supportive purchase subsidies from governments further improves life cycle value propositions of HAD solutions.

Figure 21. Policy changes to drive higher rooftop adoption

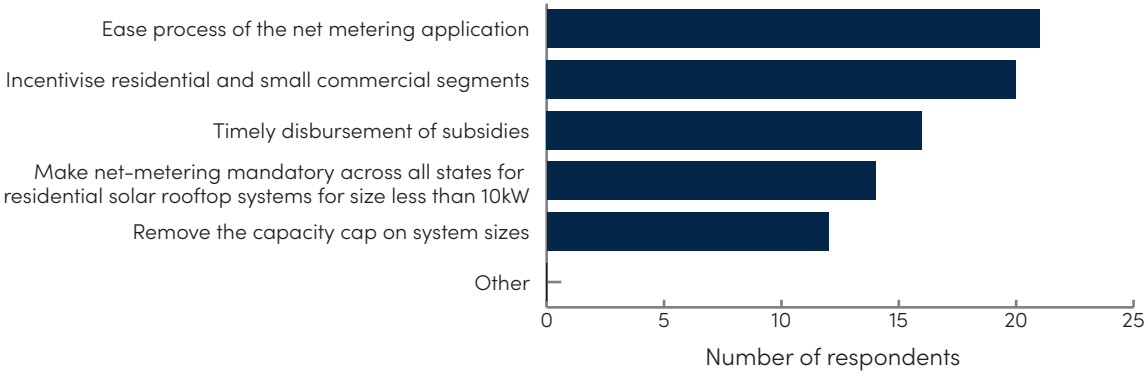


Figure 22. **Potential States for adoption of HAD Solutions**

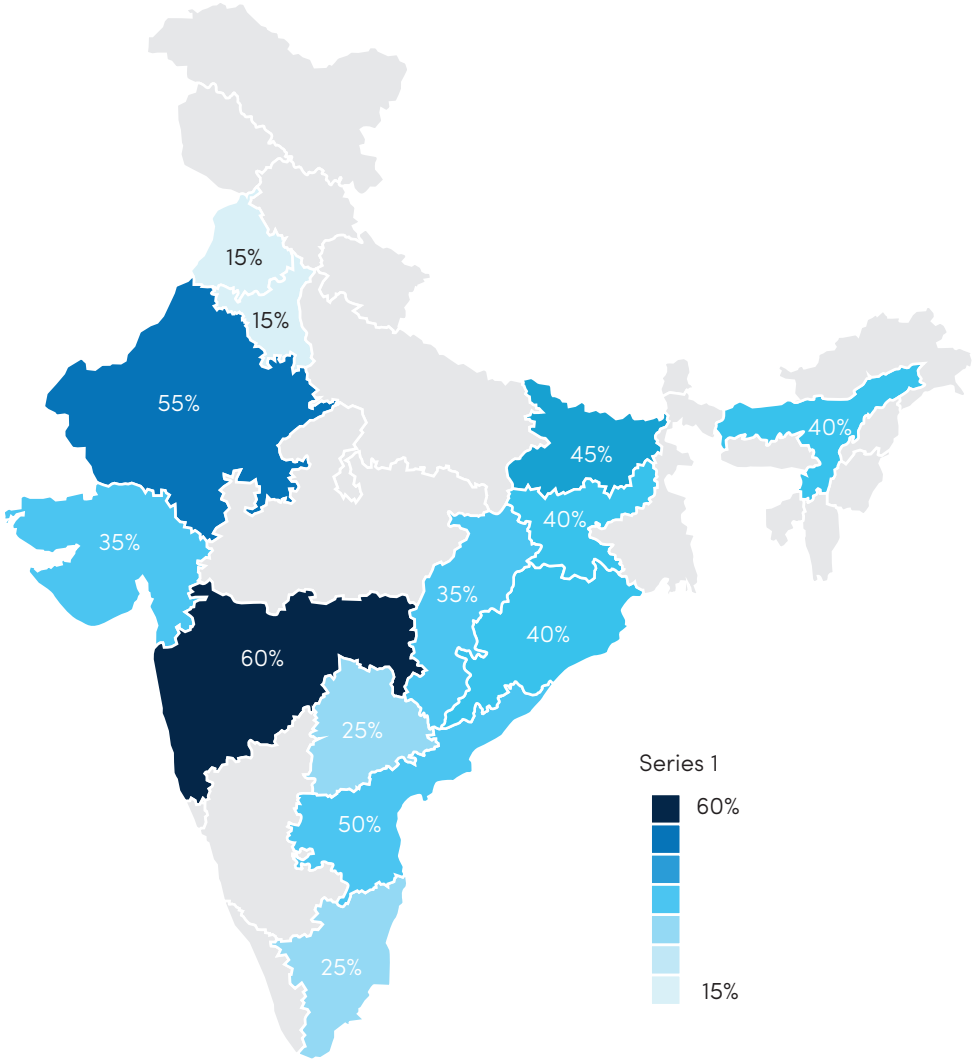
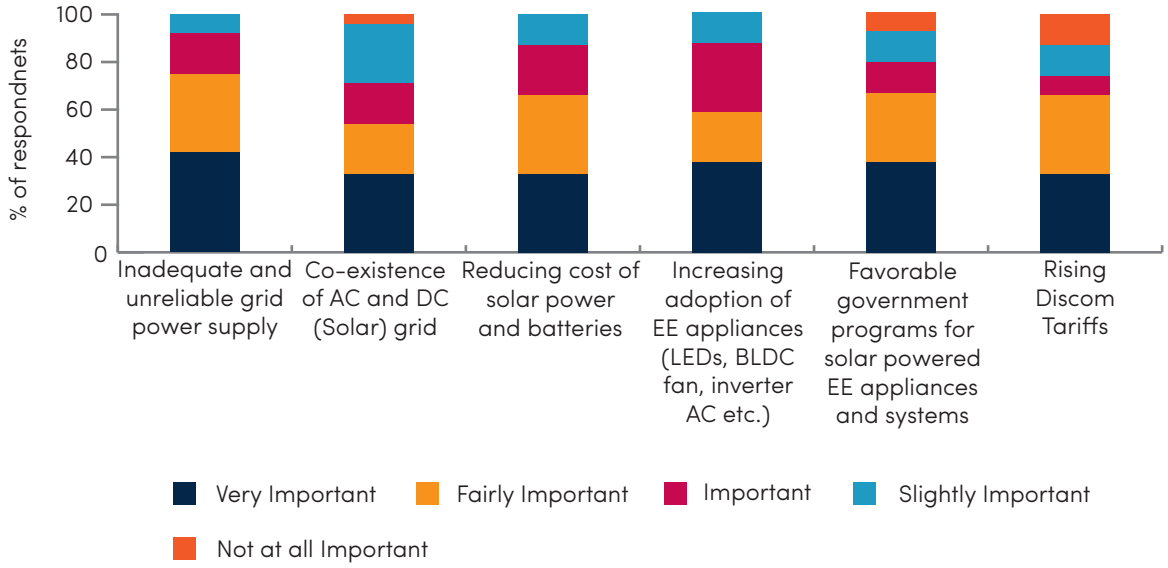


Figure 23. **Drivers for Adoption of Hybrid AC-DC Power Solutions and Appliances**



5. Challenges for the Growth of Hybrid AC-DC Infrastructure

HAD power solutions and appliances form subsets of the EE and clean power solutions/ products supply chain and have similar challenges of industry maturity, growth and scale-up. Figure 22 depicts typical value chain and challenges.

1. **Product Design and Manufacturing**

   Lack of innovation and development: Intermittent grid consumers needs are often served by start-ups and small businesses. These companies have a limited appetite for deeper investments for strengthening their products design, development and manufacturing capabilities. The lack of easy working capital financing to such businesses also impairs innovation and scaling up production. This often leads to less robust quality products going to the weak- and off- grid consumers that do not serve their stated value proposition over life, eroding consumer trust, and hence slower market development.

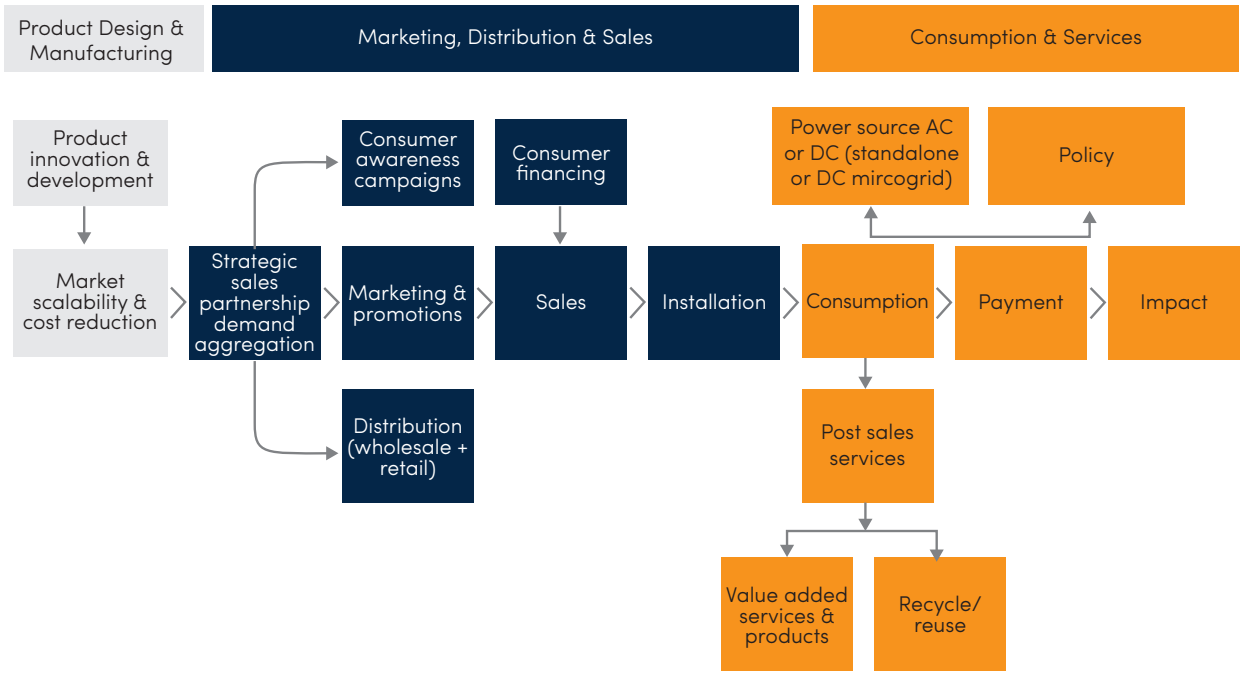
   Higher upfront cost: Hybrid appliances have a higher upfront cost compared to conventional ones. This is partly due to extra safety and protection mechanisms related to the grid-integration feature. Moreover, if HAD power solutions are integrated with lithium-ion batteries, the cost is further increased.

2. **Marketing, Distribution and Sales**

   Lack of strategic partnerships: HAD power solutions are costlier and considered to be a push and not a pull product. As a result, higher marketing efforts are required to drive sales. It may not always be possible for companies to depend entirely on in-house sales team. There is a need for growing strong strategic active sales partnerships, dealerships, and franchisee networks, including institutional sales to deepen consumer access across target geographies. Such partnerships also add to overheads resulting in increased prices of an already niche product to the end-customers.

   Capital intensive marketing and promotional activities: HAD power solutions and appliances are push products with low levels of awareness among consumers. Moreover, their business proposition is not well communicated to consumers. To communicate well and eventually increase sales, various marketing outreach activities have to be planned and executed. This

Figure 24. The Value Chain of Power Solutions and Appliances



exercise needs good investment and can be challenging for small enterprises due to limited manpower and financial resources.

Last-mile delivery challenges: In rural areas, the delivery of any product is a challenge if local dealer networks are not available. The challenge is especially hard in the case of SHS packages, consisting of PV modules, batteries, hybrid inverters and any bundled appliance(s). There are associated risks related to delivery, such as product packaging and transit damage.

Lack of end-consumer retail financing: End-consumer financing can form useful bridge for rural HHs to afford HAD power solutions and appliances. There is not yet any omnipresent successful financing models for rural HHs with a special focus on EE consumption equipment and appliances, like that for city consumers, who are able to access financing for white good products, like air conditioners, TVs, refrigerators, etc. at the point of sale. There are some limited options available like financing provided by the dealer (on personal risk) or some bank tie-ups for loans, but all are on a case to case basis. In addition, the PAYGo model is little explored in India compared to sub-Saharan Africa.

3. **Post-sales Services**

Lack of post-sales and maintenance support: This leads to degradation of the performance of the product and consumer experience. HAD products and accompanying battery systems may require frequent professional maintenance. For off- and weak- grid customers, the physical remoteness of customer sites pose challenges in providing post-sales and maintenance support. Remote monitoring and troubleshooting with a minimum number of field visits to keep cost low and serviceability high, especially in low volume conditions, is a challenge.

4. **Policy Issues**

Not much incentives are available for small HAD systems: Under the MNRE off-grid programme, small SHS (<1 kW) are not recognised. As a result, there is no central subsidy on such systems. Some state nodal agencies (SNAs) provide 20-40% subsidy on grid connected SRT systems but none for small systems.

Discoms delaying or denying SRT net-metering connections: Net-metering approval still remains a challenge in many states. The delay in approval (going beyond 3 months) is leading to lower adoption in the SRT market.

Standardisation

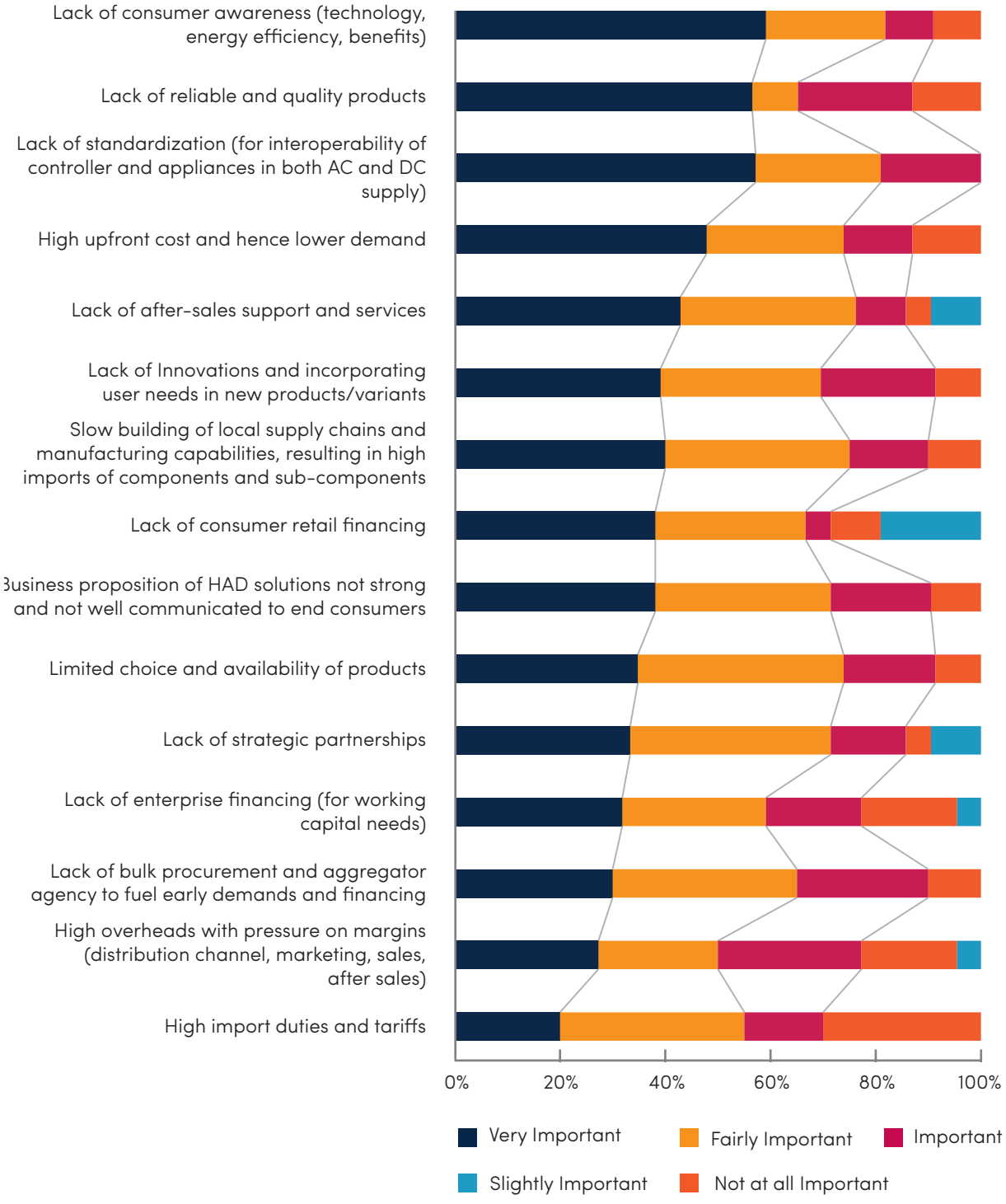
- **Lack of awareness of LVDC 48V BIS standards**: There are hybrid solar products available in the market that can give both 12/24V DC and 220V AC outputs, despite 48V DC being recognised as the DC line voltage for homes for low power applications. Moreover, there are many DC appliances using different DC input voltages making it difficult to agree on one common DC voltage output from hybrid inverter UPSs.
- **Missing interoperability standards for HAD appliances:** HAD appliances should meet standards for the connector, wiring, etc. to allow interoperability between different provider sub-systems and ensure overall safety resulting from grid interactions. There is some related work in progress in DC appliance standardisation at BIS, and once published it can be extended to HAD appliances.
- **Absence of minimum performance standards for HAD appliances:** Till date, BEE has laid down minimum energy performance standards (MEPS) for 26 appliances under the Standards and Labeling Program, which allows the consumer to make an informed choice about the energy-saving and thereby cost-saving potential of the marketed product. This should be extended to hybrid solar inverter, new high potential HAD appliances like in-built battery storage bulbs, fans, and others to raise quality bar for OEMs and ensure high performance to end-consumers.

Lower localisation of HAD products: India has an annual demand of 10 GW of PV equipment, of which 85% is imported, despite having an installed manufacturing capacity of nearly 11 GW of PV modules and about 3 GW of PV cell capacity[12]. In spite of the Government's imposed safeguard duty on solar PV cells and modules imported from China and Malaysia, there was a high amount of imports, totaling INR 80,000 in the last five years, mostly from China.

12 Policy Paper on Solar PV Manufacturing in India: Silicon Ingot & Wafer - PV Cell – PV Module by TERI, 2019

If the country was able to produce cost-effective and quality solar and power electronics components on a large scale, it could own higher percentages of the solar, LVDC and HAD industry value chain in-house and support growth of local manufacturers.

Figure 25. Important Challenges to be addressed by the HAD Industry



Evidently, the market is heading towards hybridisation, i.e. integration of AC-DC power supply and appliances that support these systems. However, challenges like high upfront equipment cost, high sales effort, low customer awareness, and lack of standardisation are an acknowledged reality.

The key industry stakeholders like OEMs, Government and Industry Associations will play a vital role towards mitigating these challenges and enabling growth of HAD infrastructure in India.

6. Recommendations and Conclusion

The following are recommendations to key stakeholders on how to promote the HAD ecosystem in India.

For OEMs

1. **Focus on the solarisation of conventional UPS inverters** as 10% of the inverter market has already moved to hybrid solar UPS systems. OEMs and system integrators can convert existing conventional inverters to hybrid solar UPS solutions that run efficient appliances. As conventional power back-up solutions are already popular, have a strong distribution network, are fairly affordable, this is a viable option. Overall, the potential market for HAD power solutions is not limited to only rural (off-grid or weak grid) users but is wider. OEMs need to improve their R&D and develop new products, integrating solar, battery, grid and EE/ DC appliances.

2. **Upgrade conventional inverter design to provide a DC output:** Such systems, even without solar, will provide much-needed support for the growing adoption of efficient DC appliances at home. Conventional inverters have an AC bus architecture. DC output can be achieved either by adding an AC-DC converter or doing a buck-conversion of their internal DC bus. The new design may not be as efficient as DC bus architecture but will make sense for the adoption of HAD systems and appliances.

3. **Appliance OEMs should add a DC input as an option** to provide flexibility to the end-user. If OEMs start promoting appliances with a DC interface, then conventional inverter manufacturers will also be forced to add a DC output line as it will be a market-driven need.

4. **Develop HAD appliances with built-in batteries** for smaller appliances like LED bulbs, tubelights, pedestal and table fans. For most HHs, lights and fans are the most common loads connected to the power back-up solution. These appliances can run easily on an AC grid system and allow the user to meet improved appliance usage hours without requiring a centralised power back-up solution or solar. These solutions are especially useful for tier 1 and 2 customers, where power availability is low and also affordability is an issue. Battery integrated appliances may present some challenges in integrating with solar.

5. **Promote hybrid EE DC appliances with hybrid solar solutions** to upscale the penetration of EE appliances. OEMs should ensure that hybrid EE DC appliances match their conventional counterparts in terms of quality and service. This will help OEMs build consumers' trust and confidence in hybrid appliances and drive more volumes.

6. **Maintain interoperability standards and labels** by critical mass of industry players to establish a HAD ecosystem and realise its benefits. This should be entirely voluntary, driven by companies that see value in alignment. As greater standardization and enhanced interoperability of grid and off-grid solar products can catalyse market growth and offer benefits to companies, consumers and the environment.

7. **Strengthen distribution and sales networks through institutional partnerships and their sales agents.** Ideally, a dealer/franchise network should be established across each state to increase sales. However, this requires dedicated efforts, brand appeal and personal visits to on-board partners, which may not be possible for many companies. In such cases, partnership with institutions, like banks/ MFIs and any established FMCG companies, and leveraging of their sales agents can be a good approach. In such cases, the margins should be large enough to incentivise agents to recover their operational costs and earn profits. OEMs' go-to-market strategies should be structured differently for different target customers.

8. **Explore consumer financing solutions** like financing through dealer networks for HAD power solutions in urban areas, in-house financing, direct partnerships with banks and micro-finance institutions (MFIs) for rural areas. India is a cash-based market and mobile money is one of the key components to unlocking PAYGo. Improving last-mile distribution will be a key factor in scaling PAYGo, as well as finding ways to collect payments efficiently and effectively.

9. **Improve sales pitch to consumers** by focusing on the techno-economics of HAD power solutions and its futuristic compatibility with solar, grid and battery storage. A significant investment in marketing and sales would be needed to educate consumers on the benefits and practicalities of this new HAD product category.

For the Government

1. **Raise awareness and promote uptake of LVDC BIS standards** by educating OEMs to avoid infiltration of products in the market using different specification.

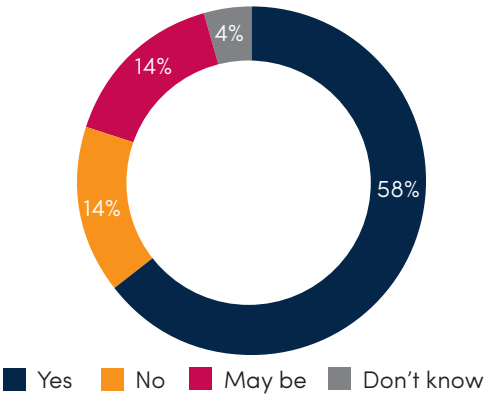
2. **Develop standards for HAD appliances and power solutions:** The BIS should develop standards for hybrid solar power solutions and appliances with special focus on safety and reliability because of AC and DC mix. The standard should also address charge controller efficiency, EMI and EMC compatibility, retrofitting specifications and other important technical parameters.

   As per IIOS-HAD 2020 survey results, 68% of the respondents acknowledged that standardisation of HAD power solutions and appliances (wiring and connectors, utilisation voltage level etc.) is very important to drive improved quality and lower costs.

3. **Allocate subsidy budget for rural installation:** Currently, under the government SRT subsidy programme (providing 20–30% subsidy), SRT installations are targeted at medium to big size cities. The penetration and outreach in rural areas is minimal. It is proposed that the government should reserve of the total subsidy allocation for rural consumers. This will improve the penetration of SRT solutions and increase awareness, which may help the private market evolve.

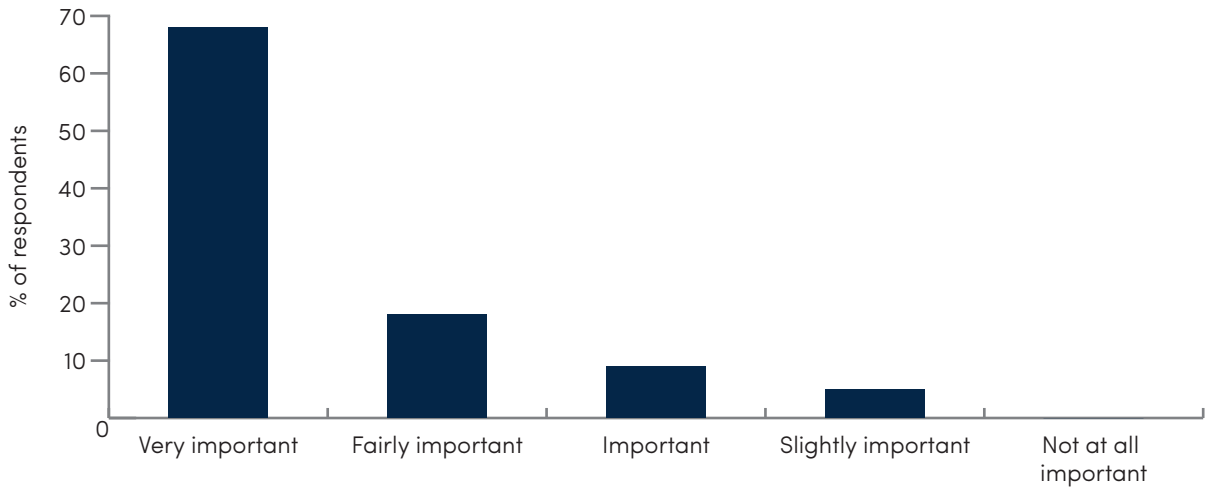
   As per the IIOS-HAD 2020 survey results, 68% of the respondents agreed that the government should allocate 40–50% of the overall subsidy for rural SRT installations. A majority of the respondents believe that distribution of the subsidy between urban and rural areas will boost solar adoption in rural areas.

Figure 26. Allocation of Subsidy for rural solar rooftop installation



4. **Provide subsidy on HAD power solutions:** Providing subsidies on hybrid grid-tied inverters can help improve the adoption of HAD solutions. The same amount of subsidy that is extended for grid-tied rooftop solar solutions can be extended to a hybrid grid-tied solar rooftop solution. Similarly, the small (<0.5 kW) and medium (0.5-2 kW) hybrid solar UPS systems with EE appliances should be extended subsidies to the extent of grid-connected solar rooftop. This will help the growth of the residential (especially rural) rooftop sector in India, which is growing at a much slower pace than expected. Since the sales of such solutions are primarily targeted at rural areas, the subsidy benefit will not be limited to only to the cities.

Figure 27 Importance of Hybrid AC-DC Power Solution and Appliances Standardisation



5. **Promote hybrid appliances with dual inputs or integrated batteries:** Promoting hybrid appliances with dual integrated batteries can help improve energy access in power deficit states. However, their cost is two to four times the cost of conventional appliances. The government can run bulk procurement and distribution programmes like UJALA for hybrid bulbs and hybrid fans in rural areas. This will help many HHs that do not have access to solar/conventional UPS back-up solutions.

6. **Promote local manufacturing with fiscal incentives:** Promoting local manufacturing of HAD appliances/components with fiscal incentives (offering low interest loans or tax credits tied to use of local products) has the potential to strengthen the industry. It will help boost local job creation, export of domestic manufactured products to international markets, and cost savings.

7. **Develop a standards and labelling programme (or minimum energy performance standards (MEPS) for HAD appliances** as it is a key steppingstone to adopting HAD appliances and power solutions. It will be important to create awareness among OEMs as well as consumers. Even though HAD technology is at nascent stage today, MEPS can be evolved with the evolving HAD technology. For instance, in India for Fans the star labelling with higher performance standards (higher service value) was announced in August 2019 which enabled use of energy efficient technology (BLDC). Standards and Labelling program will also ensure the compliance of standards by OEMs leading to the flow of quality products in the market. Moreover, providing grants for R&D activities that help local manufacturers adapt and improve HAD technology and processes.

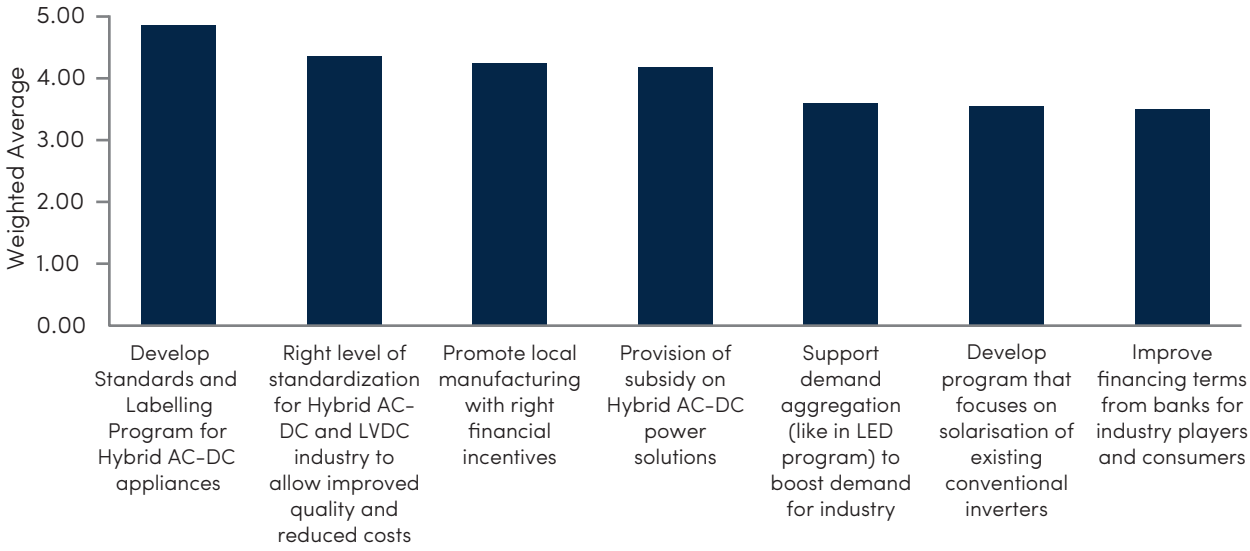
As per the IIOS-HAD 2020 survey, the top three policy interventions by the government that can help to promote hybrid solar systems in India are: i) developing a standards and labelling programme for HAD appliances, ii) development and enforcement of hybrid and LVDC standards, and iii) promoting local manufacturing with the fiscal incentives.

For Industry Associations:

1. **Support increase number of pilots** on HAD power back-up solutions integrated with EE and HAD appliances across various used cases in different geography. Share results and impact reports with state governments to create state policy support and enable increased localisation of HAD supply chains.

2. **Facilitate industry OEM members across select appliances to discuss and build consensus on practical standardisation** interventions to facilitate HAD ecosystem and infrastructure in India.

Figure 28. Key Policy Interventions by Government to Promote Hybrid Systems in India



Conclusion:

The Indian grid's expansion to rural areas has led to rural consumers aspiring to use existing appliances (DC or AC) for longer durations, as well as to purchase more appliances for an improved standard of living. However, 24x7 access to electricity via the grid remains a challenge. The growing aspiration and consumer demand for uninterrupted power has led to increased use of additional power back-up solutions and also energy efficient appliances. Moreover, there is a growing trend for adopting solar rooftops systems, SHS and various DRE solutions. Many of the DRE solutions come with a battery back-up but do not provide grid integration facility.

There is an emerging category of DRE solution in the market, i.e. hybrid solar systems, which can integrate DC solar with AC grid power supplies and can power AC and DC appliances. Both existing and new players in the market are serving this growing need by providing hybrid power solutions. Along with this, HAD appliances (dual input or battery integrated appliances) are also gaining the attention of established OEMs and new start-ups.

The HAD power solutions studied in this paper reveal that there is a potential market for two key HAD power solutions, i.e. hybrid solar inverter UPS and hybrid grid-tie inverter. Hybrid solar inverter UPS allow the load to run directly on solar (using charge controller) and charge the battery when it is not fully charged. This feature enables consumers to save on grid electricity bills for regular consumption. Its variant hybrid grid-tied inverter additionally supports grid-export and is expected to become popular in residential rooftops and also in micro-grids. On the other hand, the market adoption of HAD appliances with dual input is still limited. While HAD appliances with battery integrated is in its nascent stage. However, the HAD appliances (domestic and PULSE) with seamless AC-DC interoperability has potential to add significant value beyond energy savings for consumers in weak grid settings and lower the impact of price premium charged for energy efficient technologies.

The LVDC and solar industry need to address the key challenges of high upfront cost, lack of consumer awareness, low quality of products and lack of standardisation for the uptake of HAD infrastructure in India. OEMs will have to define their go-to market strategy and modify their product designs to tap the potential HAD market. While the Government should to provide policy/ regulatory support to the industry by providing rural subsidies, developing standards, and promoting HAD power solutions/appliances under existing schemes. This support from the government will be important to drive demand and provide volume and visibility to the OEMs. Industry associations can provide vital insights through pilots and studies to the state government to drive the right policy support and enable increased localisation of supply chains. Thus, key actors like OEMs, Government and Industry associations need to work in tandem to facilitate a HAD ecosystem and infrastructure in India.

7. Appendix

Annexure-1: Approach and Methodology

Objectives of the study

The potential market of HAD infrastructure in India: Identify potential market for AC-DC hybrid infrastructure. The first focus area for the discussion paper would be on the need for hybrid infrastructure in India, looking at the percentage of HHs under each electrification category mentioned above. This would help in detailing out the potential market for an AC-DC hybrid infrastructure.

Challenges for uptake: Evaluate challenges in the integration of existing off-grid solar systems with the main AC grid. Integrating existing off-grid solar systems with the main grid would require several technical, operational, marketing and other strategic changes for companies. These would be coupled with several challenges. Thus, another focus area for this discussion paper would be to lay out all the challenges that companies should be aware of while developing products that are grid compatible.

Recommendations: Evaluate possible business models and policy interventions required for market growth. Lay down recommendations for companies on plausible technology mix and business models to implement hybrid solutions and list out policy support required from the government for market growth.

Methodology

There is limited research which comprehensively investigates the potential of HAD infrastructure in India, identifying key trends, drivers, barriers, and projects future market potential. This discussion paper aims to explore potential opportunities and challenges for the growth of HAD infrastructure by providing a holistic understanding of the potential market and key market trends. It also hopes to inform discussions around key interventions for OEMs and the government that can help further develop and stimulate the market.

The study employed a three-staged research approach:

Secondary research: Desk research using existing secondary resources studied the current state of the market, including market research studies, survey data, OEM and distributor websites, the literature on technology research and development, as well as country-level databases from government websites to ascertain electrification level and existing supporting policies.

Primary research: In-depth, semi-structured interviews with over 16 prominent stakeholders in the hybrid power solution and appliance market, including DC appliance manufacturers, SHS distributors and technical experts. These interviews provided uniquely relevant insights on customer preferences, ground-level realities on both the supply and demand side of the market, broader trends in the conventional/hybrid power solution and appliance market, key opportunities and challenges to further develop the market.

Development of a demand-assessment model and analysis: A demand-assessment model was developed which estimated the total potential in terms of number of HHs for individual power solutions mapped across different customer segments, based on energy access (available power source). Below is a brief description of the primary inputs and analyses used in the development of this model.

Estimation of HHs electrified under different electrification categories: This measurement addresses the number of HHs with access through alternative energy sources. The study used national electrification data from portals like Saubhagya and DDUGJY and assumptions about HHs electrified through power solutions (like standalone SHS, mini/micro-grids).

Estimation of HHs using different power solutions: Based on the electrification category of HHs and source of power supply, potential power solutions used by these HHs were identified and mapped to respective HHs.

Penetration of power solutions across HHs: Based on interviews and secondary research, the percentage distribution of power solutions was determined across different HHs falling under electrification category.

Potential hybrid AC-DC power solutions and its market size: The potential HAD power solutions were shortlisted from existing power solutions used by different HHs in consultation with industry stakeholders and experts. Their market penetration was estimated based on secondary research and primary interviews.

The projection for 2023: To examine the potential market and growth of HAD power solutions, historical industry growth rate trends and adoption trends observed by experts were considered.

Annexure-2: State-wise Power Surplus and Deficit Status (2019–20)

Region / State / UT	Requirement (MU)			Availability (MU)			Surplus / Deficit (-) (MU)		Surplus / Deficit (-) (%)	
	LGBR	Actual	% Deviation	LGBR	Actual	% Deviation	LGBR	Actual	LGBR	Actual
Chandigarh	1,730	1,732	0.1	1,805	1,732	-4.0	75	0	4.3	0.0
Delhi	34,010	33,086	-2.7	41,420	33,077	-20.1	7,410	-9	21.8	0.0
Haryana	54,290	54,505	0.4	67,530	54,492	-19.3	13,240	-13	24.4	0.0
Himachal Pradesh	10,410	10,424	0.1	11,570	10,353	-10.5	1,160	-71	11.1	-0.7
UT of J&K and Ladakh	20,000	20,025	0.1	12,800	16,259	27.0	-7,200	-3,767	-36.0	-18.8
Punjab	60,680	56,776	-6.4	74,550	56,770	-23.8	13,870	-6	22.9	0.0
Rajasthan	86,260	81,281	-5.8	103,100	81,222	-21.2	16,840	-58	19.5	-0.1
Uttar Pradesh	132,600	122,549	-7.6	156,200	121,004	-22.5	23,600	-1,545	17.8	-1.3
Uttarakhand	14,470	14,472	0.0	14,220	14,376	1.1	-250	-96	-1.7	-0.7
Northern Region	**414,450**	**394,851**	**-4.7**	**483,195**	**389,285**	**-19.4**	**68,745**	**-5,566**	**16.6**	**-1.4**
Chhattisgarh	32,018	30,111	-6.0	32,494	30,107	-7.3	476	-4	1.5	0.0
Gujarat	125,450	113,940	-9.2	130,497	113,939	-12.7	5,047	-1	4.0	0.0
Madhya Pradesh	76,674	76,172	-0.7	81,899	76,172	-7.0	5,225	0	6.8	0.0
Maharashtra	153,540	155,167	1.1	148,236	155,166	4.7	-5,304	0	-3.5	0.0
Daman & Diu	2,554	2,574	0.8	2,833	2,574	-9.1	279	0	10.9	0.0
Dadra & Nagar Haveli	6,530	6,528	0.0	6,530	6,528	0.0	0	0	0.0	0.0
Goa	4,073	4,350	6.8	4,580	4,350	-5.0	508	0	12.5	0.0
Western Region	**407,350**	**388,841**	**-4.5**	**413,581**	**388,836**	**-6.0**	**6,231**	**-5**	**1.5**	**0.0**
Andhra Pradesh	71,545	65,452	-8.5	76,820	65,414	-14.8	5,275	-38	7.4	-0.1
Karnataka	78,751	72,799	-7.6	86,464	72,796	-15.8	7,713	-3	9.8	0.0
Kerala	26,480	26,315	-0.6	25,013	26,265	5.0	-1,467	-50	-5.5	-0.2
Tamil Nadu	115,497	108,816	-5.8	115,294	108,812	-5.6	-203	-4	-0.2	0.0
Telangana	85,553	68,306	-20.2	88,567	68,303	-22.9	3,014	-3	3.5	0.0
Puducherry	3,365	2,847	-15.4	3,133	2,846	-9.2	-232	-1	-6.9	0.0
Southern Region	**382,120**	**344,535**	**-9.8**	**396,219**	**344,436**	**-13.1**	**14,099**	**-99**	**3.7**	**0.0**
Bihar	33,015	31,627	-4.2	30,191	31,533	4.4	-2,824	-94	-8.6	-0.3
Damodar Valley Corporation	22,520	22,429	-0.4	24,180	22,427	-7.3	1,661	-2	7.4	0.0
Jharkhand	9,730	8,941	-8.1	7,858	8,872	12.9	-1,872	-69	-19.2	-0.8
Odisha	34,174	29,692	-13.1	29,972	29,692	-0.9	-4,202	0	-12.3	0.0
West Bengal	56,254	52,948	-5.9	53,406	52,824	-1.1	-2,848	-124	-5.1	-0.2
Sikkim	624	554	-11.2	1,065	554	-48.0	441	0	70.7	0.0
Eastern Region	**171,807**	**146,191**	**-14.9**	**160,775**	**145,902**	**-9.3**	**-11,032**	**-289**	**-6.4**	**-0.2**
Arunachal Pradesh	935	753	-19.5	852	749	-12.2	-83	-4	-8.9	-0.5
Assam	11,359	9,804	-13.7	10,672	9,288	-13.0	-687	-516	-6.0	-5.3
Manipur	970	924	-4.8	1,412	917	-35.1	442	-6	45.6	-0.7
Meghalaya	2,236	2,112	-5.6	3,046	2,064	-32.3	810	-48	36.2	-2.3
Mizoram	757	647	-14.5	1,079	643	-40.4	322	-4	42.5	-0.7
Nagaland	764	814	6.6	1,020	809	-20.7	256	-5	33.5	-0.7
Tripura	2,155	1,538	-28.6	3,441	1,515	-56.0	1,286	-23	59.7	-1.5
North-Eastern Region	**19,176**	**16,591**	**-13.5**	**21,522**	**15,984**	**-25.7**	**2,347**	**-607**	**12.2**	**-3.7**
All India	**1,394,904**	**1,291,010**	**-7.4**	**1,475,292**	**1,284,444**	**-12.9**	**80,388**	**-6,566**	**5.8**	**-0.5**

Source: CEA,2019-20

Annexure-3: Average Hours of Supply in a Day in Rural Areas

State	Average Hours of Supply in a Day in Rural Areas
Base year	**During May 2019**
Arunachal Pradesh	14.3
Jammu & Kashmir	15.0
Mizoram	16.1
Sikkim	17.1
Meghalaya	17.5
Jharkhand	17.8
Haryana	17.9
Uttar Pradesh	17.9
Karnataka	18.6
Assam	19.0
Odisha	20.1
Nagaland	21.0
Rajasthan	21.0
Bihar	22.1
Manipur	22.3
Chhattisgarh	23.0
Tripura	23.5
Madhya Pradesh	23.8
Andhra Pradesh	23.9
Uttarakhand	24.0
Gujarat	24.0
Himachal Pradesh	24.0
Kerala	24.0
Maharashtra	24.0
Punjab	24.0
Tamil Nadu	24.0
Telangana	24.0
West Bengal	24.0

Source: CEA,2018-19

Annexure-4: State-wise State Rooftop Solar Attractiveness Index (SARAL) Score

Ranking	State	SARAL Score	Grades
1	Karnataka	78.8	A++
2	Telangana	72.2	A++
3	Gujarat	67.9	A++
4	Andhra Pradesh	66.1	A++
5	Rajasthan	62.2	A+
6	Madhya Pradesh	58.3	A+
7	Delhi	54.6	A+
8	Punjab	53.4	A+
9	Maharashtra	52.0	A+
10	Tamil Nadu	50.9	A+
11	Chandigarh	48.3	A
12	Haryana	43.3	A
13	Kerala	42.9	A
14	Odisha	39.4	A
15	Jharkhand	37.7	A
16	Chhattisgarh	36.5	B++
17	Goa	31.8	B++
18	Uttarakhand	31.6	B++
19	Assam	29.0	B+
20	Uttar Pradesh	26.5	B+
21	Sikkim	22.8	B+
22	Arunachal Pradesh	21.6	B+
23	Himachal Pradesh	20.8	B+
24	Nagaland	20.5	B+
25	Bihar	20.3	B
26	Mizoram	20.3	B
27	West Bengal	19.4	B
28	Manipur	19.3	B
29	Tripura	17.7	B
30	Meghalaya	17.6	B
31	Jammu & Kashmir	14.4	B

Source: Solarrooftop.gov.in

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