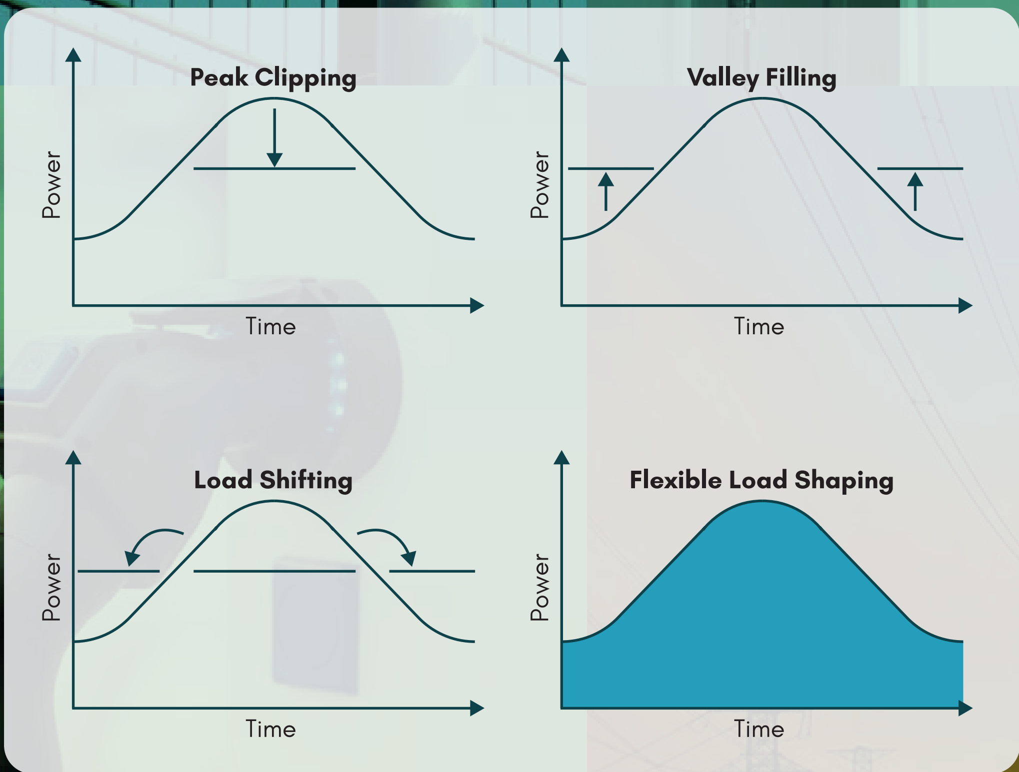
Roadmap for Demand Flexibility in India

Whitepaper on roadmap for demand flexibility in India



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Alliance for an™ Energy Efficient Economy

AutoGrid

ROADMAP FOR DEMAND FLEXIBILITY IN INDIA

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Understanding Demand Management and Demand Response

'Demand management' has not received due attention from policymakers as a resource in both short-term and long-term planning of electricity systems. For an extensive part of the history of the Indian electricity grid, system operators and distribution utilities have responded to changes in customer demand by adjusting the generation, planning for adequate supply reserves, or managing the load through supply interruptions. Demand Response (DR), on the other hand, is a method that enables the adjustment of demand, thereby allowing customers to participate in responding to changing grid conditions. The application of DR, a proven demand management tool, can effectively help electricity distribution companies (DISCOMs) in India handle their increasing future electricity demand and operate reliably in a greener grid.

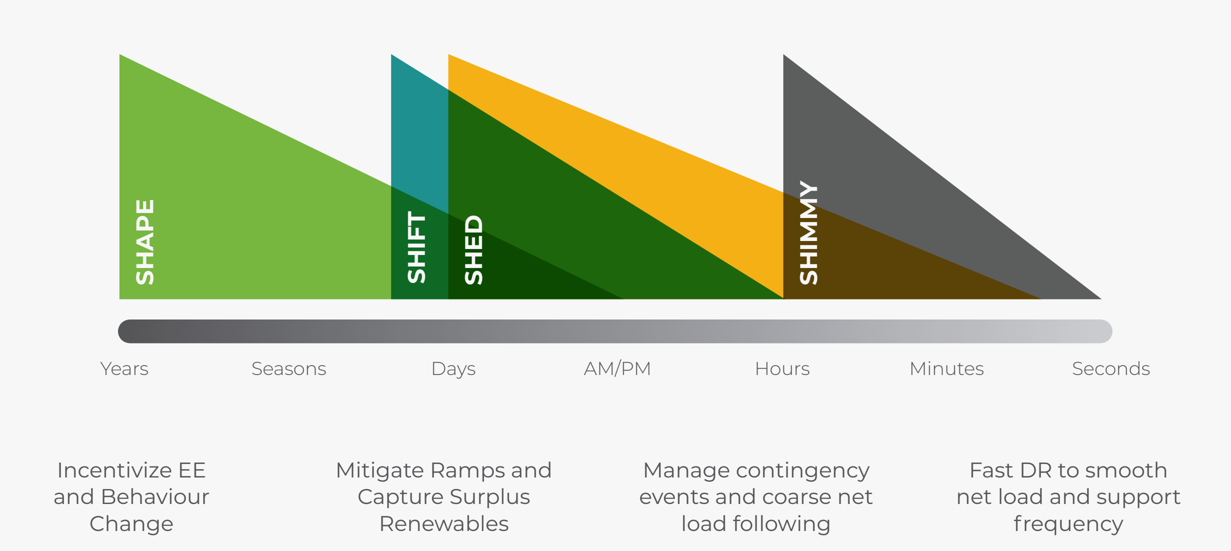
DR, in simple terms, refers to the ability of load to change and is not a new concept in the Indian regulatory ecosystem. The Central Electricity Regulatory Commission defines DR in the Indian Electricity Grid Code 2010 as 'reduction in electricity usage by end customers from their normal consumption pattern, manually or automatically, in response to high Unscheduled Interchange (UI) charges being incurred by the State due to over-draw by the State at low frequency, or in response to congestion charges being incurred by the State for creating transmission congestion, or for alleviating a system contingency, for which such consumers could be given a financial incentive or lower tariff'. In this definition, the central regulator recognises that DR's value proposition as a resource is vital to reliable grid operation. When tapped into effectively, the potential benefits of DR include reducing the cost of electricity supply, savings in grid investment, supporting reliable grid operation with highly intermittent renewable power generation, and assisting in grid emission intensity reduction.

The application of DR, a proven demand management tool, can effectively help electricity distribution companies (DISCOMs) in India handle their increasing future electricity demand and operate reliably in a greener grid

DR is a portfolio with multiple options

Globally, DR is considered the largest, most widely available, and most cost-effective Distributed Energy Resources (DER) in the grid. While technologies such as rooftop solar and battery storage are automatically recognised as DERs, demand measures are frequently ignored as resources in the distribution grid. The pathway to unlocking the benefits of DR begins with recognising DR as a virtual energy

4S's of DR services to the grid (Source: LBNL)



resource, similar to physical energy resources such as power plants and storage. The available capacity of the DR resource is not constant, varying throughout the day and seasonally. However, all types of electricity customers, domestic, agricultural, commercial, and industrial have DR potential. This potential increases with the increasing penetration of flexible and controllable loads like Electric Vehicles (EVs), cooling appliances, etc. Well-designed DR programmes, leveraging advanced metering infrastructure and other innovative technologies, can alter the electricity consumption pattern in four ways, as shown in the Figure below. These 4S's, Shape, Shift, Shed, and Shimmy are categorised based on the timescale of operation and broadly represent the four DR services available to the grid.

What are the critical factors in DR programme design?

All DR is not Auto-DR

DR offers a wide range of possibilities for DISCOMs to manage their pain points. An ideal DR strategy should be designed to include a portfolio of options that can be customised to suit the needs of different consumer segments. Planning DR programmes with human intervention is a good starting point to engage consumers.

Subsequently, with the rise in controllable loads and smart appliances, advanced Auto-DR, called Flexible DR (Flex-DR), with the ability to increase and decrease the load rapidly, can be explored. There is a common misconception that direct load control through Auto-DR is the best DR strategy. However, behavioural DR programmes are actually the 'low-hanging fruits' that are strategically important for DR programme design. Behavioural DR programmes constitute the bulk of the DR potential and are easy to tap into because of the relatively lower cost of running such a programme.

The one-size-fits-all approach doesn't work

DR programmes can only be successful if they are designed to create win-win situations for both consumers and DISCOMs. It is important to ensure that the selected consumers have above average energy consumption and that the incentives offered are significant enough to ensure savings in energy bills. A useful tactic is to leverage the energy data collected by smart meters to segment the consumers and identify potential target consumers.

The consumers who have peak demand coinciding with the DISCOM peak and those with loads that can be shifted timewise are potentially more valuable for the DR programmes. For example, commercial DR programmes are easier to implement, as higher load reduction can be achieved from minimal consumer participation. Commercial loads are suitable for DR programmes designed to reduce daytime peak demand. On the other hand, commercial energy consumption does not contribute much to the evening peak demand experienced by DISCOMs, meaning that such programmes will not help DISCOMs in managing evening peak demand. To reduce this demand, a programme designed to target high-value residential consumers with high energy use in the evenings is needed.

Technology supports Residential DR

The four widespread technology enablers for DR that have a significant impact on the DR programme cost are smart meters, smartphones, wireless communication, and the Internet of Things (IoT). Usually, for DR programmes, the commercial and industrial consumers have been the target segment, due to their inherently high individual DR capacity. The building sector and predominantly residential buildings, which are set to experience a high growth in energy usage, are now prime candidates for DR. The cost of automation in the residential sector is lower than the cost incurred for Auto-DR in the commercial and industrial sectors.

Target the right end-use

The electricity load pattern is an aggregated demand from different end-uses, including lighting, cooling, pumping, cooling, and industrial processes. The relative contribution of the end-uses to the peak demand is an essential consideration in programme design. When planning for future loads, socioeconomic factors that impact the consumer groups and end-uses are important. Choosing the right loads depends on the set of parameters, including the suitability of the load for DR, impact of the DR programme, scalability, and ease of implementation.

Plan for the future cooling load

Cooling demand is a prime candidate for future DR in India, given the large scale of the problem. The number of households in India owning an AC has increased by 50% over the last five years. One of the key challenges in India for the future will be managing the increasing peak demand from cooling appliances. A critical step to planning a sustainable cooling future for India is to be proactive and treat the increasing cooling demand as a resource.

Wi-Fi-enabled smart ACs are easily controllable loads with in-built DR capability. Non-Wi-Fi-enabled ACs can also be quickly converted into DR resources by adding Wi-Fi-enabled plugs. This exciting innovation allows DISCOMS to leverage the connected AC units as a valuable grid balancing resource by remotely adjusting temperature setpoints and reducing the ACs' energy consumption.

Smart EV charging with DR

EVs are a versatile energy resource that can act as distributed load and storage. Use of Time of Use (ToU) tariffs would enable DISCOMs to avoid network upgradation and reduce peak load impact. With flat or block-wise residential tariffs, consumers have no incentive to not charge their EVs as soon as they get home. This leads to a situation where the EV charging coincides with evening peak energy consumption hours. ToU or peak rebate-based EV charging-specific tariffs for public charging facilities can enable reduction in peak demand and shift demand to a period of surplus renewable generation. DR can be easily integrated with other charging control strategies as well.

To sustain operations in the future and achieve the goal of affordable and reliable energy supply, DISCOMs need to think beyond EE programmes and take a proactive role in engaging with consumers. In this regard, DR presents a leapfrog opportunity for DISCOMs to adapt to the realities of a cleaner grid and high electrification of demand. In the next three years, DR needs to be integrated into the fabric of DISCOM processes, along with EE. In the future, with the proliferation of more energy-efficient and controllable loads, DR programmes need to be designed with real-time applications. The future of demand resources lies in embedding DR value within the EE programmes.

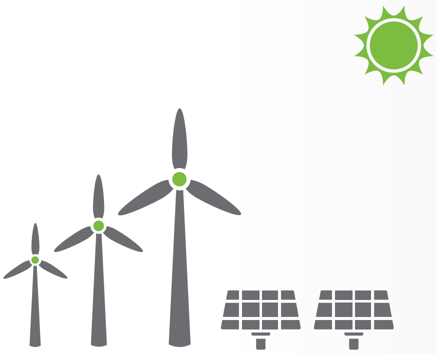
CHAPTER 01

WHAT IS THE ROLE OF DEMAND IN INDIA'S ENERGY FUTURE?

The Indian power sector is in transition. Change is evident in the way electricity is being generated in India, with an increase in the share of renewable energy (RE) that clearly supports India's climate goals. In August 2021, the total installed capacity of RE in India touched 100 gigawatts (GW). India has also set an ambitious goal of 500 GW of RE-based installed capacity by 2030. Solar power plants will make up the bulk of clean generation added to the grid, with a likely share of 50% in the generation mix in 2029-30. Needless to say, the country is transitioning from a power deficit situation to a power surplus one. While India will have surplus generation capacity with a high share of renewables, the ability to translate it to the Sustainable Development Goal (SDG) 7 goal of "affordable, reliable, sustainable and modern energy for all" will depend on the electricity network [1] [2].

The most astonishing fact about the greening of India's power grid is that decarbonisation is happening in parallel with a substantial increase in the electricity demand. With rapid urbanisation and improvement in economic conditions and living standards, the electricity demand in Indian cities is expected to increase significantly. Electrification of transport, growth of building stock, and an increase in appliance penetration are considered the major drivers of demand. It is estimated that nearly 70% of the building stock that will be there in 2030 is yet to be built in India.

The forecasted peak electricity demand for selected Indian cities for the next decade depicted in Figure 1 shows that there will be a drastic increase in peak demand [3]. As peak demand is the basis for electricity grid planning, this translates to capacity additions in power generation, transmission, and distribution. Unavailability of network capacity, particularly on the distribution side, will be a major hurdle. There are multiple dimensions to the adequacy of network capacity. First, in urban areas, there is a mismatch between the growth of the electricity demand and network capacity. While there are planned processes for network upgrades, electricity demand is increasing at a much faster pace. In rural and remote areas, the distribution network becomes a limiting factor to cater to demand growth.



In August 2021, the total installed capacity of RE in India touched 100 gigawatts (GW). India has also set an ambitious goal of 450 GW of RE-based installed capacity by 2030.

Solar power plants will make up the bulk of clean generation added to the grid, with a likely share of 34% in the generation mix in 2029-30.

Figure 1: Projected peak demand increase for Indian cities (2020-2030)

The traditional mode of electricity system operation with centralised power plants, long-distance transmission, and unidirectional distribution of electricity is also changing. With the advent of decentralised generation, there is a paradigm shift in distribution, where the generation and distribution boundaries are becoming fluid. The electricity distribution is witnessing high adoption of smart grid technologies, which is aiding the transition to an era of Distribution System Operation. This presents an enormous opportunity to support deployment of smart controllable appliances and behind-the-meter solar rooftop photovoltaics (PV), energy storage, and electric vehicles (EVs).

In the case of India, given the complex nature of the energy evolution, planning for the increase in electricity demand is not a standalone problem. The implications of the increase in electricity demand need to be evaluated along with other drivers of change in the distribution grid. This requires a holistic approach for integrated resource planning and understanding the interlinkage of demand management with penetration of rooftop solar, stationary battery storage, EVs, advanced metering infrastructure, and other enabling smart grid technologies [4].

To ensure the sustainable future of the grid, it is important to remember that, often, challenges are interposed with solutions within. A shift in perspective in understanding India's 'demand-side transition' reveals that a change in narrative is needed regarding the role of demand. It is imperative to stop viewing increasing demand as a challenge and start unlocking the latent potential of flexible grids. The aim for the future grid should be to tap into 'demand as a resource' and ensure a smooth transition of the power system. It is imperative to realise that 'demand resources' are extremely relevant for a country like India, which is planning for a future grid with a significant share of renewables.

The objective of this paper is to support the evolution of DR in India, with a particular focus on the design of an effective and scalable demand response (DR) programme with proper measurement and verification (M&V) and incentive structures for consumers. DR, being an integral part of the demand side management (DSM) mechanism, is a not a new concept for India. The limited history of DR in India shows that lack of meaningful incentives is a key barrier to mainstreaming DR. Second, the paper presents a radical approach to DR, a necessary shift from the conventional DSM philosophy. DR is a portfolio of options, with many value streams for the future grid, and as such, offers a multitude of benefits, as mentioned next page.

01

Bureau of Energy Efficiency has emphasised the crucial role of energy efficiency (EE) in India's energy transition, and it is estimated that emission reduction due to EE equates to 50% of India's total emission reduction targets. [5]

02

A study carried out by AEEE, in collaboration with Oracle, estimates a potential energy savings of 3400-10200 GWh annually from behavioural EE measures. This translates to consumer savings of approximately Indian Rupee (INR) 9-30 billion in 2021 alone [6].

03

Furthermore, AEEE's internal analysis estimates that cost savings in the range of INR 12-17 billion is possible through DR measures in Delhi alone that would help avoid the addition of new network capacity.*

*Estimated for reduction in peak demand in Delhi for the electricity demand that is experienced less than 1% of time, and network savings are assumed at INR 20 million per megawatt (MW) [50].

CHAPTER 02

HOW IS DEMAND MANAGEMENT EVOLVING IN INDIA?

'Demand management' hardly receives any attention from policymakers as a resource in both short-term and long-term planning. For an extensive part of the history of the Indian electricity grid, system operators and distribution utilities have responded to changes in customer demand by adjusting the generation, planning for adequate supply reserves, or managing the load through supply interruptions. DR, on the other hand, is a method that enables the adjustment of demand, thereby allowing customers to participate in responding to changing grid conditions. The application of DR, a proven demand management tool, can effectively help electricity distribution companies (DISCOMs) in India handle their increasing future electricity demand and operate reliably in a greener grid. This paper discusses DR's value proposition for the distribution grid and the steps to unlocking this value.

Understanding Demand Response

DR, in simple terms, refers to the ability of load to change and is not a new concept in the Indian regulatory ecosystem. The Central Electricity Regulatory Commission [7] defines DR[1] in the Indian Electricity Grid Code 2010 [7] as 'reduction in electricity usage by end customers from their normal consumption pattern, manually or automatically, in response to high Unscheduled Interchange (UI) charges being incurred by the State due to over-draw by the State at low frequency, or in response to congestion charges being incurred by the State for creating transmission congestion, or for alleviating a system contingency, for which such consumers could be given a financial incentive or lower tariff'. In this definition, the central regulator recognises that DR's value proposition as a resource is vital to reliable grid operation. When tapped into effectively, the potential benefits of DR include reducing the cost of electricity supply, savings in grid investment, supporting reliable grid operation with highly intermittent renewable power generation, and assisting in grid emission intensity reduction.

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In regulatory language, the term "demand resources' refers to both DR and EE resources. It is important to distinguish

1. DR is not yet formally defined in the model DSM regulations or state DSM regulations in India [37].

between EE and DR, although they are intertwined concepts. For the purpose of this paper, the focus is on DR, i.e. consumer behaviour-linked, timebound, short-term changes in energy use, and is considered distinct from EE. EE denotes structural actions such as appliance efficiency improvement and building retrofits, which are time-independent, long-term changes in energy use. For example, the purchase of an energy-efficient Light-Emitting Diode (LED) light, energy-efficient Brushless Direct Current (BLDC) fan, or energy-efficient Air Conditioner (AC) constitutes an EE measure.

DR, on the other hand, is associated with voluntary load reduction or load shifting measures taken by the consumer. For example, an increase in the set point temperature of an AC unit or changing washer-dryer operations to a different time are DR measures. A commercial or industrial consumer changing their hours of operation to reduce energy consumption during a peak demand period is also DR. It is possible for DR to lead to curtailment of individual loads, but it is not perceived as a curtailment, because of the customer buy-in. In this way, DR is distinct from 'load shedding' practices in the Indian power grid, where load is curtailed in a specific geographic region. With proper design, it is also possible to deploy DR, not with 100% curtailment, but only load reduction. For example, for an AC unit, switching off an AC and increasing its set point temperature are both DR measures. The second option is trickier than the first, but does not result in 100% curtailment. It is interesting to note that DR does not always entail reduction in load; an increase in load during peak generation can also be DR. DR is understood as the sum total of the collective actions of consumers to alter the demand. Both increases and decreases in demand in response to an incentive or signal constitutes DR.

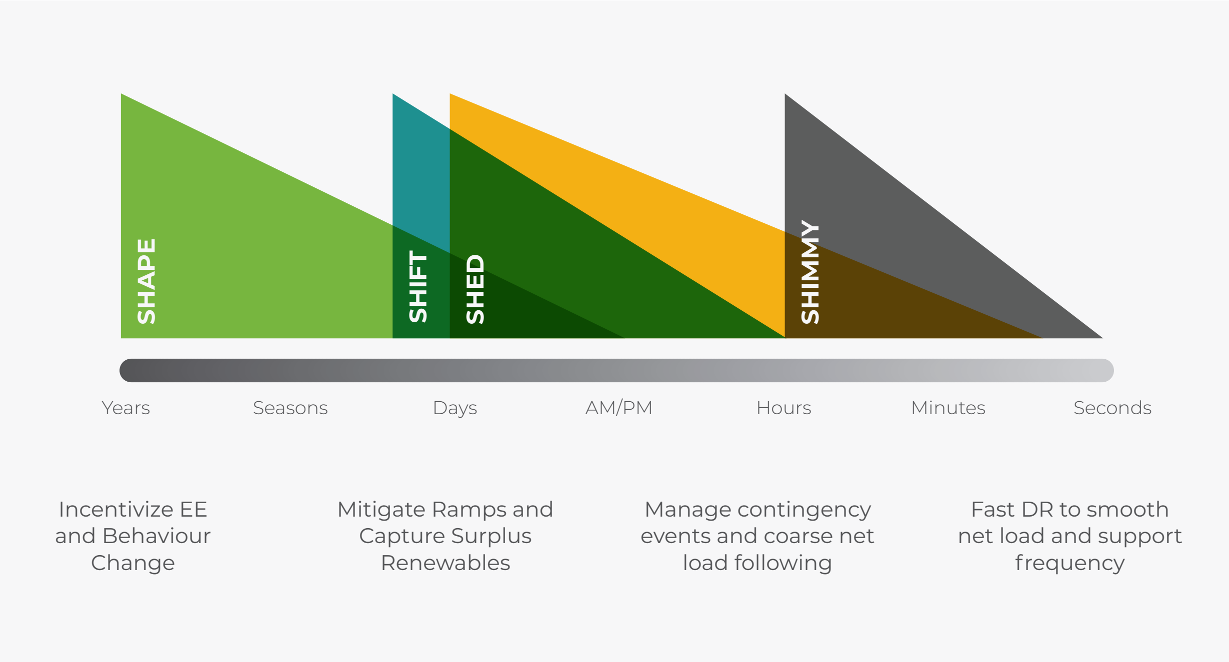
Federal Energy Regulatory Commission (FERC) definition of DR

One of the most globally accepted definitions of DR comes from the United States (U.S.) federal electricity regulator. The FERC defines DR as "changes in electric usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized". This definition has enabled the recognition of DR as a Distributed Energy Resource (DER) in the U.S. Recently, FERC Order 2222 paved the way for DERs, including DR, to participate in the wholesale energy market and provide a variety of grid services, including flexibility and reliability [8] [9].

DR is a portfolio with multiple options

Globally, DR is considered the largest, most widely available, and most cost-effective DER in the grid. While technologies such as rooftop solar and battery storage are automatically recognised as DERs, demand measures are frequently ignored as resources in the distribution grid. The pathway to unlocking the benefits of DR begins with recognising DR as a virtual energy resource, similar to physical energy resources such as power plants and storage. The available capacity of the DR resource is not constant, varying throughout the day and seasonally. However, all types of electricity customers—domestic, agricultural, commercial, and industrial—have DR potential. This potential increases with the increasing penetration of flexible and controllable loads like EVs, cooling appliances, etc. Well-designed DR programmes, leveraging advanced metering infrastructure and other innovative technologies, can alter the electricity consumption pattern in four ways, as shown in Figure 2. These 4S's—Shape, Shift, Shed, and Shimmy—are categorised based on the timescale of operation and broadly represent the four DR services available to the grid.

Figure 2: 4S's of DR-DR services to the grid (Source: LBNL)



Shape

Shape is a demand resource category that refers to long-term and persistent alterations in the demand pattern. In DR terms, this relates to changes in consumer behaviour. Any change in the end-use consumption patterns in response to a Time-of-Use or dynamic energy rate is a classic example of a shape resource. Although incentive-based mechanisms are commonly classified as a DR resource, any lasting consumer behavioural change is, in essence, DR. Actions from an empowered consumer to alter his or her energy usage can contribute to the shape resource. For example, actions taken by energy-aware residential energy consumers based on behavioural energy campaigns such as Home Energy Reports, when aggregated, serve as an easily exploitable DR resource.

Shift

Shift refers to the DR resource associated with shifting the load without any net reduction in energy consumption. The shift from the peak time period to another is typically done to balance the load curve in response to the incremental cost of power procurement and defer the investment needed to meet peak demand. In a grid with a high share of RE, Shift DR encourages the shifting of demand to a period of a surplus solar or wind generation. Shift can be considered a type of storage resource from the supply-side perspective and can mitigate the frequent ramping of power plants [10]. Customers could also participate in incentive-driven programmes to shift energy consumption to a time window that falls outside the DR event—for example, running a washing machine outside of the DR event period or, in the case of industrial facilities, shifting forklift battery charging to outside the peak demand period. Shift DR is also a method to encourage EV charging during the day to coincide with high solar generation.

Shed

The most traditional and easily identifiable value from DR is associated with load reduction programmes. The shed resource is quantified in terms of the aggregated potential to reduce demand at the time of peak demand or a system emergency through individual load curtailment by end-use consumers. The ability of consumers to curtail their loads in response to signals received from grid operators has direct implications on peak capacity reduction and reliability improvement. Shed is considered a type of generation capacity resource from the supply-side perspective and can be used to manage contingency events or economic events (e.g. when wholesale procurement costs go above the normal range or the marginal cost of power procurement is too high).

Shimmy

Shimmy is a very versatile DR resource linked to flexibility, i.e. the ability of a load to dynamically adjust demand. This constitutes fast-acting DR measures that operate on shorter timescales of seconds/minutes or an hour. Shimmy is critical for flexible grid operation, as it is used to provide ancillary services like frequency regulation. This resource is extremely handy in tackling intermittent demand-supply mismatches in a grid with a high share of renewables and is therefore valuable for the future grid, as it can assist in handling sudden fluctuations in solar generation due to changing cloud cover.

Both Shed and Shimmy are capabilities that enable DR to act as a dispatchable resource based on grid requirements. The ability to respond faster—typically within less than a minute—to grid signals enables DR to be used as an ancillary resource. Although the potential participation by individual customers might be limited to a few hours a year, the aggregation of participants can provide a reliable flexible resource base that the grid operator can capitalise on.

Future DR-related grid benefits

DR is not just about reducing energy usage or peak demand management, as shown in Table 1. If applied correctly, every type of DR can lead to a number of benefits to both the DISCOM and consumer. The direct benefits to the consumer include lower electricity costs and improved service reliability. Each type of DR can offer a set of value streams to the electricity grid based on the design. With the advent of modern loads like EVs and controllable cooling equipment, the value proposition is expanding to include supporting the clean energy integration. Effective use of DR can also help in lowering greenhouse gas (GHG) emissions, increasing RE utilisation, and replacing fossil fuel-based generation. Distributed demand participation has a strong role to play in managing the overall system balance and security in the future distribution grid.

Table 1: DR-related benefits for the future grid

DR type	Peak demand reduction	Avoided generation and transmission capacity	Avoided distribution capacity reduction	Load shifting for surplus RE generation	Frequency support	Network emergency management
Shape	☑	☑	☑	☑		
Shed	☑	☑	☑		☑	☑
Shift				☑		
Shimmy	☑	☑	☑	☑	☑	☑

Indian experience with demand management

DSM regulations

Currently, the key regulatory mechanism for demand resources in India is DSM regulations. DSM is defined[2] as "a set of initiatives undertaken by the utility on the consumer side of the meter to bring about a desired change in consumer demand and/or demand profile maintaining, or even enhancing

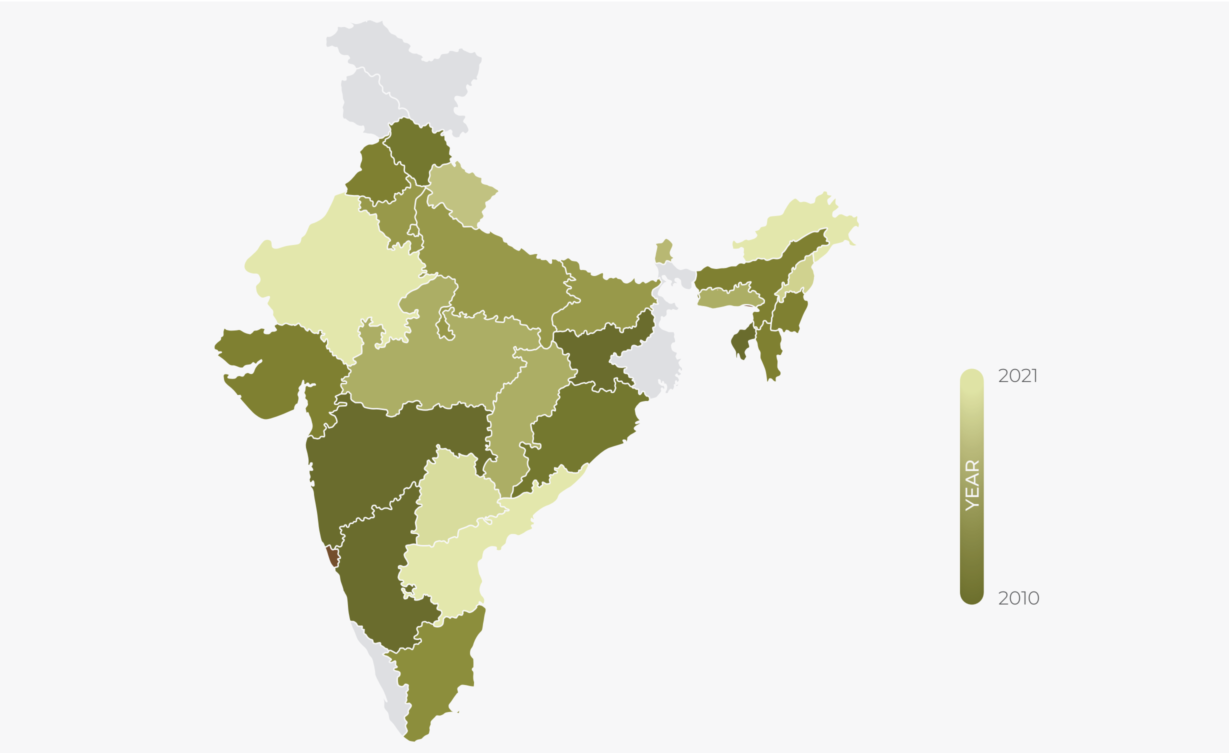
2. As defined in Model Demand Side Management regulations by Forum of Regulators

the service provided to the consumer in terms of quality, reliability and cost of service." Figure 3 shows the timeline for notification of the DSM regulations by different states in India. Maharashtra, the first state to notify the DSM regulations, also led the initiative at the Forum of Regulators to develop model regulations for DSM. These model DSM regulations, with many progressive provisions, have been the catalyst for other states. Sixteen State Electricity Regulatory Commissions (SERCs) have already notified their DSM regulations, and two SERCs have their notifications in the draft stage. Although the DSM regulations are in place, the implementation of the provisions and corresponding on-ground efforts have been nominal. Interestingly, the term "DR" is also not defined in all DSM regulations.

There is a need to adapt the regulatory framework surrounding DR to the current scenario. When DSM regulations were conceived in 2008 and model regulations notified in 2010, India had a supply-demand gap. At that time, the key issues were meeting peak electricity demand and avoiding 'load shedding' during peak demand periods. Now, with the expansion of renewables, the reality has shifted, and the issues are manifold. The need of the hour is to not only meet the demand, but also meet it in an optimal manner. The conventional understanding of DR in the past was that it was a tool for peak demand management. However, with the advent of smart control and communication techniques, DR can also be utilised to provide load increases, as well as reductions, depending on the system's requirements. Changes are needed in the regulatory framework to enable the use of DR as a resource.

*DSM regulations by Andhra Pradesh and Rajasthan will be notified in 2021.

Figure 3: Timeline for DSM regulation notification



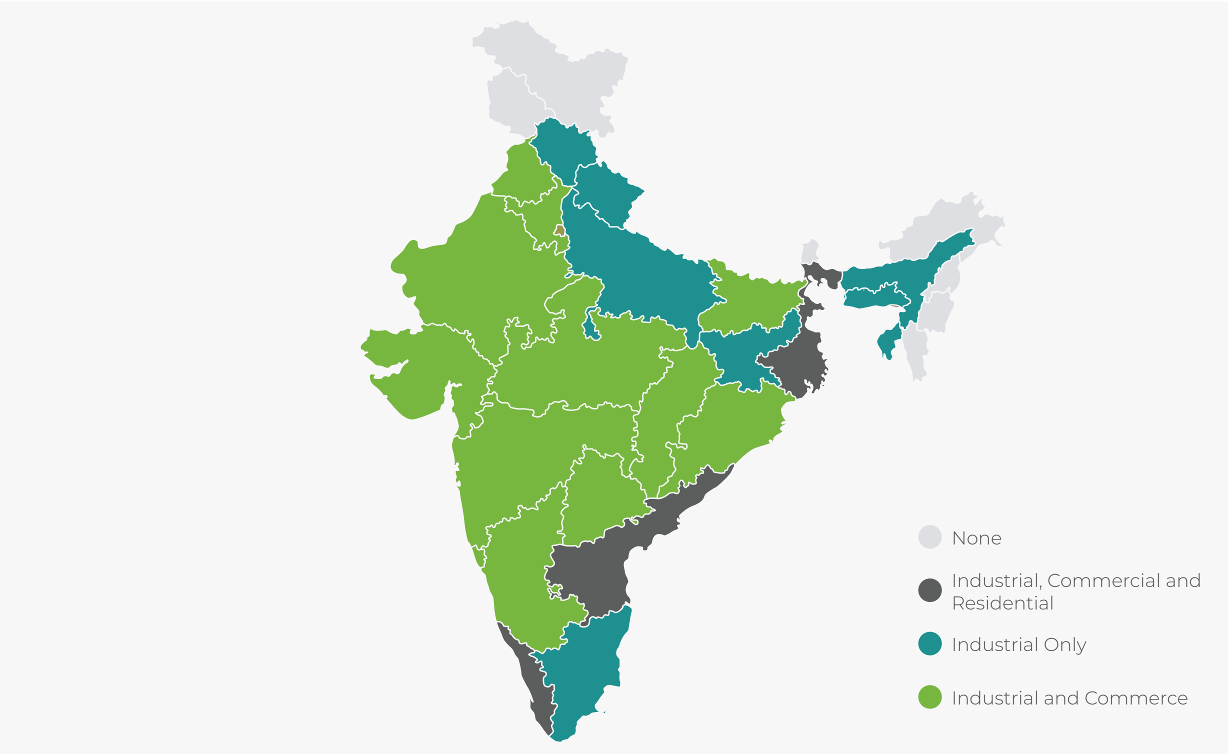
Time-of-Day tariffs

Time-of-Use (ToU) rates, also known as Time-of-Day (ToD) rates, are the most popular DR instrument used by India's regulators. As shown in Figure 4, most SERCs, apart from Sikkim and a few other Northeastern states, have ToD tariffs. The application of a ToD mechanism is mostly limited to commercial and industrial consumers. There is no standardisation in the process of determination of ToD tariffs. For example, in Delhi, ToD rates apply from May to September for consumers other than residential consumers with loads above 10 kilowatts (kW) or kilovolt-amperes (kVA). A surcharge of 20% of the existing tariff is applicable during peak hours (14:00–17:00 & 2200–01:00), and a corresponding rebate of 20% is given for electricity consumption during off-peak hours (04:00–10:00) [11]. Maharashtra has adopted a different approach. The state levies two sets of additional surcharges for different peak times, i.e. ₹0.80 per kilowatt-hour (kWh)

(09:00-10:00) and ₹1.1/kWh (18:00-22:00). They also offer a rebate of ₹1.50/kWh for usage during off-peak hours (22:00 to 06.00) [12].

It is important to remember that the electricity tariffs in India are quite low compared to those on the international electricity market. Additionally, the tariffs are not reflective of the true cost incurred in supplying the electricity. The price differential between peak and off-peak demand is not high enough to entice the consumer to reduce electricity usage. Even for a high energy use consumer, with the lack of adequate price arbitrage, potential savings from ToU are low. It can be concluded that the impact of ToU metering is rather limited in the Indian ecosystem.

Figure 4: States with implemented ToD tariffs



DR pilots

DSM has stayed alive in India via voluntary load shifting by consumers, and a few DISCOMs in India have explored the DR value proposition through pilot programmes. The application of DR contributes to critical value streams such as peak management, avoided capacity, and grid flexibility. This section attempts to provide an overview of the DR pilots in India, to examine the different value propositions. There is hardly any literature that has analysed the existing DR pilots in India in detail, and very limited information is available in the public domain on the DR pilots. The AEEE research team was able to study a total of seven DR pilot programmes in India starting from 2012, as summarised in Table 2. Mostly privately-owned DISCOMs and progressive public sector DISCOMs have undertaken DR pilot projects. Although all the DR programmes were able to achieve a reduction in demand, there are many barriers to scale-up. These pilot programmes explored diverse strategies, including demand aggregation, automatic control, and manual control, as explained below [13] [14] [15] [16] [17] [18].

Table 2: Snapshot of DR pilot projects in India

State	Electric utility	Year	Rationale	DR type	DR strategy	Consumer segments
Maharashtra	Tata Power Company Ltd – Mumbai	2012	Peak demand	Shed	Aggrega-tor-based and automated DR	Commercial and industrial
Delhi	Tata Power Delhi Distribu-tion Limited (TPDDL)	2014	Peak demand Grid stress	Shed	Automated DR	Commercial and industrial
Rajasthan	Jaipur Vidyut Vitaran Nigam Ltd (JVVNL)	2013-14	Deviation from schedule	Shed	Manual DR with energy market integration	Commercial and industrial
Delhi	BSES Yamuna Power Limited (BYPL)	2017	Deviation from schedule	Shed	Manual DR	Commercial and industrial
Delhi	BSES Rajdhani Power Limited (BRPL)	2018-19	Peak demand	Shape, Shift	Behavioural DR	Residential
Uttar Pradesh	Uttar Pradesh Power Corpo-ration Limited (UPPCL)	2019	Peak demand	Shed	Manual DR	Commercial and industrial
Delhi	BSES Yamuna Power Limited (BYPL)	2020	Peak demand	Shed	Automated DR	Residential and commercial
Delhi	Tata Power Delhi Distri-bution Ltd (TP-DDL)	2021	Peak demand	Shed, Shift	Behavioural DR	Residential

Tata Power Company Limited, Mumbai, Distribution - DR pilot

Tata Power is a privately-owned DISCOM in Mumbai that pioneered DR in India. The Tata Power DR programme tested two DR ideas – aggregator-based and automated DR.

i. **Aggregator-based DR:** This pilot saw participation from Tata Power Direct consumers – Chhatrapati Shivaji Maharaj International Airport, private commercial offices, information technology (IT) parks, and the local municipality. Twenty-one events for a duration of 2 hours each were conducted, and consumers participated in load reduction accordingly. The airport raised the AC temperature, commercial office spaces switched off chillers by engaging in pre-cooling, IT parks switched to diesel generator (DG) sets or alternate generators, and the municipality engaged in staggered sewage pump operation. The exercise rendered a cumulative DR curtailment of 15 megawatts (MW).

ii. **Automated DR:** This programme saw the use of a Demand Response Automation Server (DRAS) with compliant Open Automated Demand Response (OpenADR) software. The server, when integrated with the test site's Building Management System (BMS), had the ability to configure load curtailment schedules and strategies. The site chosen for this pilot was a hotel with a load of 600 kVA. Select loads were chosen to be altered by the programme, and access was provided through BMS integration.

The pilots brought out key takeaways for the future. The consumer perception of automated DR was that the utility was interfering in their operations, which discouraged their participation. Aggregator-based DR, on the other hand, has better acceptance and proved to be more cost-effective. To scale up these pilots, consumer interest and participation are necessary, and incentives must be offered accordingly [12].

Tata Power Delhi Distribution Limited – Smart metering and automated DR pilot

TPDDL is a privately-owned DISCOM that operates in the northern part of the National Capital Region (NCR). India's first smart meter-based automated DR pilot was initiated with the objective to demonstrate peak demand and grid stress management. Consumers with a sanctioned load of 100 kVA were approached for the programme, and 162 high-end consumers participated. Seventeen DR events were conducted with automated DR infrastructure such as servers and site controllers. Smart meters and a radio frequency (RF) mesh-based communication system were set up to enable real-time data transmission. A meter data management system and DRAS were integrated to eliminate aggregators and shadow meters. [13]

When there was a scheduled DR event, a 4-hour prior intimation was sent to the consumers. The advanced IT infrastructure enabled real-time data transmission of 15-minute load interval data to the utility. Real-time intimations regarding the load were also transmitted to the consumers through Short Message Service (SMS). The same could also be accessed through a customer portal. The load shed potential was estimated to be 12 MW. After the DR events, a maximum shed of 7.2 megavolt-amperes (MVA) was observed. The participating consumers benefitted due to the relay of real-time information. Violations with respect to power factors and load could be monitored by the consumer. The availability of a web-based consumer portal with consumption data also increased transparency, which enhanced the consumers' confidence. Overall, the provision of detailed information to the consumers enabled them to make informed decisions to control their electricity use and increase monetary savings [13].

Jaipur Vidyut Vitran Nigam Limited - DR pilot

Rajasthan is a state in North India that has a significant share of RE generation. Rajasthan was also home to a pilot where the DR programme was designed to reduce the deviation penalty that is incurred. A demonstration to establish a case for DR was set up under the aegis of Rajasthan Discoms Power Procurement Centre (RDPPC) and was conducted with the support of JVVNL. Four DR events were triggered across different identified industrial areas. The pilot in Rajasthan is distinct in that it was designed with a demand-bidding-to-the-market mechanism. Industrial consumers could submit demand bids directly to the energy market. Seventeen commercial consumers, who had enrolled on a voluntary basis, participated in the pilot programme. RDPPC informed the aggregator four hours prior to the DR event by SMS and phone call. Correspondingly, the aggregator was tasked with sending signals to the consumers via phone call, SMS, and e-mail. The consumer then acknowledged the signal and confirmed the load curtailment as per the bids. A field team was assigned to observe the consumer's load curtailment on a real-time basis through the DR portal [11] [10].

DR software was developed, and after the DR event, the software was used to measure and verify participants' load curtailment. The DR portal enabled cross-checking of participants' load patterns by both the utility and consumers. This provided an incentive for participation, by promoting transparency. The four DR events resulted in an average of 22 MW in DR, outperforming the pre-event analysis, which estimated an average of 20 MW in DR. A key takeaway was the need to gauge the demand at a localised level. There are mismatches between the state-level demand and the DISCOM-level demand that must be factored in for effective peak management. DR, through this pilot experience, has proven to be cost-effective for demand management. The scale-up of such projects will require dynamic pricing programmes and advanced metering infrastructure as we delve into other consumer segments, such as residential areas [11] [10].

BSES Yamuna Power Limited - DR pilot

BYPL is a privately-owned DISCOM that operates in the eastern part of the NCR. BYPL conducted eight DR demonstration events during the summer months, from April to June 2017. The rationale for setting up the DR programme was to balance the load, in order to reduce the gap between the scheduled and actual demand. In India, the norms surrounding forecasting and scheduling of generation and demand have tightened, and there is a heavy penalty on any deviations from the schedule based on their frequency. The project was a first-of-its-kind manual DR programme that included nineteen industrial and commercial consumers. As a precursor to the event, BYPL interacted and carried out capacity building sessions with the participating consumers. Possible measures that could be taken to reduce demand without compromising the consumers' output and business requirements were shared [9].

During the DR event, consumers curtailed their loads as planned for a duration of one hour, and the same was verified using the online billing system. The actual savings achieved was compared with the baseline consumption, and a cumulative load reduction of 17.4 MW was observed. For the duration of the event, an incentive of ₹1/kWh was provided. The post-pilot analysis revealed that the gross savings varied from ₹2.11/kWh to ₹3.3/kWh over the duration of the project, implying that incentives up to ₹2.00/kWh can be offered to the participants. This indicates that higher consumer incentives are possible, to encourage participation in DR programmes. The success of this pilot has prompted BYPL to work towards scaling up such programmes, in order to demonstrate higher targeted savings involving a wider range of consumers [10].

Uttar Pradesh Power Corporation Limited – DR pilot

Uttar Pradesh (UP) is a state in North India with significant peak demand and demand supply deficit during peak hours. UP's peak demand deficit prompted a DR pilot programme with the UPPCL to aid DISCOMs in peak demand management for select consumer categories. The Lucknow Electricity Supply Authority (LESA) was picked for the DR event, due to its position as the state utility with the highest demand. Consumers, primarily commercial ones, with a minimum contract demand of 500 kVA were shortlisted, and the participants were enrolled on a voluntary basis. This was a manual DR pilot project that was executed using the social media mobile application Whatsapp. In Whatsapp, groups were formed with the participants, and information regarding the DR event was provided in advance. Throughout the event, the participants reduced their load accordingly, and information was relayed through the Whatsapp group [7].

The result was a successful load reduction of 3 MW during the DR event. The objectives of identifying target sections for DR projects and consumer categories and demonstrating a test intervention with select consumer categories were achieved. However, the execution of the pilot did come across a few barriers on the utility and consumer end:

i. **Challenges for the utility:** Implementation of such programmes on a large scale necessitates capacity building across the organisation on new and effective load management techniques. There is an element of revenue loss involved in such measures, but the overall benefits of the programme in its sustained application will facilitate programme acceptance.

ii. **Challenges for consumers**: Because the DR pilot was a manual programme, it interfered with the daily activities of the consumers. Given the select consumers were commercial entities, seeking approval for participation was a long process [8].

BSES Rajdhani – Behavioural DR pilot project

BRPL and Oracle Utilities (Opower) initiated a behavioural EE pilot programme in 2018. This pilot is unique in that it was designed to specifically target residential consumers, whereas all other DR programmes have focused on industrial and commercial consumers. Behavioural EE programmes use proactive, personalised feedback and peer comparison to influence consumers. These programmes use relevant, eye-catching, and immediately actionable information about consumers' energy use to motivate them to alter their consumption patterns. One of the popular mechanisms in behavioural EE campaigns is a feedback mechanism called Home Energy Reports (HERs). In this pilot programme, personalised HERs were sent to two lakh customers in Southern and Western Delhi.

The effectiveness of this programme was measured and verified using a randomised control trial (RCT) approach. The 2.6 lakh customers were selected and randomly placed into a treatment group of two lakh customers who received HERs, and 0.6 lakh customers who received no additional communications, to be tracked as a control group. The customers receiving HERs were further segmented into three bands based on their consumption level. The consumers were given information using paper-based and email-based HERs. Insights & analysis were provided through the DISCOM website, and consumers could access personalised data analytics and advice by logging into their accounts. In addition to demonstrating the benefits of HERs to consumers, this programme was focused on promoting domestic consumer energy literacy and encouraging participation in other DSM programmes. This programme tried to empower consumers to save money on their energy bills and demonstrate benefits to the grid. During the customer selection, care was taken to select customers from areas with overloaded distribution transformers to check the value proposition of reducing network congestion. This pilot has been converted into a full-scale DR programme in the DISCOM now, making it a rare success story in terms of scale-up [19].

BSES Yamuna - AC demand flexibility programme

In 2020, BYPL hosted a pilot programme with the support of Panitek Power and Greencom to demonstrate the feasibility of using ACs for DR. In the pilot project, the indoor vents of commercial heating, ventilation, and AC (HVAC) systems were controlled. The objective was to reduce the cost of peak power and optimise the load shape. Over fifty DSM events were executed between April and September 2020. During the DR events, an average reduction in power of 5 kW was observed, corresponding to a 30% reduction in the actual consumption. The temperature and humidity levels of the rooms were monitored, along with energy consumption, setpoints, and modes of operation. The length of a DSM event is limited to about fifteen minutes to ensure thermal comfort. The units are not switched off completely, and only setpoints and modes are changed.

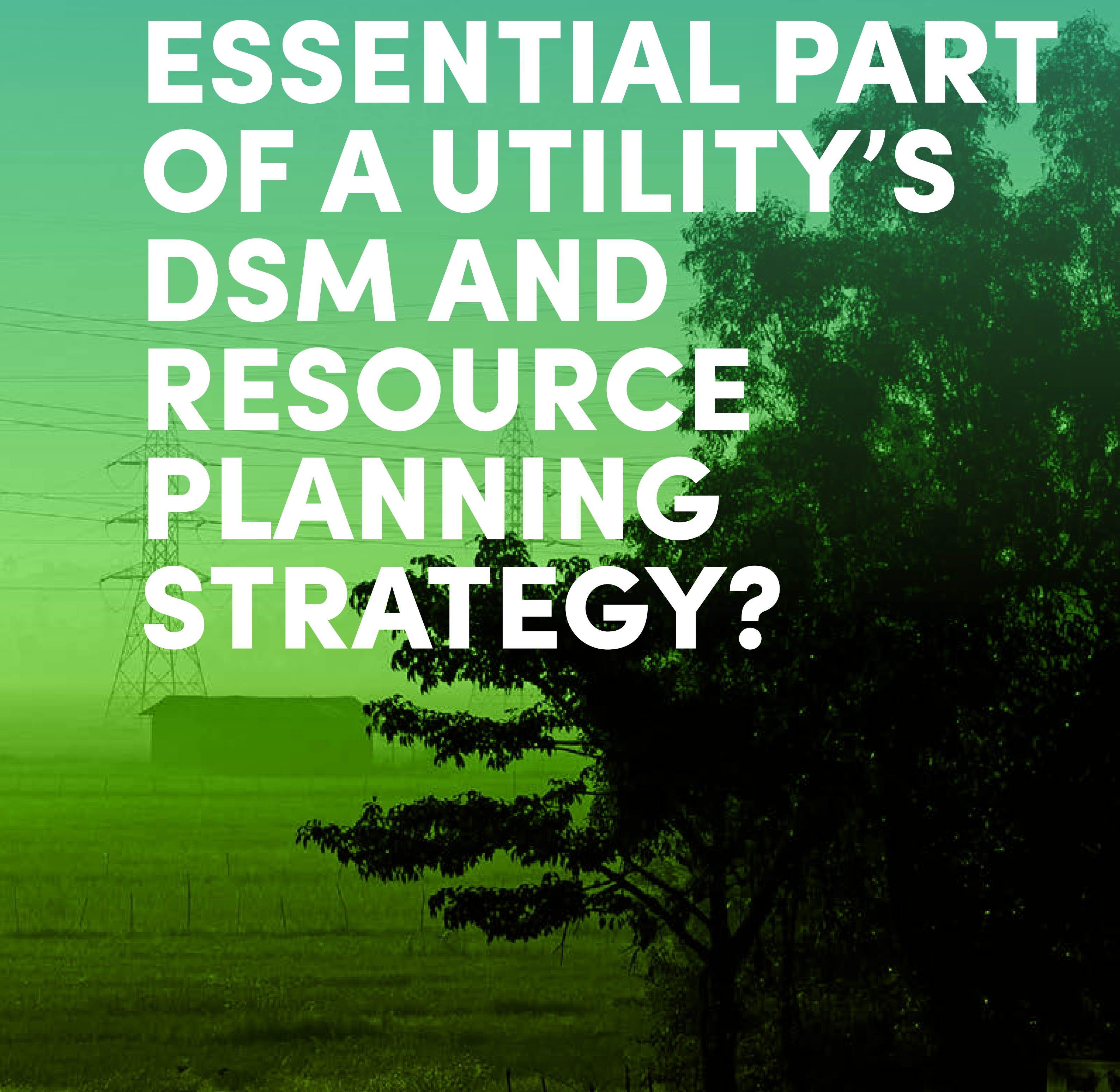
This is an automated DR solution that allows the DISCOM to monitor the grid's state and consumer loads using cloud services. Preregistered and preconfigured devices at the consumer end, such as ACs, are part of the DR system. The DISCOM provides an input to the cloud, which triggers DR and automatically sends signals to the consumer devices to reduce the load on a real-time basis. The reduction in energy consumption can be seen immediately by the DISCOM monitoring it. DR based on ACs is a suitable measure for short-term peak power reduction. To reduce the energy consumption during a specific time window, ACs are triggered to reduce the cooling demand by changing the operational behaviour—in this case, changing to fan mode. By intelligently controlling and activating only those units that ensure the most promising possible load reduction, while simultaneously maintaining comfort, a significant load shift can be achieved in the short term [20].

Tata Power DDL - Behavioural Demand Response

Tata Power's Behavioral Demand Response (BDR) pilot was developed as a price-based intervention targeted at residential consumers. The successful implementation of the smart meter rollout for urban residential consumers in Delhi, enabled real-time assessment of the load profile. The BDR program was correspondingly designed as a voluntary 'opt-in' intervention, wherein consumers were provided with peak time rebates as a nudge for load shift. The pilot was developed under the premise of demonstrating the Utility benefits of capex investment deferral and addressing local distribution system constraints. The program also showcased benefit to the consumer in the form of bill savings, thus encouraging their participation in load shift events. The details of the DR program are given as a separate case study in Annexure – A.

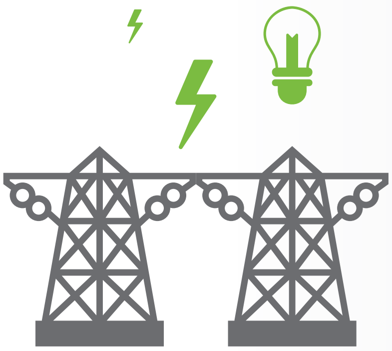
CHAPTER 03

WHY IS DR AN ESSENTIAL PART OF A UTILITY'S DSM AND RESOURCE PLANNING STRATEGY?



DR value propositions for Indian DISCOMs

Indian DISCOMs maintain one of the largest electricity distribution networks in the world. At the beginning of Fiscal Year (FY) 18, the distribution network[3] in India was 10 million circuit kilometres (ckt km) long, with 9.6 million distribution transformers with an aggregate capacity of 535,697 MVA [21]. DISCOMs are often labelled the Achilles' heel of the power sector, due to their poor financial health. They are plagued with structural challenges arising from the non-cost reflective tariffs, cross-subsidisation, and high aggregate technical and commercial (AT&C) losses. Delayed payments from DISCOMs to generators decrease the power sector's financial stability. The cost of upgrading and operating the network is a critical concern, as it has the potential to compound the existing challenges in the distribution sector.



India was 10 million circuit kilometres (ckt km) long, with 9.6 million distribution transformers with an aggregate capacity of 535,697 MVA

DR offers a wide range of value propositions for DISCOMs, as shown in Table 3, apart from the avoided energy, or 'negawatts', itself. Without any 'shed' or absolute reduction in demand, DR can assist DISCOMs in optimising investments in the distribution grid, minimise penalties for deviation, facilitate electric mobility, and improve the DISCOMs' carbon footprint. 'Shift' DR is also tactically important, as it can reduce the cost of supply or increase RE penetration without any reduction in net demand.

Table 3: DR value propositions for DISCOMs

RE Penetration	Shift demand to periods of surplus generation
	Provide ancillary services to handle intermittency
Increasing Peak Demand	Shift or shed load to reduce cost of supply
	Behavioural campaign for demand shape change
Reduced need for system upgrades	Defer transmission & distribution capacity additions
	Avoid cost of setting up peak power plants
Grid operation an management	Reduce penalties for schedule deviations
	Improve reliability at the lower risk
Transport electrification	Minimised grid Impact from EV charging
	EVs as grid flexibility resource
Avoided negawatts	Avoid cost of power procurement and associated losses
	Reduce indirect costs - fixed cot of power, cost of flexibility
Avoided emissions	Reduce emissions from avoided thermal power
	Improve grid emission factor due to high RE

3. All supply lines less than or equal to 33 kV

Well-planned and -executed DR can effectively reduce the cost of service and help in reducing peak loads in a predictable and measurable way. Geo-targeted DR has proven to be an effective tool in reducing demand in specific areas facing distribution capacity constraints. With smart technologies, the potential for grid services is high. One can easily monitor load and control equipment in a way that was previously not possible.

More Shift, less Shed

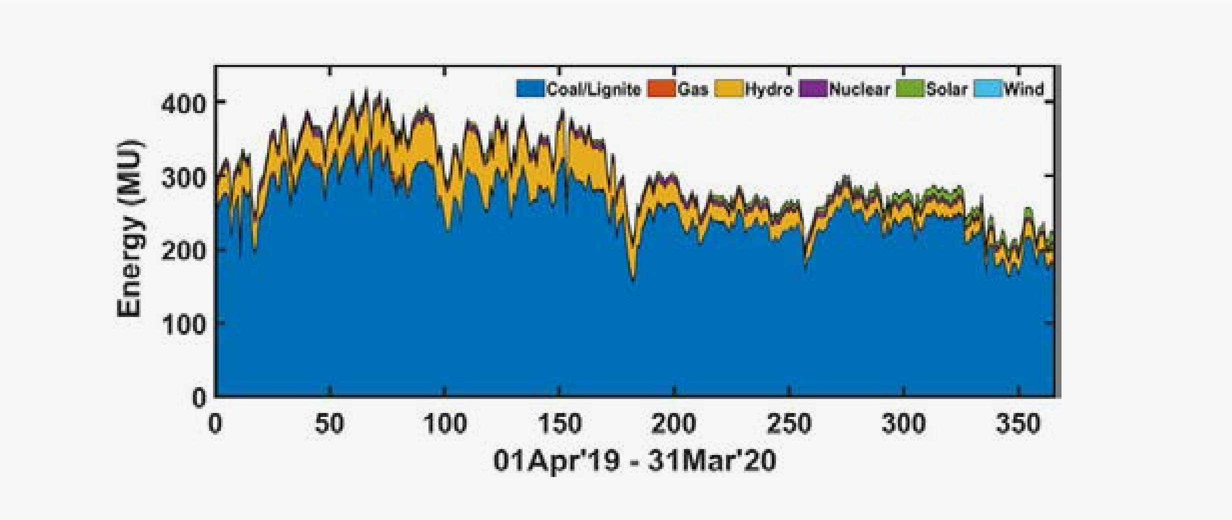
The two major legacy issues that have weakened the financial health of DISCOMs are the non-cost reflective nature of tariffs and cross-subsidisation. The current tariff regulations are such that the cost recovery of a utility is aligned with the volume of energy sales. One of the deterrents for Indian DISCOMs regarding DR adoption is the fear of loss of revenue from the avoided energy sales. Here, the application of DR as a shift resource, where consumers are incentivised to change the time of their demand without leading to any overall reduction in energy sales, is of particular significance. In this case, load reduction during a peak demand period is explicitly compensated for by a load increase at another time. The goal of providing an equivalent energy service to the customer but at a more convenient timing works best for both the DISCOMs and consumers.

Shift DR is aligned with the Indian power sector's decarbonisation goal. The shift of agricultural pumping loads to high solar PV generation hours is a good example for cost and emission reduction. In the future, enabling daytime charging of EVs can also be a good strategy to manage charging demand. A recent assessment has shown that Shift DR is even more economical than energy storage applications. It is important for India as a practical high RE integration strategy to prevent curtailment during surplus generation and support in grid balancing [10]. Shift DR is also a brilliant scheme for emissions reduction, as shown in the following case study.

Shift case study on emission and economic reduction

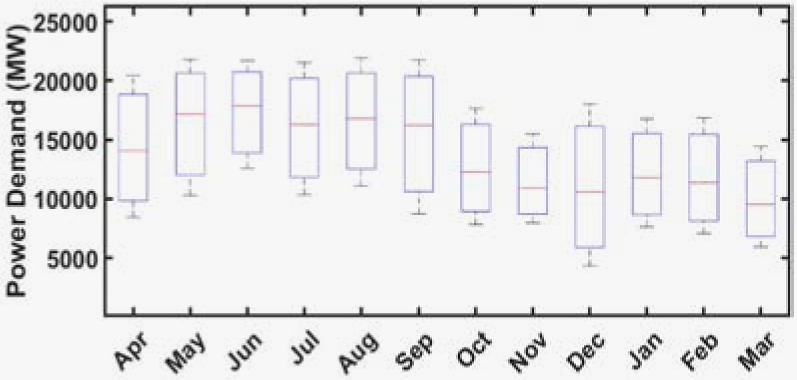
DR measures, in addition to managing the utility grid, can assist significantly in reducing the GHG emissions. AEEE implemented a case study on an Indian state to assess the potential benefits of implementing shift DR measures in reducing the emissions. The case study used the FY 2019-20 load pattern as a baseline to analyse the benefits of DR. The energy mix of the state, given in Figure 5, shows the high reliance of the state on thermal generation.

Figure 5: Energy mix of the state in FY 2019-20



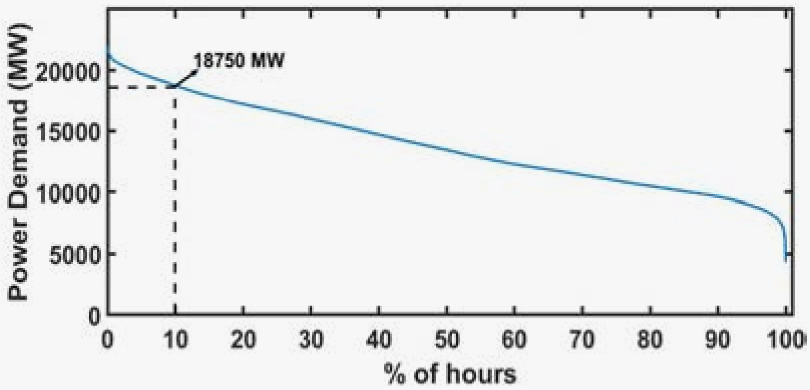
The state can effectively reduce its emissions by taking advantage of the increasing RE generation and shifting the load to match solar / wind generation. This state experiences high electricity demand in the summer. The monthly demand variation of the state is given in Figure 6 and shows the period of high demand from April to September, corresponding to the summer months.

Figure 6: Monthly load variation



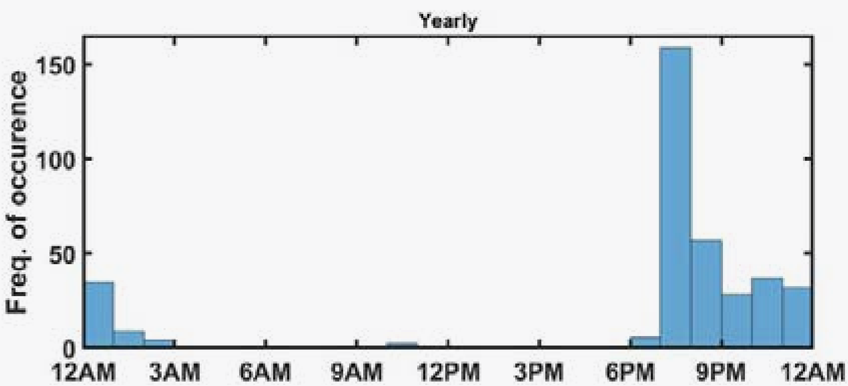
A closer look at the load duration curve for the state, given in Figure 7, reveals that even though the highest demand touches ~22 GW, demand above 19 GW is experienced by the network for less than 10% of the entire year, i.e. less than 900 hours annually. Since the grid infrastructure is planned based on the peak demand levels, this highlights the fact that expensive infrastructure is built with inefficient utilisation of the network assets.

Figure 7: Load duration curve



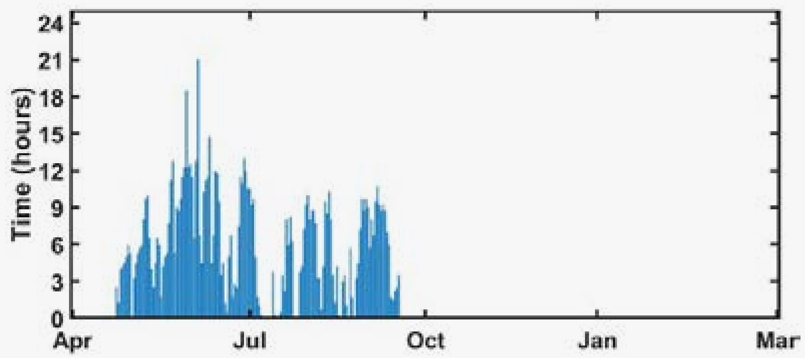
It is important to understand the time period of the peak demand. Analysing the hours of peak demand, as shown in Figure 8, it was found that the state mostly experiences its peak demand level between 7 PM and 1 AM. This is a time period when thermal power plants supply demand, further strengthening the argument for acknowledging Shift DR as a resource in reducing emissions.

Figure 8: Occurrence of peak demand



To assess the potential benefits of implementing Shift DR, a resource simulation was performed using a random deployment strategy. The threshold value for the initiation of a DR event was set at 18.75 GW, i.e. any time the demand level goes beyond this value, the DR event is triggered. DR deployment was simulated for the time period that had the maximum number of threshold violations, i.e. 15th May '19 – 14th Jun '19. To factor in the variation in availability of the demand resource, a random deployment strategy was adopted. The amount of DR resource available at any time was a random value set between 2% and 2.5% of the peak demand. The frequency of DR events simulated in the case study is given in Figure 9.

Figure 9: Occurrence of peak demand beyond threshold value



Based on the simulation, the average load curve for the period of May-June before and after DR interventions is provided in Figure 10. To calculate the emission reduction potential, the average value of specific thermal emissions (tonnes of carbon dioxide per megawatt-hour (tCO_2/MWh)) from coal/lignite power plants is taken as 0.95 tCO_2/MWh. The emission reduction gained during the period, along with other impact-related indicators, is given in Table 4.

The analysis of economic savings potential was carried out under the assumption that a state procures solar power at a cheaper cost compared to that from peaking thermal power plants.

Figure 10: Load curve before and after DR interventions

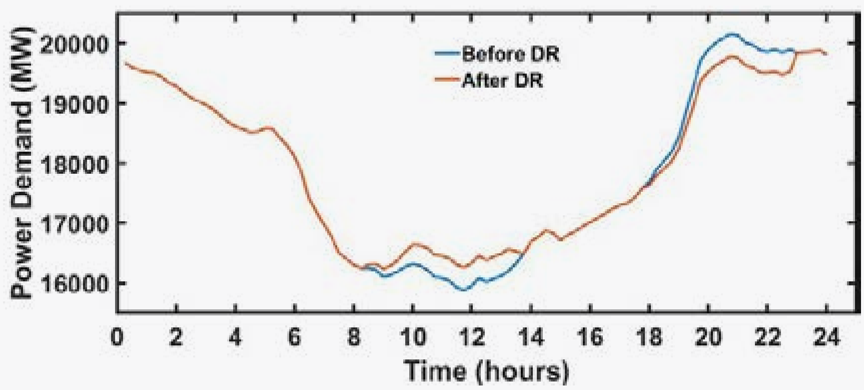


Table 4: Impact of DR interventions

DR strategy	Shed	Shift
Energy (MWh)	46400	
Emission reduction (tCo2)	44081	
Impact on revenue (Million INR)	194.88	0
Impact on power procurement cost (Million INR)	315.52	171.68
Net savings (Million INR)	120.64	171.68

The case study shows that Shift DR interventions are an essential strategy to enable Indian DISCOMs to benefit from falling RE costs. Shift DR could be considered the most effective way to reduce the GHG emissions from thermal plants. This can be achieved without hampering the revenue generation for the DISCOMs, as it does not result in a reduction in the overall end-user energy consumption. Furthermore, it will also help DISCOMs realise their renewable purchase obligations (RPOs), along with reduced power procurement costs.

DR to unlock demand flexibility

Flexible demand can go a long way in ensuring the supply-demand equilibrium in grid operation with variable supply and increasing demand. The decarbonisation of the grid is fundamentally changing power system operations and planning. For reliable operation of electrical systems, electricity supply and demand must be in equilibrium. The addition of RE generation has increased the need for grid flexibility, i.e. the ability of the electrical system to adapt to variations in demand and supply and maintain the balance throughout all timescales. As the supply-demand levels vary, there is a need to deploy mechanisms to mitigate the imbalances, thereby reducing the risk of grid failure. The two major mechanisms that play is a significant role here are the balancing energy market and ancillary services market.

The conventional design of electrical systems involves inflexible base load and flexible peak load plants. These peak load plants are 'demand following', i.e. their supply levels are quickly adjusted to match the demand at any given moment. Hydropower plants and gas power plants are the supply-side options for India. The bulk of the Indian electricity supply is coming from coal-based power plants, which are inflexible in nature, without significant ability to quickly ramp up or ramp down generation. Currently, India is focusing on increasing the supply-side measures to derive flexibility, such as retrofitting coal power plants for flexible operation.

Demand flexibility is the pathway to allowing consumers to participate in mechanisms to offer grid support services. Recently, the draft ancillary services regulations, 2021 called for the inclusion of energy storage and demand-side resources in the secondary and tertiary reserve mechanism. Enabling active demand-side participation will require regulatory reforms to facilitate DER aggregation. Under the right conditions, DISCOMs can play a proactive role in aggregating DERs for local and bulk power system services. Demand flexibility is an underexplored option, and to study the related DR value proposition, a case study was carried out, as described below.

Case study on DR-related flexibility

In India, the proxy to study the balancing and ancillary market is the deviation settlement mechanism pool. The balancing requirement arises from the deviation between the scheduled and actual draw of power by DISCOMs. There is a penalty on DISCOMs for any deviation from the given schedule. This penalty is linked to the electricity market clearing price and depends on the frequency variation during the deviation. The cost of deviation is an indirect cost to the supply of electricity that the DISCOMs incur. The effectiveness of DR as a flexibility mechanism to reduce deviation costs has received attention in a few pilot projects. Energy storage, or loads with inherent storage capabilities, could be useful for this DR application. One easy way to ensure load reduction is through Shed DR, but this might be a good case for the application of Shimmy DR as well, which relates to both the increase and decrease of loads.

The value proposition from implementing Shift and Shimmy DR measures to minimise the cost associated with the Deviation Settlement Mechanism was evaluated in this case study. The difference between the scheduled draw and actual draw for four Indian states, which are anonymised, was studied for FY 2019-20 [22]. The four states were selected such that they do not exhibit similarity in the magnitude of the draw and ratio of deviations to total draw. The average deviation exhibited by the states and the corresponding penalty incurred due to the deviation are presented in Table 5. It was observed that the states show a noticeable difference between positive and negative deviation and the associated cost. It should be noted that the total power procurement cost of these states is so high that the cost of deviation is only a small fraction of the total cost. Nevertheless, the cost of deviation is not small in terms of its absolute value and can be deemed sufficient to support a demand flexibility market.

Table 5: Deviation penalty incurred by the states

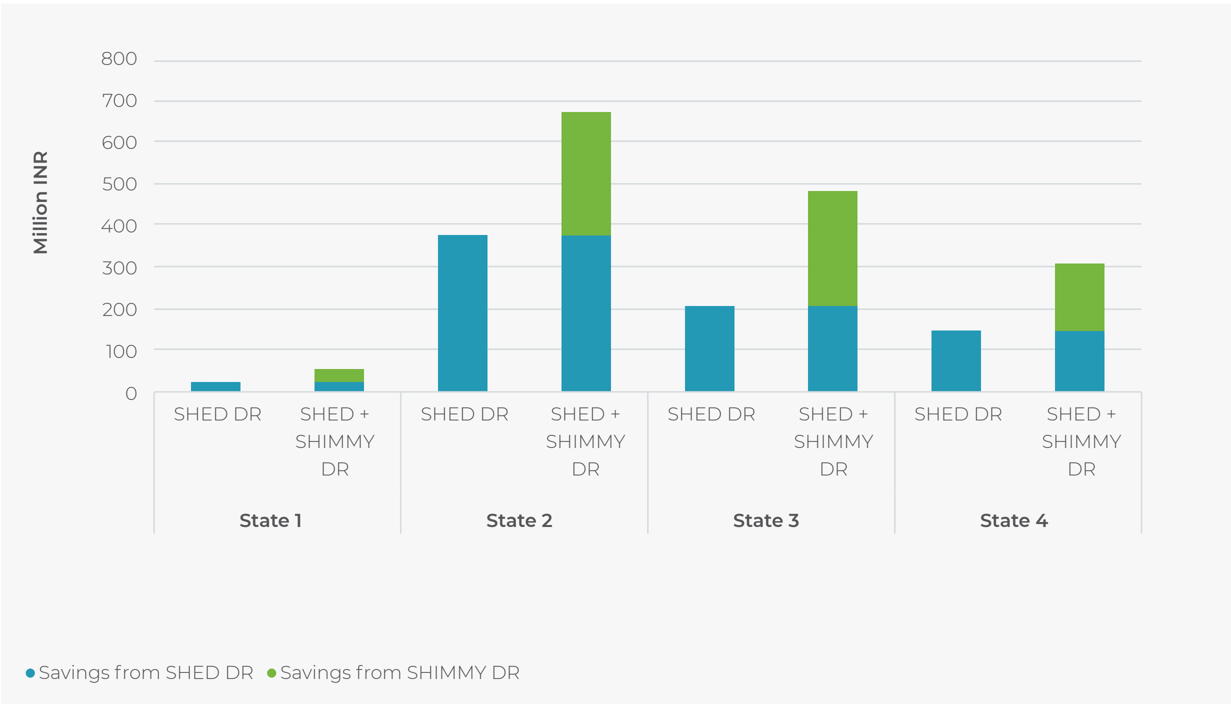
	Average positive deviation (MW)	Average negative deviation (MW)	Ratio of positive to negative deviation	Cost of deviation (million INR)
State 1	58	65	0.89	1483.9
State 2	205	202	1.01	4956.4
State 3	148	171	0.86	3837.5
State 4	125	121	1.03	3117.3

The aggregate DR resource available in each state is assumed as 20% of the average deviation of a state. There could be two types of DR events to facilitate balancing: Shed and Shimmy:

- **Shed DR:** Shed DR corresponds to a load reduction DR event, which is triggered only when the deviation is positive, corresponding to overdraw, i.e. the actual demand is higher than the scheduled demand. The DR event is triggered when the difference between the actual and scheduled demand is greater than a certain threshold. The threshold value for each state is assumed to be 100 MW for the study. In the first scenario, Shed DR, the strategy is to deploy a reduction in load equivalent to 20% of the average deviation through DR.
- **Shimmy DR:** The second type is a DR event that can be called upon for both the underdraw and overdraw scenarios. This can help address both positive and negative deviations, by decreasing and increasing the load, respectively. The threshold value for DR deployment is taken as 100 MW for both cases. In the second case, with a 'Shimmy' DR deployment of 20% of the average deviation, DR could potentially offer greater savings. If there is a mechanism to deploy DR as close to real time as possible, this value proposition can be explored. The value proposition of this use case is linked to demand forecasting, and flexible demand can potentially improve accuracy in load forecasting techniques.

The rough estimates for potential savings from DR measures for both the Shed and Shimmy scenarios are given in Figure 11.

Figure 11: Value proposition of Shed and Shimmy DR



Analysing the Shed DR savings, i.e. load reduction, for all the six states, it was found that the states can eliminate around ₹20-380 million of the deviation charges. The deployment of Shimmy DR, a type of flexibility DR with load variations in both the directions, can effectively save ₹50-670 million. The deviation charges vary from state to state and depend on the average frequency values of the grid for a particular time block. Therefore, each state has different savings potential. Nevertheless, the above figures show that most of the states have a high potential to reduce their deviation penalties by implementing DR measures. For some states (State 2 and State 3), DR programmes could effectively translate into cost savings in the range of 8-10% of the associated deviation penalties.

DR as a resource for power procurement optimisation

The power procurement portfolio of a DISCOM is dominated by its long-term contractual obligations with the generating stations, a.k.a. Power Purchase Agreements (PPAs). These agreements have been made with thermal and hydropower stations and are considered a risk mitigation measure for power plants against their large capital investments. Under PPAs, in addition to the energy charges based on the actual procurement cost, states are obligated to pay a hefty fixed amount to the generating station, even if the plant is not utilised. Many of these expensive thermal power plants are scheduled for less than 10% of the time, but the total cost to the DISCOM is high because of the associated fixed cost. With the advent of cheaper alternatives and strengthening of the power market, optimisation of power procurement has garnered increasing interest. Generally, a power plant is dispatched based on the merit order framework, which only considers the economic aspect. Furthermore, the grid operators consider the available network capacity while dispatching. However, recently, regulatory changes have allowed the DISCOM the "first right of refusal" for procuring electricity from power plants that are over 25 years old.

An alternate philosophy to pure economics planning and dispatch is adopting the lens of emissions impact. With an emphasis on decarbonisation, the AEEE research team has looked at the possibility of optimising power procurement and dispatch in terms of both emissions and economics. The rationale for this is that the cheapest power plant in terms of its economic value is not always the one with the lowest emissions. Hence, a case study on power procurement optimisation, considering both emissions and economics, is presented below.

Case study on power procurement optimisation

To analyse the potential benefits of a DR event, a model-based case study was developed, which analysed the existing demand patterns and generation mix of an Indian state for FY 19-20. From the load heatmap of the region given in Figure 12, it can be seen that the power demand is high during the summer months, suggesting significant energy consumption for space cooling. This is also evident from the correlation plot shown in Figure 13 between power demand and cooling degree days (CDD) at a threshold temperature of 24 degrees Celsius (°C). As the regional demand is higher in April-September than October-March, the study is restricted to the period from 15 Apr '19 to 14 Aug '19. Analysing the peak demand levels is critical, as this serves as the basis for power procurement planning. The load duration curve given in Figure 14 depicts the demand level for the respective time duration during the summer months. The curve shows that demand greater than 6000 MW stays on the system for less than 10% of the total duration, leading to inefficient utilisation of network assets. Therefore, this threshold value is taken as a base value for the initiation of a DR event.

Figure 12: Load heatmap

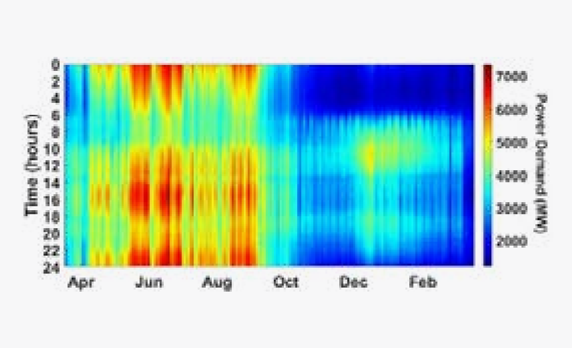


Figure 13: CDD vs. demand

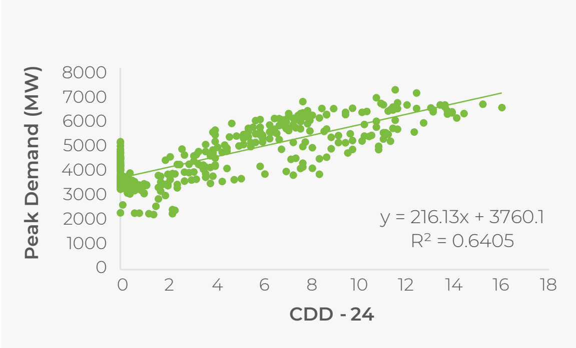


Figure 14: Summer load duration curve

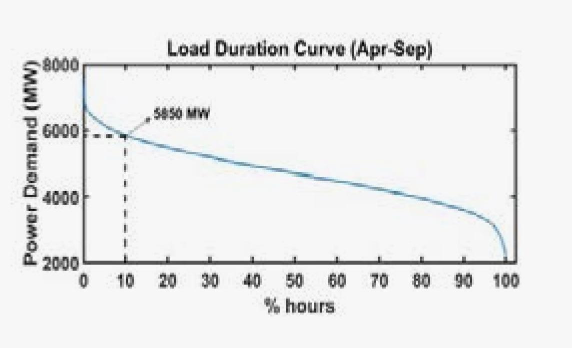
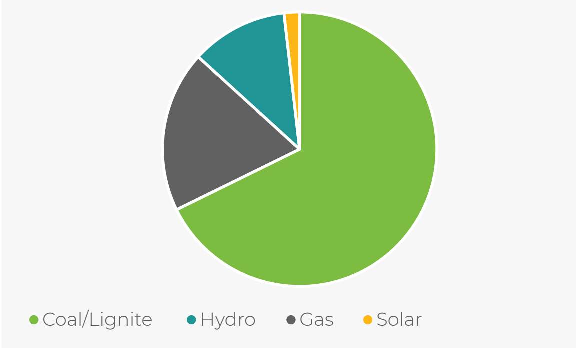


Figure 15: Energy mix



The energy mix in the state, given in Figure 15, shows high dependence on coal/lignite-based thermal plants, which contribute ~70% of the total energy supply for the state. To assess the potential benefits of DR programmes, three distinct scenarios were developed:

01

The first scenario analyses the potential benefits of DR measures in decreasing the cost of energy through reduced thermal generation.

02

The second scenario depicts the benefits of DR measures as a tool for reducing emissions. This is facilitated by taking the social cost of carbon and translating the specific emissions of a plant into its associated emission value.

03

The third scenario takes into consideration both the emission and energy costs with equal weightage.

The energy mix of the Indian state was analysed by considering the variable costs of each thermal (gas and coal/lignite) plant. In the model, the DR event is initiated in a given time block if the demand within that block exceeds the threshold value of 6000 MW. The power reduction achieved through a DR event for a particular time block was simulated as a random value between 150 MW and 200 MW, i.e. within 2-3% of the peak demand level, for all case scenarios. Then, reduction of supply is carried out based on the merit order and emissions date. The benefits acquired in terms of economic and emission savings in all the scenarios are summarised in Table 6. The emission savings value was calculated by considering the socialised cost of carbon, assumed to be INR 6000/tCO_2, and multiplying it by the specific emissions (tCO_2/MWh) of the plant. The Social Cost of Carbon is a monetary estimate that quantifies the environmental damage caused due to the release of one tonne of CO_2 into the atmosphere. The load reduction achieved in the DR event is correspondingly multiplied by the Social Cost of Carbon at the rate of ₹6000/tCO_2.

Table 6: Savings potential of DR interventions

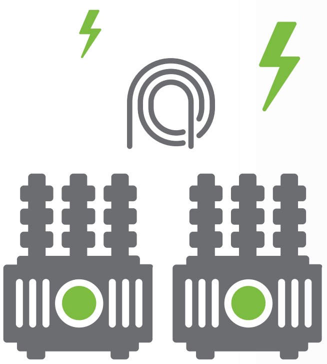
	Case 1: Economic optimisation	Case II: Emission optimisation	Case III: Economic and emission co-optimisation
Emission reduction (tCO_2)	514	1071	992
Equivalent emission savings (INR)	3088264	6427200	5964951
Energy savings (INR)	4571858	1915339	4343418

- In Scenario I, the state is able to save a significant amount in terms of energy costs, i.e. ₹4.57 million. However, the amount of emission reduction possible in that case is only 514.7 tCO_2.
- In contrast, in Scenario 2, emission savings increased to more than 1071 tCO_2, with total energy savings amounting to ₹1.9 million.
- Scenario 3, i.e. optimising both energy and emissions with equal weightage, results in a high emission reduction potential of over 990 tCO_2, along with significant energy savings, ₹4.34 million.

This case study proves that there is a case for considering co-optimisation of emissions and economics in power procurement optimisation.

DR as a non-wires alternative

Although DSM has made it possible to treat DR as a flexible resource, the peak load is still the foundation of distribution network planning. The concept of non-wires alternatives (NWAs) tries to break away from the traditional mentality of grid expansion based on increases in peak load; it is a collective term for decentralised solutions that can assist in deferring the need for investments in the legacy grid. One of the innovative strategies to ensure reliable and cost-effective electricity delivery is to focus on non-traditional solutions beyond the 'poles and wires'. NWAs can include physical resources like distributed generation, along with virtual resources, including DR, which can be deployed to eliminate the need to upgrade, replace, or add new electric grid equipment.



To meet the summer peak demand, 600 distribution transformers were augmented, and over 650 km of new wires were added.

A vital characteristic of the electricity distribution network in India is a low load factor, i.e. peak demand only lasts for a few hours per year. Non-optimal planning results in the oversizing of distribution equipment, which is underloaded for the vast majority of the year. As per the guidelines for network upgrades, if any distribution assets, including distribution transformers (DTs), are overloaded more than 70%, DISCOM have to increase the capacity. Two DISCOMs in Delhi had to make an investment to the tune of ₹10 million per MW to augment their systems to meet the peak demand [7]. To meet the summer peak demand, 600 distribution transformers were augmented, and over 650 km of new wires were added. However, for over 50% of the time, assets are loaded at only around 50% capacity. The end result of this is an increase in system losses, as the cascading effect of inefficient operation of distribution equipment severely hampers the technical efficiency.

In urban areas, constraints on land availability impact network adoption. The utility has to incur additional expenses for land costs, including right of way charges, along with incremental costs for equipment maintenance. Reduction in distribution investments is also beneficial for consumers, as it will translate to a reduction in the fixed electricity costs.

Arguments for Emergency DR

DR is arguably one of the most reliable and quick response control resources that utilities can exploit. Emergency DR programmes are deployed with the short-term objective of maintaining grid security and reliability in response to an “emergency” security event. Emergency events can only be forecasted on a short-term basis when the system is operating in an ‘insecure’ mode, i.e. there is an inadequacy in operating reserves. With the unavailability of operating reserves, if a contingency occurs on the system, the system goes into an emergency state. If the emergency control measures fail to operate effectively, such events can cause major harm to the overall system, which can potentially lead to a black/brown-out. Emergency DR measures have a high value proposition in terms of reduction in economic losses per MWh, as they facilitate secure operation of the grid by preventing black/brown-outs, which, in turn, can prevent large-scale plant shutdowns.

DR programmes have proven quite essential in mitigating the effects of emergency security events. Cases of emergency DR deployment are common in the U.S. For example, the New York Independent System Operator (NYISO) has an Emergency Demand Response Programme (EDRP) as one of its emergency procedures, along with the In-day Peak Hour Forecast response to an Operating Reserve Peak Forecast Shortage. These programmes are initiated in response to a Major Emergency State, as defined in the NYISO Emergency Operations Manual. The impact of the EDRP could be as high as USD 500/MWh of reduction in economic losses.

A well-known emergency event in India was the Mumbai power outage on 12th Oct ’20. While it is well-known that the transmission infrastructure of Maharashtra (Maharashtra State Electricity Transmission Company Limited (MSETCL)) is critically loaded, efforts are being made to upgrade and augment the existing transmission capacity. However, the occurrence of such an extreme event could have been mitigated through the deployment of emergency DR measures, preventing a widespread power outage to essential facilities, while also reducing the adverse economic impact on the financial capital of India.

CHAPTER 04

WHAT ARE THE CRITICAL FACTORS IN DR PROGRAMME DESIGN?

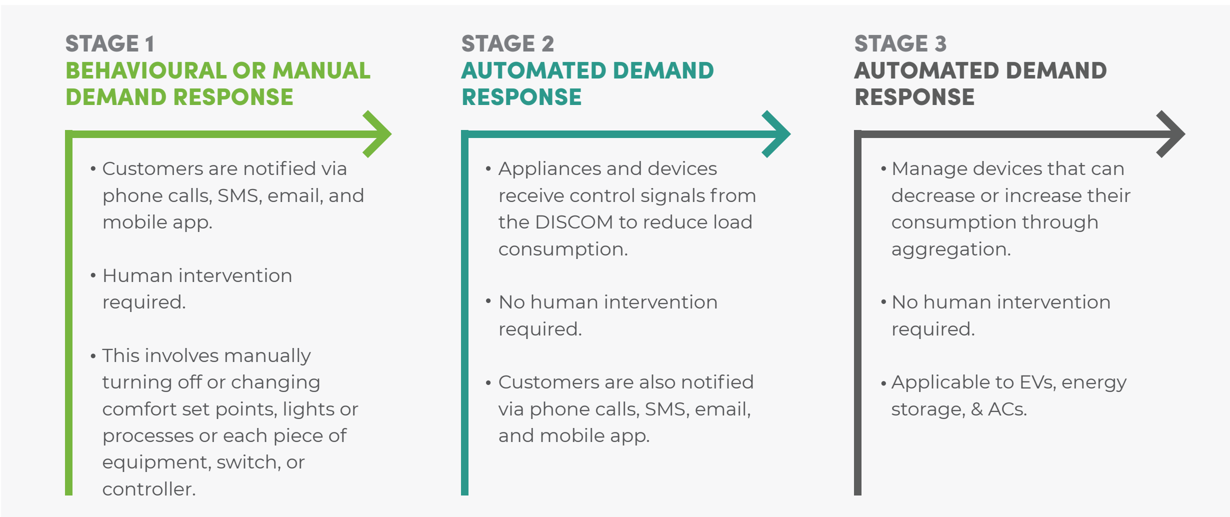
All DR is not Auto-DR

DR offers a wide range of possibilities for DISCOMs to manage their pain points. An ideal DR strategy should be designed to include a portfolio of options that can be customised to suit the needs of different consumer segments. Planning DR programmes with human intervention is a good starting point to engage consumers. With the improvement in the economics of supportive technologies, automated DR (Auto-DR) is also a practical option. Subsequently, with the rise in controllable loads and smart appliances, advanced Auto-DR, called Flexible DR (Flex-DR), with the ability to increase and decrease the load rapidly, can be explored. An effective strategy is needed to design a failsafe mechanism to ensure the optimal mix of automatic and manual DR programmes, as shown in Figure 16. 100% automated DR is not a financially viable solution, whereas 100% manual DR is unreliable and flaky.

Recent assessment of India's behavioural DR potential indicates that the annual energy savings potential could be 3.4-10.2 terawatt-hours (TWh) in 2030.

There is a common misconception that direct load control through Auto-DR is the best DR strategy. It is true that Auto-DR for residential consumers is popular among the DR measures that are being deployed by utilities in the U.S. However, behavioural DR[4] programmes are actually the 'low-hanging fruits' that are strategically important for DR programme design. Behavioural DR programmes constitute the bulk of the DR potential and are easy to tap into because of the relatively lower cost of running such a programme. A recent assessment of India's behavioural DR potential indicates that the annual energy savings potential[5] could be 3.4-10.2 terawatt-hours (TWh) in 2030. The emissions and economic savings potential are 1.8-5.3 $MtCO_2$ of yearly GHG mitigation and ₹17-51 billion annually, respectively [19]. India has already taken a progressive step to embrace behavioural DR with the pilot programme in Delhi in 2019.

Figure 16: DR rollout strategy



4. Behavioural DR can be considered a subset of behavioural EE programmes, and this study considers short-term campaigns with proper monitoring and evaluation Behavioural DR.
5. Estimated based on international experience, which consistently shows an average of 1-3% energy savings per household.

Flex-DR is the final step in the DR rollout strategy. There are two distinguishing features of Flex-DR that unlock demand flexibility:

- Demand aggregation, which enables the management of multiple devices at multiple locations
- Bidirectional control, i.e. the ability to increase or decrease demand.

Within the supportive smart grid ecosystem, Flex-DR provides the pathway to generate valued-added grid services from demand resources, including virtual power plant (VPP) operation and provision of ancillary services. This innovative DR application will play an important role in managing the impact of increasing space cooling demand and EV charging demand in India.

The one-size-fits-all approach doesn't work

DR programmes can only be successful if they are designed to create win-win situations for both consumers and DISCOMs. It is important to ensure that the selected consumers have above average energy consumption and that the incentives offered are significant enough to ensure savings in energy bills. A useful tactic is to leverage the energy data collected by smart meters to segment the consumers and identify potential target consumers. Studies have shown that providing energy data to customers alone does not result in energy savings [23]. The winning strategy is to combine smart meter energy data with DR strategies such as customer engagement tools, pricing mechanisms, and incentive schemes. Metering data is useful in designing DR programmes that enable, motivate, and support customers to take action to modify their energy use.

The consumers who have peak demand coinciding with the DISCOM peak and those with loads that can be shifted timewise are potentially more valuable for the DR programmes. For example, commercial DR programmes are easier to implement, as higher load reduction can be achieved from minimal consumer participation. Commercial loads are suitable for DR programmes designed to reduce daytime peak demand. On the other hand, commercial energy consumption does not contribute much to the evening peak demand experienced by DISCOMs, meaning that such programmes will not help DISCOMs in managing evening peak demand. To reduce this demand, a programme designed to target high-value residential consumers with high energy use in the evenings is needed.

Technology supports Residential DR

The four widespread technology enablers for DR that have a significant impact on the DR programme cost are smart meters, smartphones, wireless communication, and the Internet of Things (IoT). Usually, for DR programmes, the commercial and industrial consumers have been the target segment, due to their inherently high individual DR capacity. However, the economics have changed with the rapid adoption of technology enablers, which create a viable environment to run DR programmes with a wider range of consumers. The building sector and predominantly residential buildings, which are set to experience a high growth in energy usage, are now prime candidates for DR. The cost of automation in the residential sector is lower than the cost incurred for Auto-DR in the commercial and industrial sectors. This is because the cost of integration of automatic controllers into building energy management systems and process monitoring instrumentation in industry is a relatively expensive proposition, whereas relatively inexpensive technologies are required for automation in the residential sector. Auto-DR programmes for the residential sector can be designed with the support of the four technology enablers shown in Table 7.

Table 7: Technology enablers for DR

DR Options	Technology Enabler	Shape	Shift	Shed	Shimmy
Behavioural	Smart Meter, Smart Phone	Yes			
Behavioural	Smart Meter, Smart Phone		Yes		
Manual	Smart Meter, Smart Phone			Yes	
Automatic	Smart Meter, Smart Phone, WIFI, Internet of Things		Yes	Yes	
Flex	Smart Meter, Smart Phone, WIFI, Internet of Things		Yes	Yes	Yes

Smart Meter   Smart Phone   WIFI   Internet of Things

Target the right end-use

The electricity load pattern is an aggregated demand from different end-uses, including lighting, cooling, pumping, cooling, and industrial processes. The relative contribution of the end-uses to the peak demand is an essential consideration in programme design. The design should also factor in the demand characteristics of different consumer segments and consumer mix of the DISCOMs. When planning for future loads, socioeconomic factors that impact the consumer groups and end-uses are important. Choosing the right loads depends on the set of parameters, including the suitability of the load for DR, impact of the DR programme, programme scalability, and ease of implementation. The results from stakeholder consultations[6] regarding the relative priority of potential loads for a DR programme are presented in Table 8. Particularly in India, two end-uses that require particular attention are residential cooling and EV charging.

Table 8: Sample ranking of end-uses for DR

End use	Suitability	Impact	Scalability	Ease/cost of implementation	Relative ranking for prioritisation
Commercial cooling	⊗⊗⊗⊗	⊗⊗⊗⊗	⊗⊗⊗	⊗⊗⊗	2
Industrial processes	⊗⊗⊗⊗	⊗⊗⊗	⊗⊗⊗	⊗⊗⊗	3
Residential cooling	⊗⊗⊗⊗	⊗⊗⊗⊗	⊗⊗⊗⊗	⊗⊗⊗⊗	1
Other residential appliances	⊗⊗	⊗⊗⊗	⊗⊗⊗	⊗⊗⊗	5
EV home charging	⊗⊗⊗	⊗⊗	⊗⊗⊗	⊗⊗	7
EV public/fleet charging	⊗⊗	⊗⊗⊗	⊗⊗⊗	⊗⊗	6
Agricultural pumping	⊗⊗	⊗⊗	⊗⊗	⊗⊗	8
Others - Public water, lighting, etc.	⊗⊗⊗	⊗⊗⊗	⊗⊗⊗	⊗⊗⊗	4

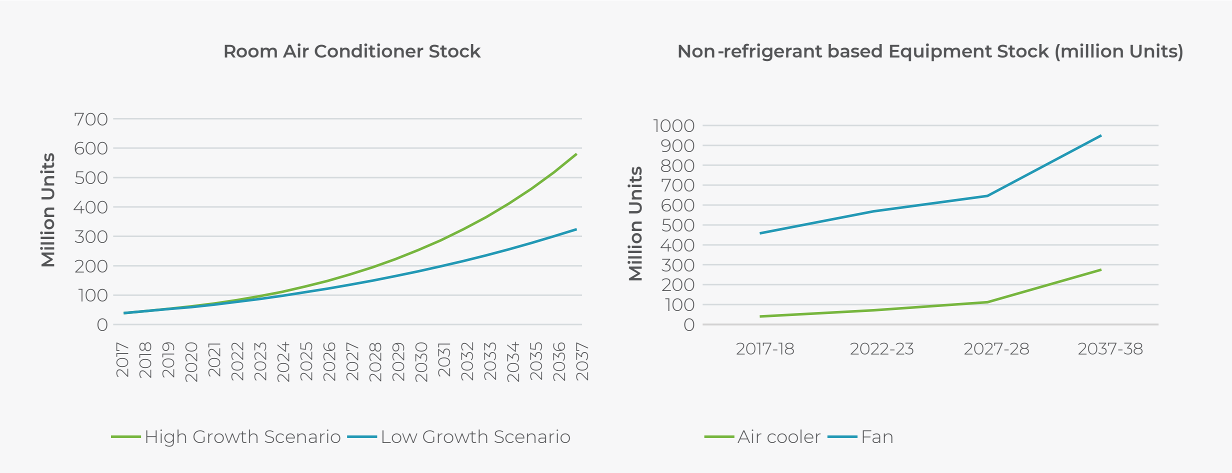
6. The stakeholders were asked to rate the end-uses on a scale of 1-5, where 1 represents the worst-case scenario and 5 represents the best-case scenario. Relative priorities are identified based on the ranking according to the cumulative scores. The results are subjective in nature and should not be considered as a final recommendation.

Agricultural consumers are normally considered best-fit candidates for DR programmes globally. Although agricultural pumping is a shiftable load, it is already being supplied during off-peak hours. At the same time, with the practically negligible tariff regime, there is hardly any incentive for agriculture consumers to shift their loads. However, with the increasing amount of solarisation of agricultural feeders and pump sets, the demand is being automatically shifted to daytime hours to match the surplus solar generation hours.

Plan for the future cooling load

Cooling demand is a prime candidate for future DR in India, given the large scale of the problem. Cooling is recognised as essential to people's health, well-being, and productivity in hot climates. The need for space cooling is the leading driver of increasing summer peak power demand in India. There has been a significant increase in AC penetration in India, facilitated by rising per capita income and rapid urbanisation. The growth is expected to continue, with the building sector cooling demand expected to grow 11 times by FY 38 as compared to the FY 18 baseline [24]. The India Cooling Action Plan (ICAP) projections illustrated in Figure 17 show that the increase in AC stock will be higher than that of air coolers and fans. Promotion of DR-enabled cooling technology is a strategy already identified under ICAP [24].

Figure 17: ICAP cooling load projections for India



An increase in the AC load, especially from the residential sector, is a common factor contributing to the observed increase in peak demand in urban and semi-urban areas in India. Between fans, air coolers, and ACs, the grid impact of cooling units is significant.

The number of households in India owning an AC has increased by 50% over the last five years [25]. One of the key challenges in India for the future will be managing the increasing peak demand from cooling appliances. A critical step to planning a sustainable cooling future for India is to be proactive and treat the increasing cooling demand as a resource. If not handled effectively, the growing electricity demand from space cooling in buildings will lead to colossal investments in generation, transmission, and distribution. The impact of space cooling on the distribution grid is localised network congestion. As 70% of AC growth is expected to come from the residential sector alone, it is critical to design DR programmes targeting residential AC units [25].

Combining smart meter data with weather data, the DISCOM can tap into the possibilities for use data analytics to target cooling loads. With the help of predictive analytics and IoT based controllers, there are different possibilities for cooling DR, such as (1) switching ACs on/off; (2) adjusting thermostat settings; and (3) load cycling. Wi-Fi-enabled smart ACs are easily controllable loads with in-built DR capability. Non-Wi-Fi-enabled ACs can also be quickly converted into DR resources by adding Wi-Fi-enabled plugs. This exciting innovation allows DISCOMS to leverage the connected AC units as a valuable grid balancing resource by remotely adjusting temperature setpoints and reducing the ACs' energy consumption [26].

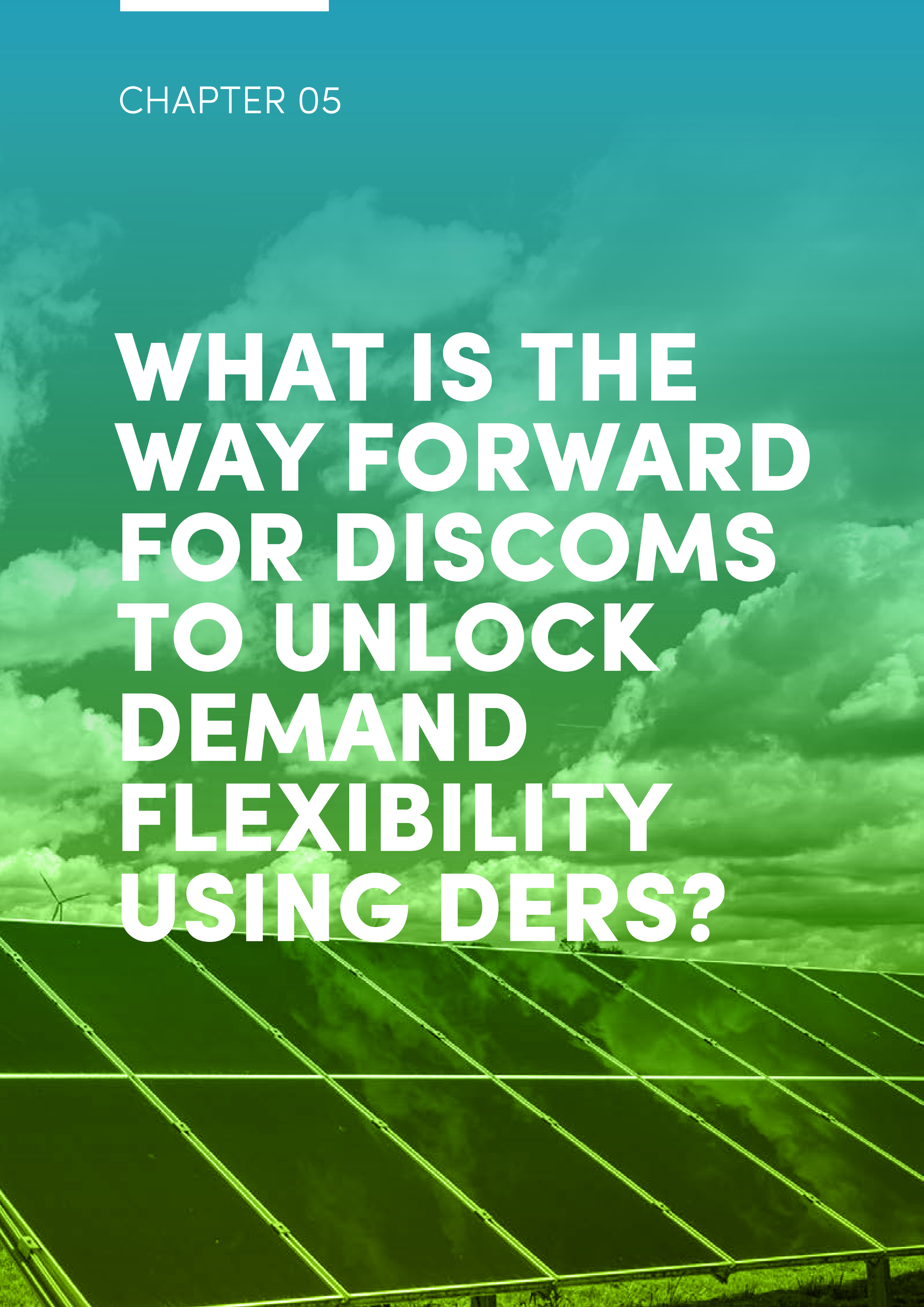
Smart EV charging with DR

EVs represent a significant load addition and an additional revenue stream for DISCOMs. If not managed properly, EV charging demand can increase the peak load in the localised pockets in a DISCOM's service area. EV charging at domestic and public charging facilities will have similar but distinct impacts on the local electricity grid. High-power charging at public charging facilities is a dynamic load that can cause sudden spikes in the demand curve. The slower domestic charging of EVs can lead to local network congestion, as charging demand could be higher than the rest of the residential demand [27].

However, EVs are a versatile energy resource that can act as distributed load and storage. Use of ToU tariffs would enable DISCOMs to avoid network upgradation and reduce peak load impact. With flat or block-wise residential tariffs, consumers have no incentive to not charge their EVs as soon as they get home. This leads to a situation where the EV charging coincides with evening peak energy consumption hours. ToU or peak rebate-based EV charging-specific tariffs for public charging facilities can enable reduction in peak demand and shift demand to a period of surplus renewable generation. DR can be easily integrated with other charging control strategies as well, as shown in Table 9 [28] [29].

Table 9: DR application for EV charging

DR strategy	Reduce peak demand	Increase RE usage	Provide grid services
ToU rates	⊗		
Smart charging	⊗	⊗	
Aggregated smart charging	⊗		⊗
Bidirectional charging	⊗	⊗	⊗



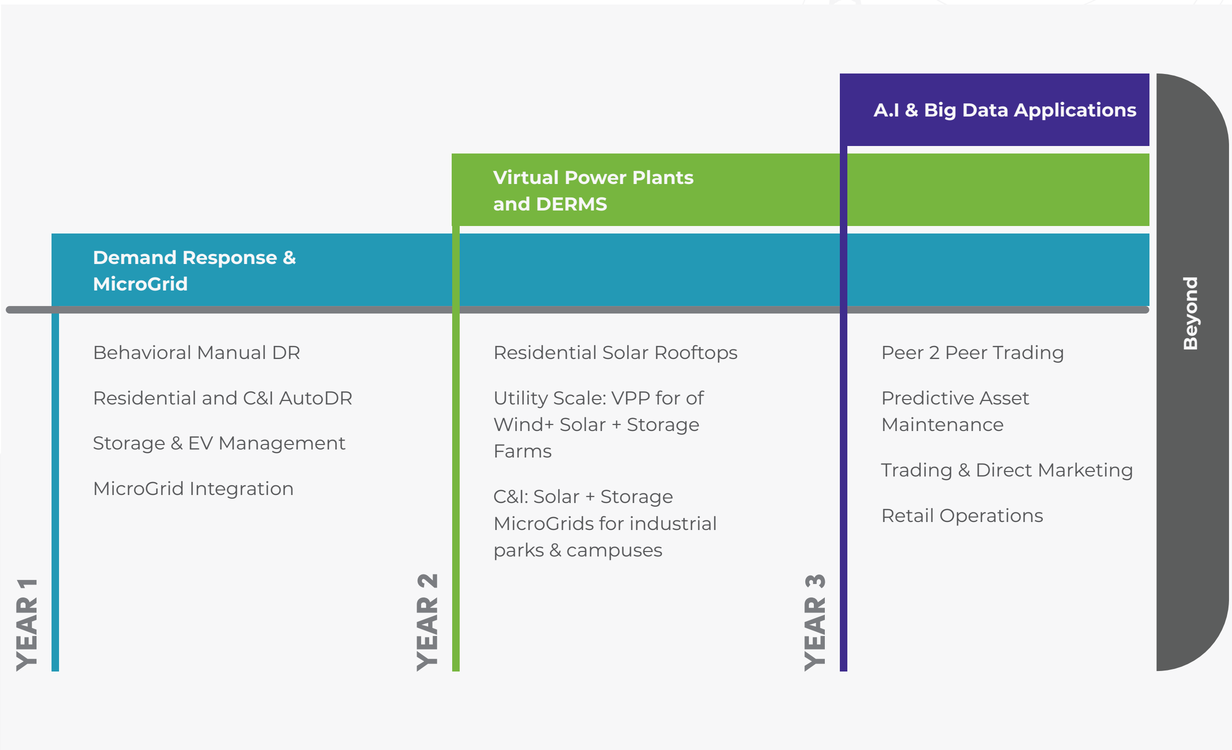
CHAPTER 05

WHAT IS THE WAY FORWARD FOR DISCOMS TO UNLOCK DEMAND FLEXIBILITY USING DERS?

New technologies and business models are being introduced to DISCOMS at an unprecedented rate. This could overwhelm the key decision makers in DISCOMS and hinder their ability to prioritise the adoption of new models and technologies while keeping in mind their investment & growth strategies. The following roadmap presents a well-defined path forward for DISCOMS to explore various technologies and develop their internal rollout and scalability strategy.

As discussed in the above sections, behavioural DR and Auto-DR are the lowest hanging fruits, as they are easy to implement and have the highest internal rate of return (IRR). DR programmes can be used as a tool to align DISCOM programmes with the Ministry of Power's (MoP) recent announcement to improve customer centricity and enable them to have higher levels of engagement and improve quality of service. In addition to this, new DER integration is also being supported by the MoP's new guidelines to treat self-generating customers (prosumers) on par with general customers, necessitating the DISCOMS to ensure the smooth integration of DERs into the grid. There is also a growing emphasis on urban and rural microgrids, which are excellent candidates for integration using DR technologies to enable efficient operations and maximise energy consumption from onsite generation resources.

Figure 18: Roadmap for DISCOMS to start their digital transformation journey (Source: AutoGrid)



The roadmaps for DISCOM transformation as shown in Figure 18, to suit a digital grid comprises of three stages, starting with intervention on Demand Response and microgrids. Subsequently, in the next stage advanced demand management tools are needed which includes distributed energy resources management system (DERMS) which will help the DISCOMs manage loads in their system. In this stage, Virtual Power Plants (VPP) can help integrate loads, storage and distributed generation to manage demand. Subsequently, in the later stage with the support of Big Data and Artificial Intelligence new applications such as peer to peer trading is possible.

CHAPTER 06

WHAT ARE THE IDEAL INCENTIVE MODELS FOR DR IN INDIA?

Incentives to attract consumers

DR is a consumer-centric approach to demand management measures, and consumer incentives are the key feature for good DR programme design. Global DR programmes have gained widespread participation because of the provision of adequate incentive structures. The absence of attractive incentives remains the major barrier to scaling up DR programmes in India. For example, the ToD tariff is one of the most popular DR options tested in India. However, the programmes' success remains limited because of the relative price difference between peak and off-peak costs, which usually amounts to less than 20 percent. Additionally, the tariff itself is pretty low for many consumer categories, and, therefore, altering the energy usage will not significantly impact consumers' monthly bills.

For example, Maharashtra's ToD rates for low-tension (LT) non-residential consumers equate to a price difference of 6-20% between the peak (base tariff + INR 1.1/kWh) and off-peak (base tariff – INR 1.5/kWh) periods, depending on the connected load [30]. For a consumer with a base tariff of INR 7.3/kWh, during peak hours, the consumer will only experience an increase to INR 8.4/kWh. Analysing similar programmes implemented by utilities of other major economies worldwide, it was found that the peak prices were sometimes more than double off-peak prices. A study of residential ToU rates revealed the average price difference is equal to ~INR 7.4/kWh. This study also showed that the impact of the ToU regime can get diluted by fixed costs or other flat charges [31].

A review of the incentive design for DR pilots in India shows there have been limited efforts to understand consumer expectations on incentives. A rare example where the interlinkage of incentives and available DR potential was studied was the BYPL DR pilot in 2017. Under this pilot, a survey carried out with a limited number of consumers showed the incentive expected by consumers to achieve 100% DR potential was INR 3/kWh. When the incentive decreases to less than INR 1.25 per kWh, the DR potential reduces to 60 percent [17].

From the abovementioned examples, it is clear that the success of DR programmes in India or elsewhere primarily depends on the compensation mechanisms and value to customers. To that end, there are several possible compensation schemes that can be considered in the programme design. The following section presents a few models that are widely used around the world and could also be applied in Indian context.

I. Enrollment & participation credit model

This type of incentive structure can be used for mass market programmes and is extremely useful for targeting residential customers and AC-based DR programmes. This programme can be designed in combination with existing DSM programmes on increasing the penetration of super energy-efficient appliances; the incentive structure can be an add-on to upstream EE rebates that are offered on 5-star rated ACs and other appliances. Under this model, the appliances that receive an additional subsidy should be DR-ready, so they can be controlled remotely during an Auto-DR event dispatch.

The important points to incorporate into such a programme are given below:

- The customer receives a one-time electricity bill credit for enrolling in the programme. The first year's enrollment credit could be a direct bill credit or could be applied towards the cost of a smart plug or other IoT connected devices that are capable of reducing load during an event.
- The customer receives a fixed annual payment for staying enrolled & participating in load reduction events—a fixed & predictable amount each month.
- M&V for each customer is not required for each event, and site-level data is also not required. M&V can be performed at the substation level to understand network-level benefits.

An example of consumer earnings for enrollment in a DR programme for 3 years is presented in Table 10.

Table 10: Sample consumer earnings in DR enrollment programme

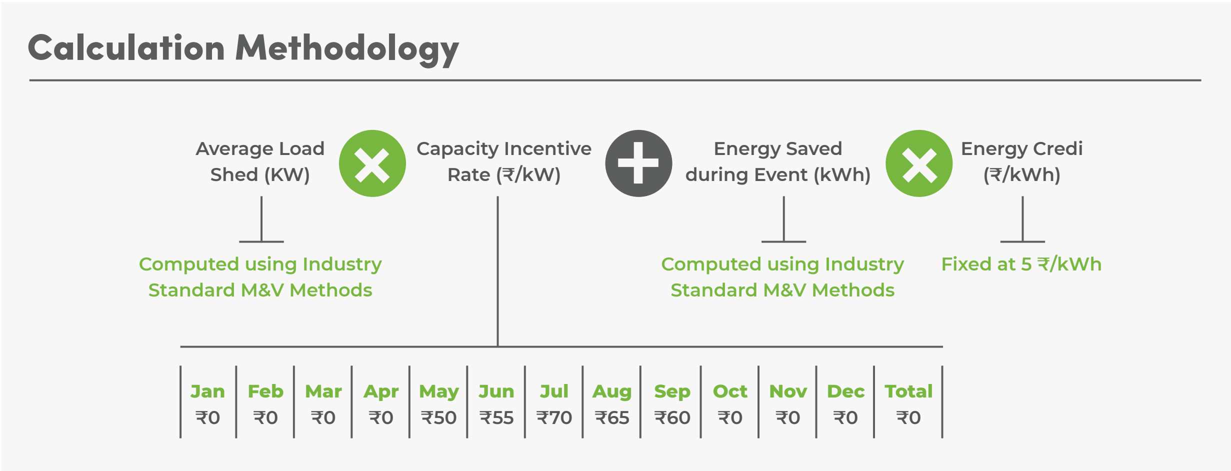
Programme year	Year 1	Year 2	Year 3
One-time enrollment credit	₹ 1000	Nil	Nil
Annual participation credit	₹ 750	₹ 750	₹ 750
Total earnings	₹ 1750	₹ 750	₹ 750

Over a 3-year period, a customer could be eligible to earn ₹3250[7] by enrolling and participating in the DR programme.

II. Performance-based incentive model

The performance-based incentive (PBI) model is widely used in programmes where commercial & industrial customers enter into a contract with the local DISCOM for a nominated kW reduction. The total eligible incentive amount is based on the total load shed (kW) achieved during the event, as well as the energy (kWh) displaced as a result of a change in the facility's operating patterns.

The following formula can be used to compute the incentive amount based on the performance:



Here is how the structure works:

- It requires site-level energy consumption data, preferably from smart meters or automatic meter reading (AMR) meters.
- The customer receives payments based on the load shed achieved per event.
- M&V for each customer is done using 15-min or 30-min interval data.
- M&V can be performed at the substation level to understand network-level benefits.

7. The figures used in this example are for illustration purposes only regarding the incentive breakdown, and the authors do not make any recommendations on the exact amounts.

Using the following approach, let's look at an example of a customer who can deliver 50 kW of load shed per hour and the resulting incentive payment by month, as well as the total sum.

Customer Participates in 4 events in different months and delivers 50 kW avg load shed

Average Load Shed (KW) × Capacity Incentive Rate (₹/kW) + Energy Saved during Event (kWh) × Energy Credi (₹/kWh)

Every Month	Average Load Shed (kW)	Capacity Incentive Rate (₹/kW)	Event Duration (Hours)	Energy Reduced (kWh)	Energy Credit (kWh)	Capacity Credit	Energy Credit	Toral Earnings
May	50	₹50	4	200	₹5	50 x 50 = ₹2500	₹200 x 5 = ₹1000	₹3500
Jul	50	₹70	4	200	₹5	50 x 70 = ₹3500	₹200 x 5 = ₹1000	₹4500
Sept	50	₹60	3	150	₹5	50 x 60 = ₹3000	₹150 x 5 = ₹750	₹3750
Oct	50	₹55	4	200	₹5	50 x 55 = ₹2750	₹200 x 5 = ₹1000	₹3750

Capacity Incentive Rate by Month

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
₹0	₹0	₹0	₹0	₹50	₹55	₹70	₹65	₹60	₹0	₹0	₹0	₹0

Total Earnings in DR Season = **₹15500**
Number of Events Called = 4
Number of Hours Participated = 15

Note: The figures used in this example are for illustration purposes only regarding the incentive breakdown, and the authors do not make any recommendations on the exact amounts.

In summary, depending on the type of the programme and target customer base, DISCOMS can consider one of the abovementioned incentive structures in the programme design phase.

CHAPTER 07

WHAT SHOULD BE DONE TO ENABLE DR PROGRAMMES IN INDIA?

Provide regulatory incentives

Under the aegis of the current tariff-related regulatory ecosystem, there are multiple barriers to enabling DR programmes. The current tariff determination process in India is a hybrid mechanism that bifurcates the utility expenditure into controllable and non-controllable cost elements. For the controllable elements, such as technical and commercial losses, operation and maintenance costs, and capital expenditure (CAPEX), targets are set. Cost recovery is allowed for uncontrollable cost elements like the cost of power procurement on a 'cost-plus' basis. This provision has serious implications for DR adoption, as it allows for recovery of the power purchase cost via tariffs. Even though the power procurement cost of a DISCOM could be high, the DISCOMs have the ability to recover the expenditure, including any additional costs incurred for the peak power procurement—such costs are simply passed on to the consumers. There is therefore no incentive to reduce the cost of peak power procurement.

The electricity rates in India, intricately intertwined with the political economy, remain quite low for the vast majority of consumers. The incentives are not high enough to warrant interest from the consumers within the current tariff scheme, as potential savings would be low for them, as well. The lack of price arbitrage is a deterrent for DR, even with a ToD rate mechanism. DISCOMs are hesitant to implement any actions that would reduce energy sales, as cost recovery under the tariff process is directly linked to the volume of energy sales. Furthermore, regulators are not prioritising DR programmes in an ecosystem with surplus installed capacity for power generation. The implications of the additional costs incurred by the DISCOM to maintain surplus capacity are also ignored.

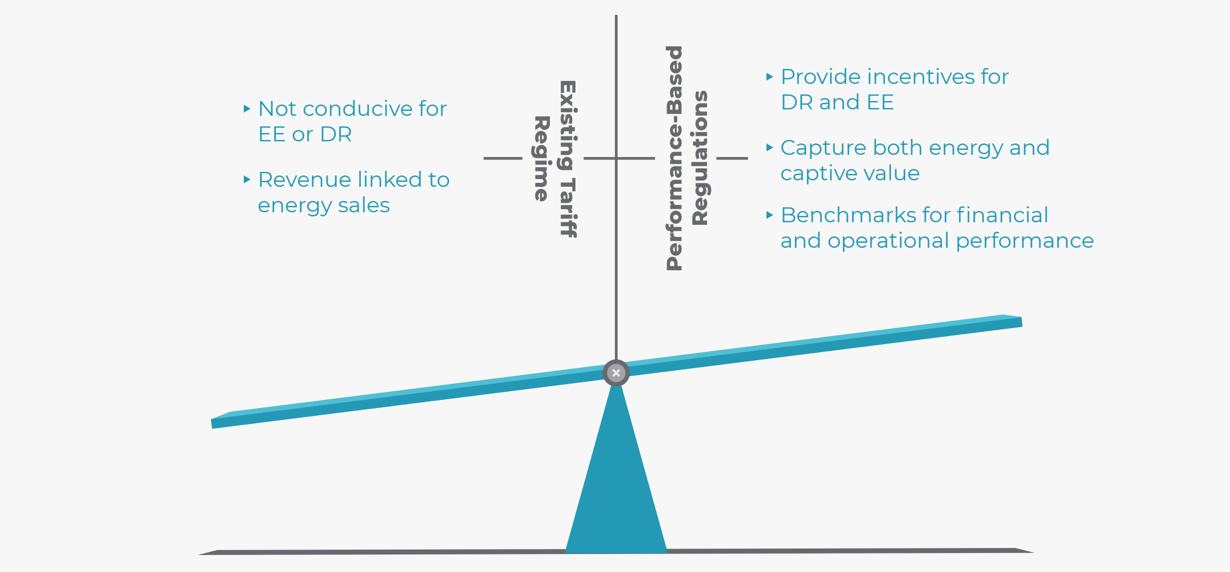
Investment decisions regarding network upgrades and adding more infrastructural assets are encouraged as consumer-friendly practices. Any CAPEX, although highlighted in front of the regulator, is easily recoverable through the tariff process. Overall, there is hardly any incentive for DISCOMs to adopt DR to reduce their costs or investment. Even with progressive regulatory provisions, there is no well-defined mechanism to finance DR programmes through the tariff determination process. The traditional business model of utilities centred on revenue recovery requires a paradigm shift to adapt to the new era of DERs.

Performance-based regulations

A new regulatory framework is necessary wherein DISCOMs are allowed to generate new revenue streams and recover their operating costs. The need of the hour is to transform DISCOMs to proactively engage with prosumers with behind-the-meter applications to hedge against future demand reduction. DISCOMs need to be rewarded for DR initiatives and encouraged to adopted data analysis-centred decision-making. DISCOMs need realistic and verifiable targets for improvement in demand performance, such as targeted reduction in peak demand, improvement in load factor, savings in energy procurement, and reduction in operational costs.

Performance-based regulations (PBR) reward good performance by providing maximum incentives to DISCOMs. Instead of a fixed return on capital, performance benchmarks are set for both key operational and financial parameters, as shown in Figure 19. This makes PBR a data-centric decision-making tool, which can be custom-designed to meet the needs of Indian DISCOMs. Historical data related to all major cost components of DISCOM operations can be benchmarked. The cost of financing a DR programme will be an additional cost layer against which performance benchmarks can be set.

Figure 19: Existing tariff regime vs. performance-based regulations



PBR with a price cap regime, which is already practiced in other economies, might be the right fit for India. The regulator sets a price cap, and the DISCOMs have the freedom to make retail tariff decisions. The SERCs in India can adopt an approach of setting a price band for different consumer categories based on the normative costs and allowing DISCOMs a chance to design effective DR-integrated tariff schemes and other strategies to manage demand.

Under the current regime, the DR incentives are only applicable for energy savings, while the value for capacity related services is not captured. With PBR, incentive schemes can be designed to also include incentives for capacity. A prerequisite for this is proper cost allocation for the investments for the power system capacity in generation, transmission, and distribution. While cost elements such as the CAPEX for network upgrades are straightforward, the cost of generation capacity is difficult to account for. DISCOMs currently include it indirectly under the fixed cost of power procurement. Optimisation of power procurement is challenging in a regime of long-term PPAs, but it is an integral element in the power chase on energy markets. Capacity-related incentives to minimise network capacity upgrades could be the starting point for performance benchmarking. Combining capacity value with energy value will also make incentives attractive for consumers.

Implement robust M&V protocols

The fundamental issue surrounding DR is that it is impossible to meter or directly observe demand reductions. Therefore, the evaluation problem translates to how to accurately measure that which cannot be directly observed. Hence, evaluation of the performance of any 'demand resource' translates to an estimation of the theoretical baseline and comparison with observed demand. There is no unambiguous, incontrovertible way to measure what the Business-As-Usual (BAU) load would have been. The role of M&V protocols is therefore to provide the best estimate of the BAU and develop a methodology for performance evaluation. Without proper M&V protocols, DR cannot be a reliable, measurable, and verifiable resource [32].

A robust BAU baseline is the prerequisite for the performance measurement of a DR resource. The baseline is the most crucial determinant of the success of any DR programme. When designing a baselining method, the challenge is finding the right balance between contradictory traits. Baselines, when intended for accuracy, are complex, whereas the simplest approaches might lead to manipulation. The baseline has to be neutral towards the natural load variances, yet simultaneously have the ability to account for changes unrelated to the DR programme [33].

Selecting an appropriate time interval for data collection and calculation is critical to effective baseline establishment. Smart metering has improved the granularity of data capture for a large set of consumers, and it is possible to adopt five-minute, fifteen-minute, or hourly intervals for metering and settlement. As the increased granularity of telemetry is directly proportional to an increase in cost, the selection of an appropriate baseline time interval should be a factor in both cost-effectiveness and improvement in performance [26].

M&V is essential for DR, as the accurate and timely quantification of reductions is critical to ensuring fairness and transparency. Proper M&V protocols are also crucial to designing, monitoring, and assessing a DR programme's effectiveness. With the support of advanced metering and M&V, the effectiveness of a DR programme will increase by enabling savings predictions. Applying M&V techniques to the metering data and aggregating load shapes helps in both forecasting and determining DR-related reductions [32] [34].

It is imperative that M&V be integrated into the programme from the planning phase. Global experience with the M&V of EE and DR programmes has shown that M&V activities are often not undertaken in the initial phase. It is not uncommon for programme evaluation to happen several months after the completion of the programme. The time lag between the programme implementation and review is a barrier that limits the ability to make timely payments and undertake course correction, if needed.

Demand Response Baseline Methodology

Demand Response programs are based on incentivizing the customers to reduce their load and energy consumption and contribute to load shedding or load shifting objectives of energy providers. For this reason, a reliable measurement and verification (M&V) method is necessary to assess the reduction in energy consumption by customers. An accurate baseline forms the basis of measuring the curtailment during a DR event.

A baseline is an estimate of the electricity that would have been consumed by a customer in the absence of a demand response event [52]. Baseline provides grid operators and utilities means to measure the performance of DR event by comparing the actual energy consumption by the customer during the DR event with respect to the calculated baseline. For calculating baseline, a set of three factors need to be considered- accuracy, simplicity and integrity.

Accuracy: Participants of DR event should receive credit no more and no less than the load curtailed at their end. In order to achieve this, the selected baseline method should estimate the baseline with available data with accuracy to represent the actual consumption of customers in absence of a DR event.

Simplicity: The baseline method selected should be simple for all stakeholders to understand, implement and estimate as part of a DR program. In doing so, the role of a software platform that deploys the DR program becomes critical which simplifies the job of selecting a suitable baseline.

Integrity: A baseline method should not allow or encourage customers to distort their actual consumption pattern and game the overall system.

Types of Baselines Methodologies

It has been found through experience of implementing DR programs across North America that suitability of DR program depends upon customer type, program type and season. Further, there is no perfect baseline method as these are merely estimates from available data. Therefore, depending upon the program characteristics, an optimal baseline method may be selected for the DR program. North America Energy Standard Board (NAESB) defines five types of baseline methodologies:

Types	Baseline Characteristics	Data Used
Baseline Type I	Average load baseline based on historical data from days immediately preceding the event	Historical meter data, weather data and calendar data to adjust baseline
Maximum Base Load	Static baseline	Historical meter data from previous year
Meter Before-Meter After	Static baseline (Ancillary programs)	Historical meter data from a small interval of time before the event
Baseline Type II	Statistical sampling to estimate energy consumption	Aggregated meter data representative of group of sites

Baseline Type I

A baseline performance evaluation methodology based on a demand resource's historical interval meter data which may also include other variables such as weather and calendar data.[53]

This is the most widely used method in demand response programs. Several variations of this Type I baseline method are averaging, matching day, regression and rolling average. The baseline shape is average load curve of the users and relies on historical meter data from days preceding the event day.

Maximum Base Load

Maximum baseline load (MBL) method is based on reducing demand to a specified level i.e., static baseline method. Customers 'drop to' a level in contrast to 'drop by' in Type I baseline. An MBL can be coincident (based on system load peaks) or non-coincident (based on customer load behavior) type. MBL methods are suitable for scenarios: customers with volatile loads or loads are not exceeded a certain level for planning purpose.

Measurement and verification (M&V) lies at the core of any successful DR program which depends upon the selected baseline methodology. As per advanced studies carried out on baseline methods in United States by organizations such as NAESB & EnerNOC, High X of Y baselines with day of adjustments achieves a better balance among the three pillars of accuracy, simplicity and integrity, compared to any other method.

In order to simplify the job of program manager and enable selection of best baseline for M&V, a software platform deployed for managing the DR program plays a decisive role. In the case of TPDDL Behavioural Demand Response program for Delhi, the DR platform has multiple options of baseline methods as discussed above. Further, the job of estimating the best fit baseline based on statistical errors was also featured in the platform.

Facilitate demand aggregation

Demand aggregation is the grouping of consumers and appliances to act as a single entity and engage with DISCOMs or power markets to offer services. Demand aggregation is critical to implementing residential DR in India, as individually, the household appliance loads are not big enough to make a noticeable impact on grid operations. Aggregation extends the reach of the DR programme, providing a path for the participation of consumers who were previously not considered potential targets. When aggregated, the DR value proposition expands, and it enables demand bidding into energy markets, as well. A power market is also a conducive place for demand aggregation, as, due to the nature of the operation, traders in the market automatically perform aggregation.

Demand aggregation can be performed by DISCOMs or via specialised agents called demand aggregators, who act on behalf of their customers. Demand aggregators can be considered a new opportunity for energy service companies. DISCOMs are logically inclined to be demand aggregators and are well-suited to expand their business models by offering DR services. Aggregation enables an ecosystem for the DR industry where the DISCOM can either complement or compete with demand aggregators, as shown in Table 11.

Table 11: DR aggregation with DISCOMs

Aggregation model	Description
DISCOM as sole aggregator	The DISCOM maintains the monopoly and directly engages with the consumer. There is no competition, and DISCOMs can perform demand bidding on the energy market.
DISCOM as meta-aggregator	The demand aggregator is an intermediary between the customer and DISCOM. There is no competition, and demand aggregators can offer services to both the DISCOM and energy market.
Hybrid model	Both DISCOMs and demand aggregators engage with consumers. There is competition. Demand aggregators can offer services to the DISCOM or energy market. DISCOMs can bid into the energy market.

Extend value of EE programmes with DR

Before the notification, only 42 DISCOMs whose annual losses were over 1 billion kWh were allocated loss reduction targets under the PAT scheme. With the new notification, 102 DISCOMs are being encouraged to take actions towards reducing losses.

DISCOMs are energy- and emissions-intensive industries. Under the Perform, Achieve and Trade[8] (PAT) scheme to promote EE, DISCOMs are labelled as designated consumers. Recently, MoP, in consultation with the Bureau of Energy Efficiency (BEE), announced that all DISCOMs have to follow the provisions under the Energy Conservation Act, 2001 [35]. Before the notification, only 42 DISCOMs whose annual losses were over 1 billion kWh were allocated loss reduction targets under the PAT scheme. With the new notification, 102 DISCOMs are being encouraged to take actions towards reducing losses. This opens a window of opportunity to closely monitor and recommend solutions that would increase DISCOM efficiency and profitability. However, the policy push will only be effective if active consumer engagement is integrated into it.

BEE has been spearheading campaigns in India focused on improving the EE of cooling, lighting, and pumping end uses. Appliance efficiency improvements through standards and labelling has been at the core of the EE programme. Energy Efficiency Services Limited (EESL) has been leading the initiatives on promoting the adoption of super energy-efficient appliances. Apart from this, the focus has been on improving EE through retrofits and implementation of building energy codes. The other side of the coin, i.e. changing consumer behaviour, remains relatively unexplored.

8. The PAT scheme is a flagship programme that was introduced by BEE under the National Mission for Enhanced Energy Efficiency. It is a regulatory instrument to reduce the specific energy consumption in energy-intensive sectors, with an associated market-based mechanism to enhance the cost-effectiveness through the trade of energy savings certificates.

To sustain operations in the future and achieve the goal of affordable and reliable energy supply, DISCOMs need to think beyond EE programmes and take a proactive role in engaging with consumers. DR presents a leapfrog opportunity for DISCOMs to adapt to the realities of a cleaner grid and high electrification of demand. In the next three years, DR needs to be integrated into the fabric of DISCOM processes, along with EE. In the future, with the proliferation of more energy-efficient and controllable loads, DR programmes need to be designed with real-time applications. The future of demand resources lies in embedding DR value within the EE programmes.

Combining DR with EE programmes is a rational choice that will expand the value proposition of DSM by improving energy savings. Energy-efficient AC replacement campaigns can be integrated with DR programmes involving converting ACs into controllable loads. These loads can be cost-effectively utilised as DR resources. With enrollment in DR programmes, the consumers have a chance to recover the additional costs incurred for upgrading to more efficient equipment.

Coupling DR and EE is also important for achieving climate goals. A recent study found that, in comparison with EE programmes, consumer behaviour-linked programmes can achieve the same levels of reduction in GHGs quickly and at a lower cost. Furthermore, near-term reductions in GHGs are more beneficial from the climate perspective, as they reduce the risk of exceeding dangerous thresholds. [36]

ANNEXURE – A: TPDDL BEHAVIOURAL DR PILOT

Tata Power's Behavioral Demand Response (BDR) pilot with critical peak rebate program targeting residential consumers with smart meters. The successful implementation of the smart meter rollout for urban residential consumers in Delhi, enabled real-time assessment of the load profile. The BDR program was correspondingly designed as a voluntary 'opt-in' intervention, wherein consumers were provided with peak time rebates as a nudge to encourage load shift/shed during critical peak hours. The pilot was developed under the premise of demonstrating the utility benefits of capex investment deferral and addressing local distribution network constraints. The program also showcased benefit to the consumer in the form of bill savings, thus encouraging their participation in load shift events.

Pilot Overview

As illustrated in Table 12, a description of the target group substantiates the premise of conducting a BDR pilot in this region. A large residential consumer base, significant smart meter coverage and high peak load demand are supporting factors.

Table 12: TPDDL service area details

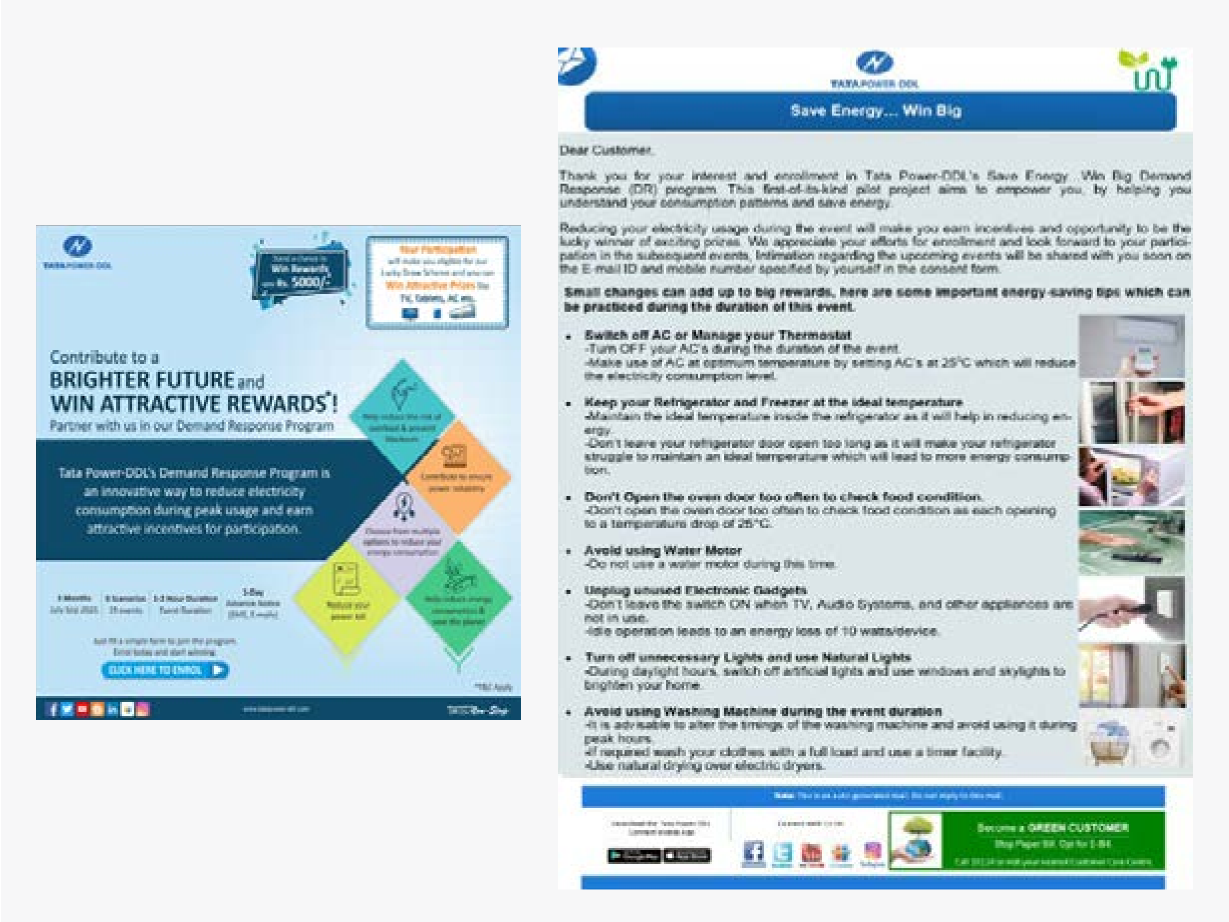
Parameter	Detail
DISCOM service area	510 sq. km
Summer peak load	2000+ MW
Registered consumer base	1.7+ Million
Population	7+ Million
Smart meters installed	2,00,000
Peak load duration	Afternoon peak: 2:30pm-5:30pm Night-time peak: 9:30pm-12:30am

Source: [37]

Enrolment process: The program was kicked off late summer of 2021. As seen in Figure 20, dedicated Information Education Communication (IEC) materials were developed to promote participation in the pilot program. Consumers were reached out through 4 steps, listed as follows-

- **Direct call:** ·Over 4000 residential consumers were reached out via phone to intimate them concerning the pilot program.
- **Program brochures:** Communication materials were distributed within TPDDL's service area to create awareness concerning the program and inform the consumers about the associated incentives to encourage participation.
- **Follow up on phone:** Periodic messages and calls were passed onto the consumer to maintain a communication momentum.
- **Special announcements:** Participation rewards were also communicated to the consumers through reminder calls.

Figure 20: Pilot program IEC materials



Source: [37]

Program Specifics: The pilot was conducted over a period of 11 weeks. The outreach activity through calls and brochures resulted in the enrolment of 2044 residential consumers. A monetary incentive of was given out as a one-time enrolment bonus and a further reward of was provided for participants who successfully shed load amounting to greater than 10% of the baseline. The critical peak rebate intervention resulted in an average capacity shed of 0.5 kW per consumer per event and a cumulative energy shed in excess of 15 MWh for the duration of the program over 16 DR. The break-up of the DR events is as shown in Table 13.

Table 13: DR events triggered

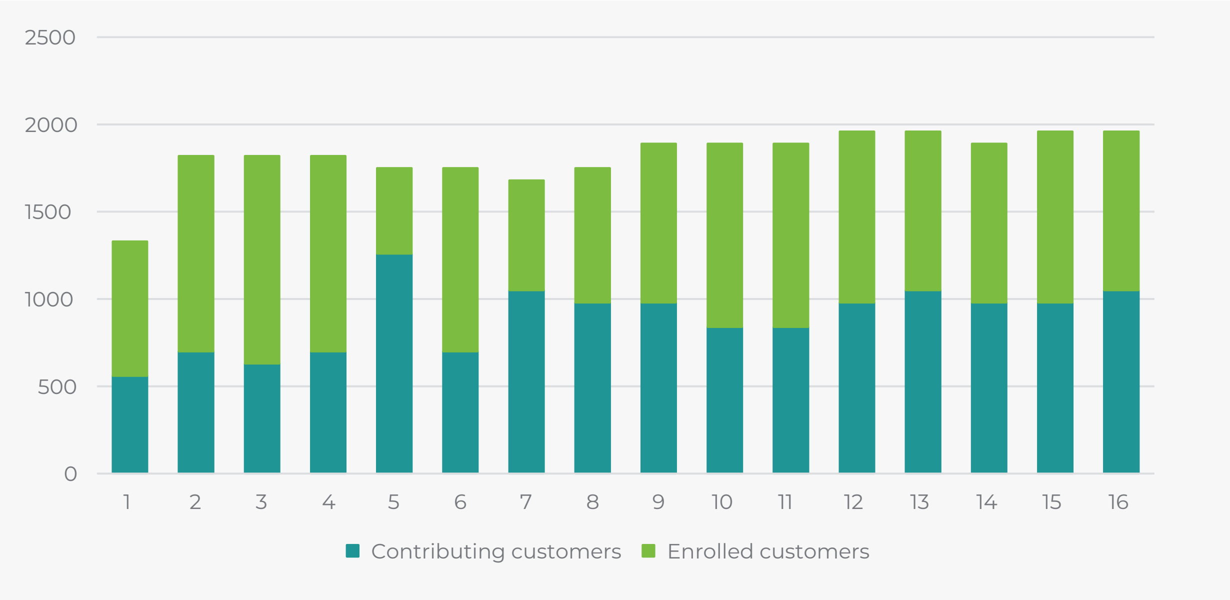
	TOTAL	WEEKDAY	WEEKEND
AFTERNOON	11	7	4
NIGHT	5	4	1
TOTAL	**16**	**11**	**5**

Source: [37]

Results

Participation rate: As shown in Figure 21, over the 16 DR events, it was observed that on an average, a good 48% of the consumers participated as a percent of enrolled count.

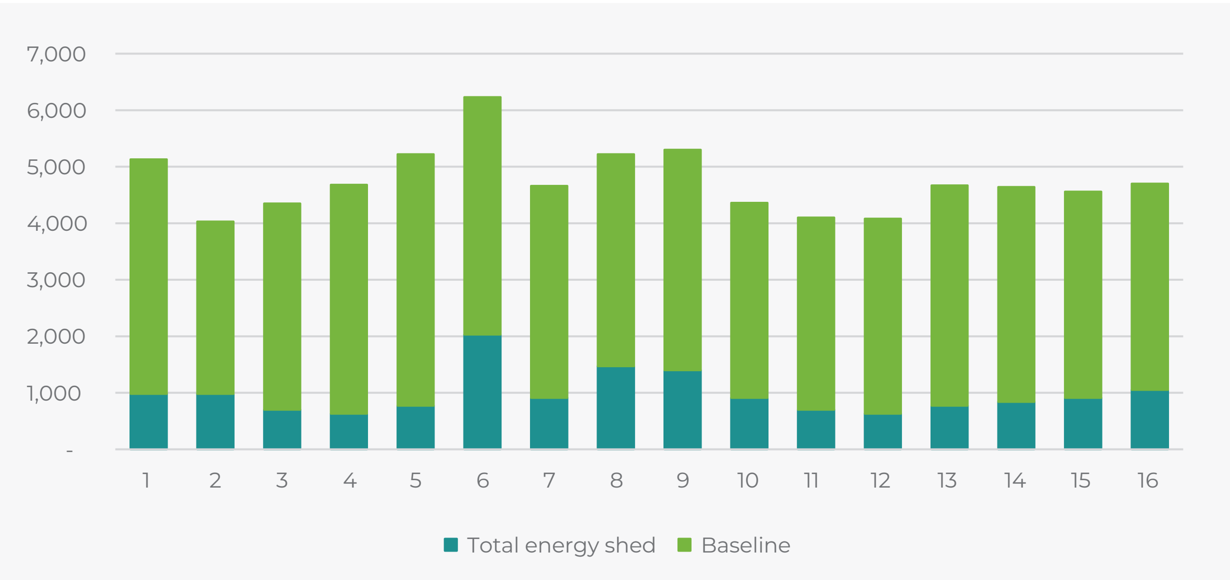
Figure 21: Participation vs consumers bringing qualifying shed



Source: [37]

Shed per event: As observed in Figure 22, the highest shed amounting to more than 1 MW was achieved in the 6th DR event. On average 470 kW shed was achieved over the 16 DR events.

Figure 22: Energy shed as a percent of Baseline consumption



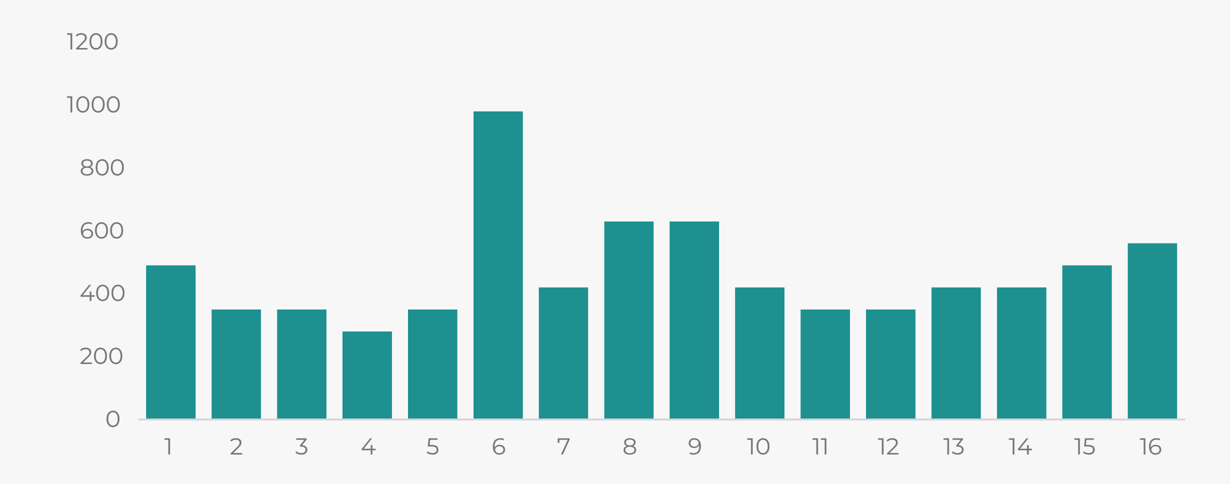
The above graph shares the baseline load profile and associated shed provided by consumers for those particular events. It can be observed that the participation was much higher for event 6 which can be attributed to special flash reward announcement that took place a day before the scheduled event, thus encouraging participation.

Figure 22: Average capacity shed per eve

Source: [37]

Shed per consumer: Corresponding to the analysis from the above figures, the 6th DR event showcased the highest capacity per consumer in an event amounting to 0.75 kW. As observed in Figure 23, the average capacity shed per consumer per event amounts to 0.5 kW, over the 16 DR events.

Figure 23: Average capacity shed per consumer per event



Source: [37]

Takeaways for future program design

Clustering analysis: As BDR program evolves as part of mainstream program, utilities can stack incentives specific to various consumers binned methodologies such as either based on their sanctioned load or even as shed as a percent of its baseline load.

Table 14: Clustering analysis of participating consumers

Cluster	Binning based off Baseline load profile	Avg energy shed/ consumer (kWhr)		
		Event A (kWhr)	Event B (kWhr)	Event C (kWhr)
#1	0.0-5.0kWhr	0.7	1.2	0.6
#2	5.1-10.0kWhr	2.6	2.9	2.2
#3	10.1-20.0kWhr	3.9	5.3	3
#4	>20.0kWhr	3.1	-	8.4

Source: [37]

Table 15: BDR Program design for residential segment.

Cluster	Binning	Avg kWhr/ consumer	Expected participant count	Expected energy shed/ event (MWhr)
#1	0.0-5.0kWhr	0.5	36,000	18
#2	5.1-10.0kWhr	2	11,000	22
#3	10.1-20.0kWhr	2.5	2,000	5
#4	>20.0kWhr	3	1,000	3
			50,000	48

Source: [37]

Similarly, BDR program expanded across different consumer classes in Delhi, have the potential to contribute 500 MW in load savings through BDR interventions. The details of the same along with the expected minimum participant count for each consumer class, and average load shed per consumer is as shown in Table 16.

Table 16: BDR potential for Delhi scaled across consumer classes

Target Segment	Avg capacity shed/ consumer	Expected participant count	Available capacity in MW
Residential	0.5	7,20,000	360
Small business	2	10,100	20
Commercial	5	5,600	28
Large commercial	20	2,400	48
Industrial	45	760	34
Other - Agricultural	10	1,000	10
		TOTAL MW	**500**

Source: [37]

In conclusion, scaling BDR programs across Delhi will require focus on the following aspects:

- A sound regulatory framework and in-principal approval for BDR program across BSES and BYPL along with TPDDL.
- The incentive planned must be revised base off clustering analysis as opposed to a uniform reward system to attract the higher contributing participants.
- Spot award program to create awareness and improve consumer engagement.
- Such a program offers smart utilization of smart meters with real time interval load profile to bring improved efficiencies across the system and all the while creating incentive structures for consumers to encourage participation
- When deployed across a region can significantly reduce dependencies on thermal plants and contribute to reduced carbon emissions.

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