ELECTRIC VEHICLES AND SMART CHARGING

Charging Forward

In this article, **Shweta Kalia** and co-authors say that to enable a smooth transition to accommodate India's projected increase in e-mobility and electricity demand, adoption of smart charging is a necessity. Smart charging is crucial to ensure that EV uptake is not constrained by grid capacity. A number of interventions can be adopted and implemented to enable a smarter, efficient, and sustainable way of scaling up the adoption of EVs in India. Keep reading to know more…

Electric vehicles (EVs) have seen a rapid growth with the global electric car stock hitting the 10 million mark in 2020 (IEA, 2021). This rapid adoption comes as a response to growing environmental concerns and to decarbonizing the transport sector. The transition to e-mobility is projected to increase continually with more than 20 countries announcing the full phase-out of internal combustion engine (ICE) car sales over the next 10–30 years. The same report also states that electricity demand from the global EV fleet will reach 525 TWh in the Stated Policies Scenario (STEPS) and 860 TWh in the Sustainable Development Scenario (SDS), which will account for at least 2% of global total electricity consumption by 2030.

This projected increase in electricity demand for EVs will have an adverse impact on the existing grid structure, more so with uncontrolled charging. The uncontrolled charging, also known as dumb charging, will result in the increased peak demand and upgradation of the grid infrastructure. Network overloading condition, which includes overloading of equipment, faster aging of devices may lead to frequent occurrence of faults and in extreme cases can even lead to system instability. Equipment stressing and faster aging due to network overloading will further give rise to requirement of major upgradation and reconfiguration of the grid, which is both time-consuming and expensive. Smart charging, thus, becomes a key determinant in mitigating the challenges of dumb charging without sacrificing the transition to electrified mobility.

What is Smart Charging?

The definition of smart charging is rather broad with different sources having different definitions of smart charging. According to International Renewable Energy Agency (International Renewable Energy Agency (IRENA), 2019), "Smart charging means adapting the charging cycle of EVs to both the conditions of the power system and the needs of vehicle users. This facilitates the integration of EVs while meeting mobility needs." As per ElaadNL (ElaadNL, 2020), "Smart Charging is essentially a control signal that indicates when and at what speed an electric car is charged. Smart technology ensures that it is charged at the best time and at an optimum speed."

Generally, smart charging is a means of managing the EV load to reduce the impact of EV integration on the distribution network and may also incorporate grid support services. It can be achieved by customers responding to price signals, EVSE responding to control signals from the Distribution Company (DISCOM) or a Central Management System (CMS) while at the same time retaining enough charge in the battery to fulfil the EV users travel requirements.

The different types of smart charging (from basic to advanced level of charging) are listed here.

Smart charging essentially involves a control signal that controls the time of charging and the rate of charging power. The control strategies in smart charging introduce flexibility in the charging process such that EV users can incentivize by deferring their charging time to reduce stress on the grid. Consequently, instead of immediately charging when an EV is plugged to the charger, smart charging technology ensures that the EV is charged at the best time and at an optimum speed. Therefore, by controlling the time and rate of charging, smart charging ensures a better distribution of the power demand. This helps avoid peak demand stress and reduces cost associated with reinforcing electricity infrastructure. It, therefore, plays a vital role in achieving different objectives, such as cost minimization, loss minimization, congestion management, grid support and grid stability depending on the type, preferences, and required infrastructural and computational capabilities of consumers.

Table 1: Levels and types of smart charging

Type of Application	Control over Charging Power	Possible Uses	Maturity
Uncontrolled but with ToU tariffs	None	Peak-shaving	High
Basic Control	On/off	Grid congestion management	Partial market deployment
Unidirectional controlled (V1G)	Increase and decrease in real time the rate of charging	Grid congestion management, RE integration, Ancillary service	Partial market deployment
Bidirectional V2G and G2V	Instant reaction to grid conditions	Grid congestion management, Ancillary services, RE integration	Advanced testing
Bidirectional V2X	Integration of V2G and home/building management systems	Micro-grid optimization, RE integration	Partial market deployment
Dynamic Pricing	EVSE embedded meter and close to real time communication between vehicle, EVSE and grid	Load following, RE integration	Partial market deployment

Smart Charging Control Strategies

The classification of the smart charging strategies is based on topology/ architecture, location, ownership, methodology/approach, price structure, and objective(s). Based on the control architecture of smart charging, EV charging strategies can be categorized into five categories: centralized control, decentralized control, distributed control, hierarchical control, and local control. The network operator, aggregator, and EV owners are involved in the exchange of information or control signal according to the strategy.

Centralized control strategy facilitates direct control on global network constraints. In this strategy, the aggregator decides the pattern for EV charging within its contract considering the system operator's constraints and the charging energy requested by the EV owner. Further, the aggregator's role in the strategy is to maintain the system while fulfilling the energy demand of the EVs. However, the controlling unit in the centralized control does not permit the plug-and-play mechanism, which might discourage the owners due to the lack of assurance on immediate starting of EV charging.

In decentralized control architecture, the EV owners decide EV charging. Simultaneously, the aggregator/system operator indirectly tries to influence the decision of the EV owners by offering incentives, varying electricity prices, potential revenue, etc. This control architecture provides a plug-and-charge facility to the users, and it is relatively popular among EV customers. However, unlike the centralized control architecture, the decentralized charging approach does not guarantee the global optimum solution for the system.

Distributed control is the advanced version of decentralized control as the EV owners take the decisions in it. In contrast, the aggregators communicate among themselves to find the optimal operating point considering the maintenance of system stability (Nanduni I. Nimalsiri, Nov. 2020). This control benefits the system reliability as it continues charging operations if any fault occurs in the central unit.

The hierarchical control strategy is divided into several layers as per the nature of problem space and types of participants. The architecture is divided into a central aggregator, subordinate layers of sub-aggregators, followed by EV owner layer (Nanduni I. Nimalsiri, Nov. 2020). The control can again be sub-divided into several control strategies based on the decision-making authority, information signal flow, and required computation.

In local control strategy, only the EV owner is involved in maintaining local parameters and EV charging decisions. Local control only considers the local parameters, constraints, and pricing signals for making charging decisions (Kevin Mets, April 2010). This control only deals with the limited local constraints and linear single objective function, so the computation power required is significantly less than other

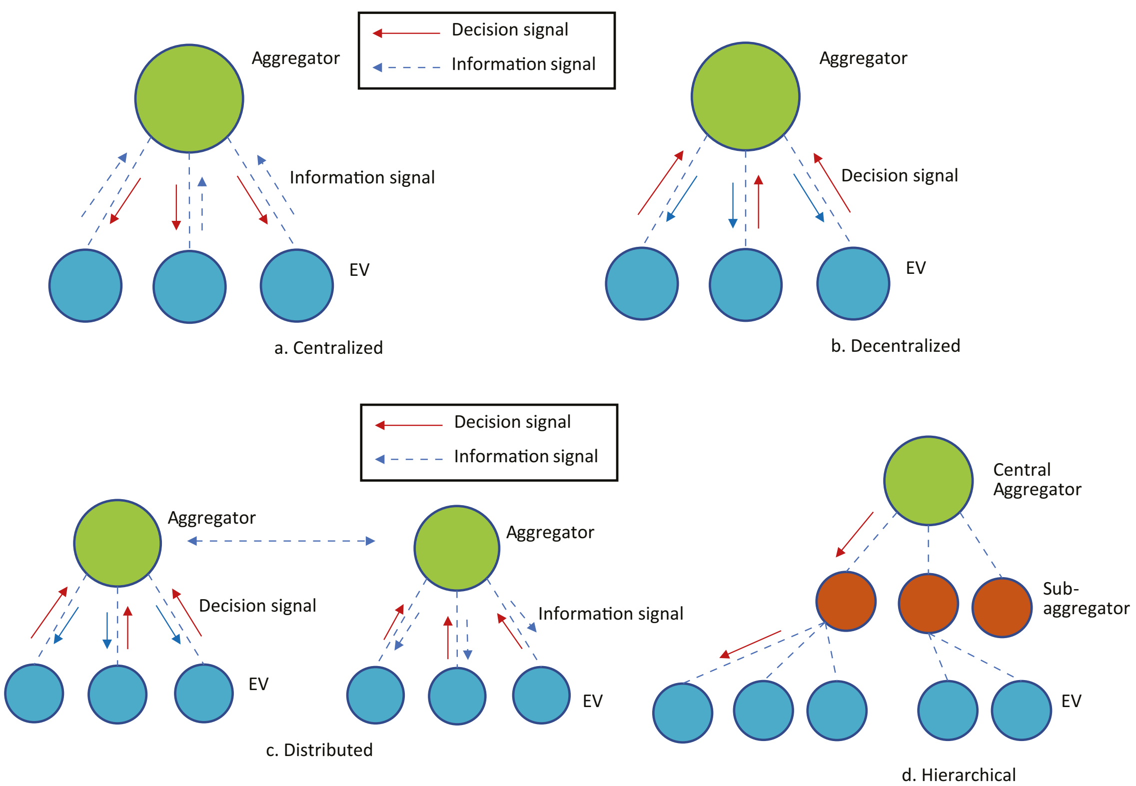

Figure 1: Key smart charging control strategies

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Smart Charging using pricing mechanism: Smart charging strategy can also be implemented using price mechanism, that is, charging of EV in response to electricity price. The price may be set in advance (static) or determined in real time based on the system conditions (dynamic). Some of the price-based mechanism are real time price, time-of-use, critical peak price, and peak time rebate (Figure 2).

In **real-time pricing**, the electricity cost is updated every time step as per the network's requirement. Charging requests or charging demand, availability of energy, maximum allowable power limits, and available RE supply are the major reasons behind price variation. Some other constraints like feeder capacity line loading and transformer burden also indirectly affect the electricity prices. This real-time price variation allows the charging cost minimization objective to be performed in a real charging scenario. Decentralized and distributed control strategies majorly adopt real-time pricing mechanisms.

The **time-of-use (ToU) tariff** can perform smart charging without actually controlling the charging rates. In this method, a fixed price is allotted to time slots. These prices are published so that the customer can schedule the operation of appliances to reduce the electricity cost by shifting the flexible loads to a low price period. Using time-of-use tariff, the grid operator tries to influence the EV owners to shift their EV charging to an off-peak period such that the load is levelled, thereby, mitigating the increase is peak demand. TOU tariff is used in centralized charging where the aggregator considers this tariff to optimize the charging to reach the desired objective.

Critical peak pricing (CPP) works under the same TOU principle. The difference is that it is applied for a period of high demand. It is not decided on historical data, but rather forecasted data is used to apply and publish quickly. The electricity price is very high in CPP compared to TOU, so it is more effective than TOU for peak load reduction.

In the **peak time rebate tariff** structure, the utility provides a rebate to the customer to limit consumption within a predefined limit. Customer views it as a gain. However, shifting load to off-peak time is considered a loss. The economic effectiveness of the scheme is dependent on the predefined critical baseline load as it requires development of precise baseline load.

Communication Standards, Interfaces, Connectors in Smart Charging

As smart charging involves control of time and charging rate of EVs, communication between the EV, the charging operator, and the utility company is essential. Thus, communication standards, interfaces,

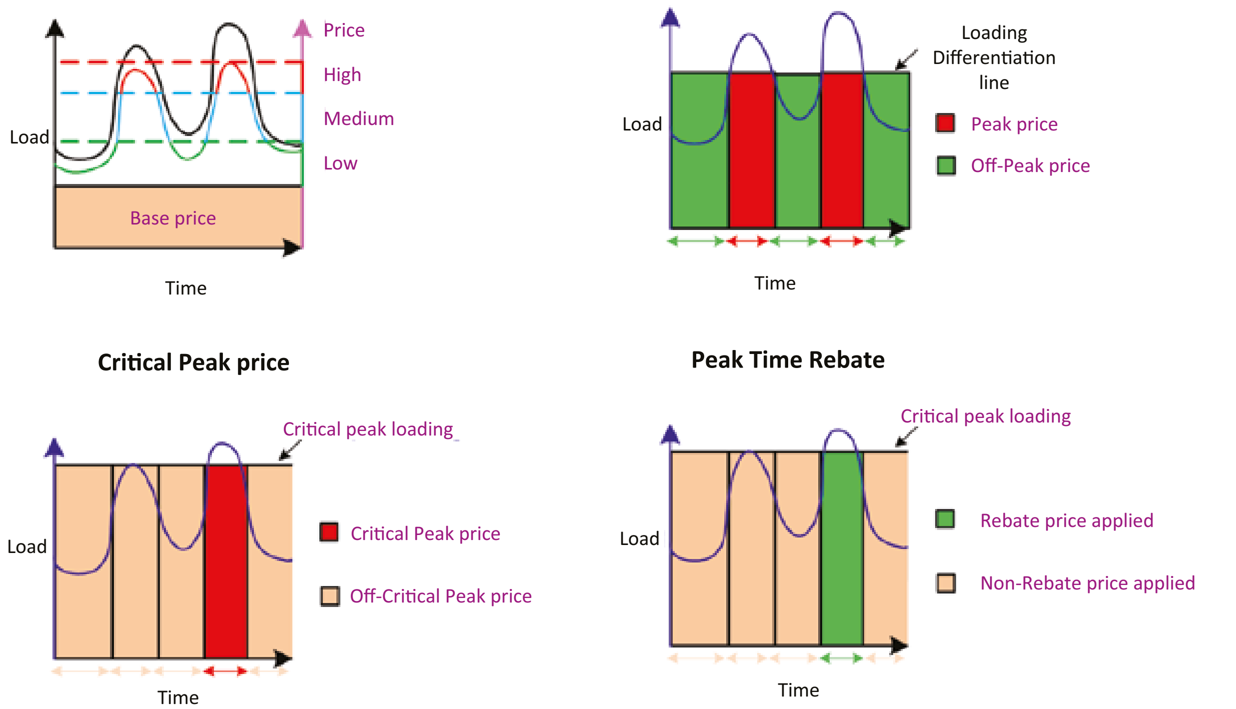

Figure 2: Smart charging using pricing mechanism

connectors are an integral part to realize smart charging functions.

Charging standards

Indian charging standards for AC and DC conductive charging given by Automotive Industry Standards (AIS) are named as AIS 138 part-1 and part-2. These standards cover all the aspects of conductive charging ranging from general requirements for charging, rating, charging modes, connectors, the safety of EV Supply Equipment (EVSE), and protection against electric shocks. The Bureau of Indian standards (BIS) has issued the IS 17017 series of standards for EVSE connectors, socket plugs, outlets, its design, compatibility, and interoperability. These standards majorly follow the IEC standards.

Bharat AC 001 and Bharat DC 001 are the two chargers introduced by the Department of Heavy Industries (DHI) for the Indian EV market. Bharat AC 001 uses IEC 60309 pin, however, without communication protocols between EVSE and EV. For communication and authentication between EVSE and the CMS, Open Charge Point Protocol (OCPP) is used. On the other hand, Bharat DC 001 is developed considering IEC 61851-1 and it is recommended to use GB/T 20234.3 connector. It uses CAN bus communication based on IEC 61851-24.

Communication protocols and interfaces

Communication between an EV and a charging station uses the IEC 61851 and ISO 15118 standard. IEC 61851 allows basic information on the charging process to be exchanged based on analog communication between the vehicle and the charging station. The ISO 15118 standard is based on IEC 61851 and supplements it with digital communication via Powerline. This makes it possible to exchange more complex information such as the vehicle's charging status and battery capacity, tariffs, and charging schedules.

Communication between charging station and IT backend uses protocols such as Open Charge Point Protocol (OCPP), Open Smart Charging Protocol (OSCP), IEEE 2030.5, Open Automated Demand Response (OpenADR), and EEBUS. The OCPP protocol handles the exchange of charging data and can trade information between EVs and the electricity grid. OSCP is an open communication protocol between a charge point management system and an energy management system. This protocol imparts a 24-hour forecast of the accessible capacity of an electricity grid. IEEE 2030.5 is designed to use the modern internet for transport of its messages between devices. The OpenADR standard available in version 2.0 allows the exchange of price signals, setpoints, and metered values between loads, electric storage, distributed generators, and EVs on the one hand, and energy providers and aggregators on the other.

For communication between charging station and e-mobility service Provider (eMSP), Open InterCharge Protocol (OICP), Open Charge Point Interface (OCPI), eMobility Inter-Operation Protocol (eMIP) are used. OCPI is an open protocol used for connections between charge station operators and service providers. Simply put, this protocol facilitates automated roaming for EV drivers across several EV charging networks.

Several EV smart charging products are already available in the market (Figure 3). These products can be categorized based on their applicability. The scope of applicability of products is network tools, optimization solutions, charging stations or charging boxes. Network tools can again be classified into interactive communication tools or mobile applications for communication platforms.

A network tool is used to connect to the communication network for indicating the charging request and other information on charging specifications, vehicle specification, and authentication. Mobile applications and cloud-based platforms are ways of connecting and communicating with responsible charging entities. Platform products such as Snapcharge, Juicenet, and ChargePoint have both mobile and cloud-based platform that provides real-time charging station's status and EV charging status.

Indian Situation in EV Policies, Regulations, and Incentives

In India, although the e-mobility plan is developed at the central level, the onus largely lies on the state and union territory governments, who must develop and implement relevant policies, schemes and regulatory frameworks to enable the adoption of EVs and deployment of charging infrastructure in their respective states. Thus, considering India's federal structure as well as the wide variance in the social-geographic and economic variances between states, a one-size fits all approach cannot be applied. Nineteen states/UTs have notified their final EV policies and 3 states/UTs have released draft EV policies as of November

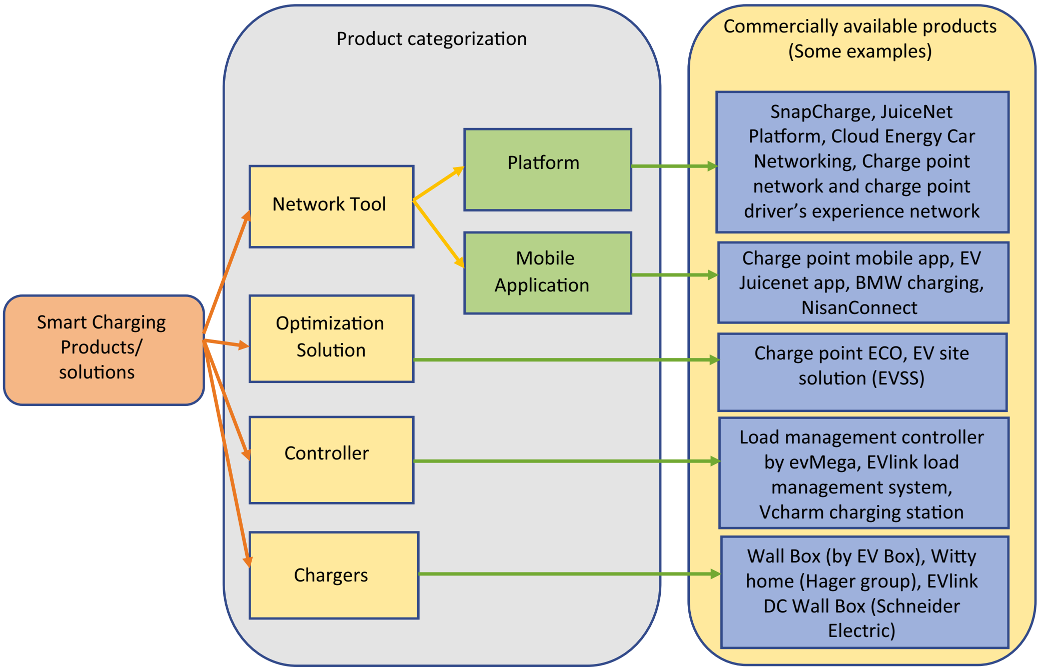

Figure 3: Globally available commercial EV smart charging products

2021. Some provisions in various policies from the viewpoint of smart charging, including communication and ICT technology have been made. Provisions such as Time-of-use special EV tariff for controlled charging, charging stations to be linked to mobile applications to track, monitor, and record historical and real-time data, separate EV tariff based on peak and off-peak loading time have been introduced. Figure 4 illustrates the roadmap of India's E-mobility journey. The figure below provides an overview of certain provisions and gaps in Indian State EV policies (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, 2021) Analysis of the provisions related to smart charging in different state policies and the evaluation of charging infrastructure shows that the underdeveloped and incipient communication infrastructure, inadequate CMS infrastructure, immature regulation framework forms the major disparity between existing charging points and smart charging-enabled charging points. To enable smart charging infrastructure,

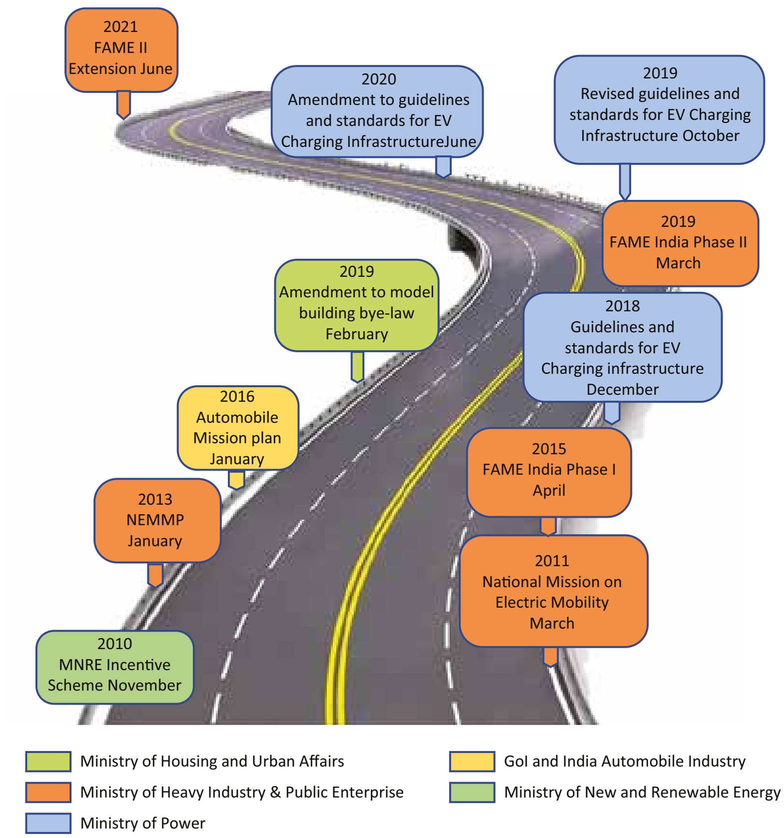

Figure 4: Roadmap of India's E-mobility journey

	Key Point	DL	WB	KA	OR	MH	AS	AP	KL	BR	UP	GJ	TN	CH	MP	PB	TL	ML	UK	RJ
1	Incentives for public charging infrastructure	#	×	✓	#	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×	×
2	Mandate on DISCOMs for establishing charging infrastructure	×	~	~	~	×	~	✓	~	×	✓	~	✓	×	✓	×	~	×	×	~
3	Incentives for residential/ workplace charging infrastructure	✓	×	×	✓	✓	×	✓	×	×	×	×	×	✓	×	×	×	×	×	×
4	Incentives for retrofitting of vehicles	✓	×	✓	✓	×	✓	×	×	×	×	×	×	×	×	✓	✓	×	×	×
5	Purchase incentive for EVs	✓	×	×	✓	✓	✓	×	*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
6	Public awareness programme	✓	✓	×	✓	✓	×	✓	✓	✓	×	×	✓	×	✓	✓	×	×	×	×
7	Information on reimbursement of financial incentives	✓	×	×	✓	×	×	×	✓	×	✓	✓	✓	×	×	✓	×	×	×	×
8	EV-specific tariff	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	×	✓
9	Land allocation/ concession for setting up the charging station	✓	✓	✓	✓	✓	×	✓	×	✓	✓	×	✓	×	✓	✓	✓	✓	✓	×
10	Focus on transitioning of government and public vehicles	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	×	×
11	Provision of R&D	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	×	✓	✓	✓	×	×	×

× : Key attribute is not addressed in respective state EV policy, ~ : DISCOM is not mandated but encouraged to invest in charging infrastructure, # : Provision for a capital subsidy for the cost of charger installation expenses to the selected Energy Operators; * Incentives only for 3-wheelers
DL: Delhi, WB: West Bengal, KA: Karnataka, OR: Orissa, MH: Maharashtra, AS: Assam, AP: Andhra Pradesh, KL: Kerala, BR: Bihar, UP: Uttar Pradesh, GJ: Gujarat, TN: Tamil Nadu, CH: Chandigarh, MP: Madhya Pradesh, PB: Punjab, TL: Telangana, ML: Meghalaya, UK: Uttarakhand, RJ: Rajasthan (Policy draft under final stage, and concept paper)

interventions can be made in the state-wise policies through financial incentives, non-financial incentives, and creating awareness programmes. Some futuristic broad-level suggestions are mentioned in the subsequent section, which would require further investigation in detail. Figure 5 illustrates smart charging in Indian EV policies/ schemes/regulations.

Financial incentives can be provided for establishing a smart charging station and in purchasing smart charging software and services to attract the charging station operator. Special incentives may also be provided for retrofitting older charging stations and fuelling stations with smart charging stations.

Smart charging and ToU incentive may be provided for eligible residential EV customers. Private players can be allowed to provide EV owners and fleet operators' special offers for buying and participating in their smart charging using ToU or any other strategy. Local strategies can be encouraged such as using the locally controlled smart charging station by providing a small rebate on the monthly charging bills. Further, subsidies on procurement of metering equipment, required software, and communication networks required for smart charging may be introduced by the government.

DISCOMs can play a significant role in supporting smart charging by providing an initial logistic support (viz., network information, access to required data, historical data of load, etc.) required to implement a smart charging station. Government offices/PSUs can be

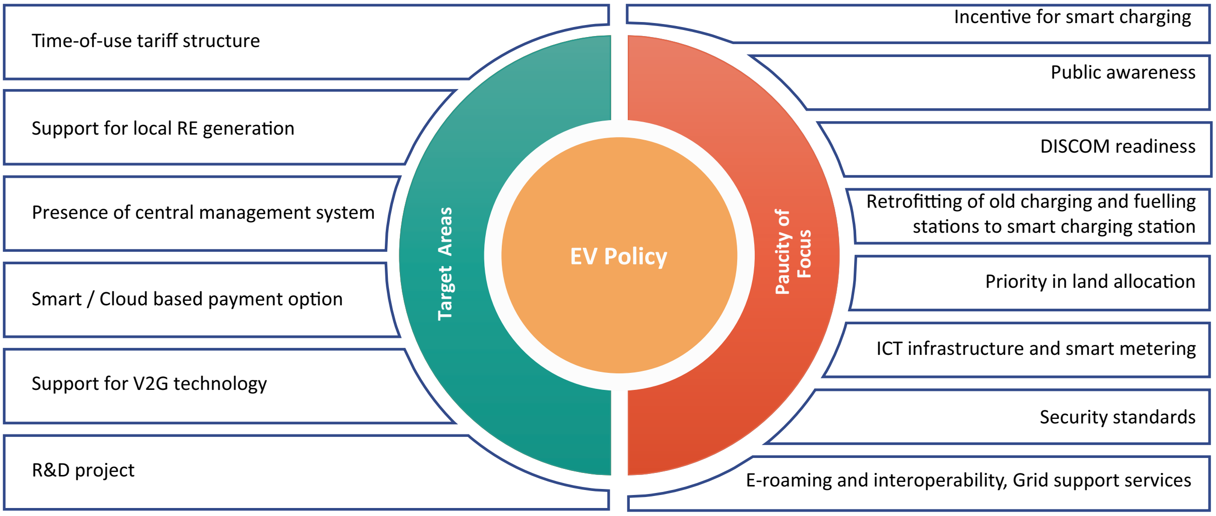

Figure 5: Smart charging in Indian EV policies/schemes/regulations

mandated to establish smart charging stations in the respective region and offices. Also, relevant agencies may be mandated to create a complete package of required logistics, software, network service providers, and training material. If a charging station owner/ service provider wishes to opt smart charging strategy, he could directly avail of this complete package and establish a smart charging station.

Reward points or green certificates can be issued to EV owners for using the smart charging option and charging their vehicles for more than pre-set aggregated charging energy (kWh). Free parking at government parking spaces against green certificate and concession in electricity bill against reward points could be provided.

Awareness programmes can be launched to spread the benefits of EV, state's EV policy, and smart charging in reducing electricity bills and promoting environmental welfare. R&D projects can be given grants to investigate and develop modern ICT-based integration and smart charging techniques for EV ecosystem in the presence of EV loads, smart grid, renewable generation, and digital billing.

Security standards can be structured or adopted from any standard organization to safeguard the users, charging stations, metering, and sensing equipment's data to maintain users' privacy and charging stations to avoid cyber threats on users or charging stations. Investigation of vulnerable nodes in the system can be done on a regular basis.

Conclusion

To enable a smooth transition to accommodate India's projected increase in e-mobility and electricity demand, adoption of smart charging is a necessity. Smart charging is crucial to ensure that EV uptake is not constrained by grid capacity. Smart charging is necessary to manage the charging demand with the available grid infrastructure and generation capabilities. As mentioned in the above section, a number of interventions can be adopted and implemented to enable a smarter, efficient, and sustainable way of scaling up the adoption of EVs in India. Let's hope that India, both at central and at state level, supports policies, regulations, and schemes that complement smart charging adoption for EVs at large.

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