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A Review on Smart Charging Infrastructure for Electric Vehicles

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Abstract –
Electric vehicles (EVs) are transforming the way we think about transportation. With the rise of climate change and increasing concerns about air pollution, EVs offer a sustainable alternative to traditional gas-powered cars around the world. Rechargeable batteries power these vehicles and produce zero emissions, making them an environmentally friendly choice for drivers. While the electric vehicle (EV) market is now fully developed, users still have concerns about key areas of the electric vehicle charging infrastructure. The transition from conventional vehicles to electric ones dictates the design and development of user-centric charging solutions aiming to facilitate the accessibility to as well as the usability of the charging network and improve the user's charging experience. This paper aims to highlight the critical issues of the electric mobility sector and analyze smart charging approaches supporting the large-scale implementation of electric vehicles.

Keywords - *Electric Vehicles, Smart Charging, Control Strategies,Pricing Mechanism, E-mobility.*

I. INTRODUCTION

Currently, the sales of electric vehicles (EVs) are increasing but their drivers still have concerns about the adequacy and the accessibility to the charging network. EV users are just as satisfied with their driving experience as internal combustion engine vehicle users, but the charging experience is still below user's expectations. This is one of the main barriers hindering the wide market adoption of EVs.[1]

Another concern of users is the lack of clear information on what the payment for charging consists of for different eMSP (e-Mobility Service Provider)/CPOs (Charging Point Operator). This differs significantly from refueling a conventional vehicle, where users are aware of exactly what they will have to pay and how much the fuel costs per liter.[2]

The lack of reliable and real-time information on the availability of the charging network is also a concern as charging infrastructures are frequently blocked by parked cars, conventionally or electric ones.[3]

The increased charging electricity needs to serve EV mobility, especially via the "plug-n-charge" approach at home and high-power charging, can lead to potential increase in the network peak demand [4],[5]. Thus, network operators must be prepared to respond promptly to this sudden increase in the energy demand, otherwise, network operational problems might arise such as congestions and voltage excursions [8]. The future electricity networks should be planned and operated not only based on the worst- case principle (i.e., networks are upgraded based on the maximum loading) but also consider the flexibility that can be provided in managing the charging process of EVs [9], [10], [11].

User-centric smart charging strategies and innovative micro grid system approaches for high-power charging stations aims to serve EV user's charging needs and expectations and support electricity suppliers/grid operators to serve the increased energy charging needs in the most cost-efficient way. There is need for tools that will enable the efficient and sustainable planning of the charging network considering diverse charging technologies, the region characteristics, local society needs and the local network capacity [6].

The goal of the paper is to expose the critical issues of the electric mobility sector and analyze smart charging services aimed at supporting the large-scale implementation of electric vehicles.

II. INTRODUCTION TO EVAND CHARGING TECHNOLOGIES

Three types of EVs are available on the market-

- Hybrid vehicles.
- Plug-in Hybrid Vehicles.
- Battery Electric Vehicles.

A. Hybrid vehicles

The hybrid vehicles use both an internal combustion engine and an electric motor for propulsion.

Hybrid vehicles use different technologies to improve efficiency and reduce emissions:-

- the regenerative braking.
- an internal combustion engine to generate electricity and recharge the batteries or to power the electric motor.
- the electric motor as a propeller for most of the driving time, reserving the internal combustion engine only for when it is necessary. Hybrid vehicles can operate autonomously without the need to recharge the battery usingthe electrical distribution network.

B. Plug-in Hybrid Vehicles

The Plug-in Hybrid Vehicles use the same technology as traditional hybrid vehicles, also implementing a high- capacity battery that can be recharged by connecting to the electricity grid, as happens for electric vehicles. There are two possible configurations for this type of vehicle:-

- Series Plug-in Hybrid Vehicles or Wide Range Electric Vehicles, where only the electric motor provides traction to the wheels, while the internal combustion engine is only used to generate electricity. The vehicle uses the electricity stored in the battery until it is discharged, at which point the internal combustion engine intervenes which generates enough electricity to power the electric motor. For short- term journeys, these vehicles may not use any type of fuel, other than electricity supplied by the battery.

- Parallel or Mixed Plug-in Hybrid Vehicles, where both motors are mechanically coupled to the wheels, and bothpropel the vehicle under most driving conditions. The purely electric power supply usually occurs at low speeds. Compared with battery electric vehicles, the plug-in hybridvehicles have a longer driving range and a shorter chargingtime.

C. Battery Electric Vehicles

The Battery Electric Vehicles use high-capacity rechargeable batteries (usually lithium ion) to store electrical energy and electric motors (which can be DC motors or synchronous or asynchronous AC motors) for propulsion. Recharging the battery requires connectivity between the electric vehicle and the electrical distribution network. Depending on the battery capacity, the maximum driving range is ranging from 100 to 400 km. As for the recharging times, they strictly depend on the type of battery installed on the vehicle and the type of recharge being used [9]. About the charging methods, three levels are available [13]:-

- Level 1, supported on all types of electric vehicles and uses a domestic power socket connected to the distribution network as a power source. It does not require particular types of installation, but it requires long charging times.
- Level 2, makes use of special charging equipment designed to speed up charging times and therefore requires the installation of some dedicated electrical devices and circuits.

- Level 3, DC Fast Charging, further minimizes charging times, but requires systems suitable for charging management and requires the greatest number of auxiliary installations. It is also not supported by all vehicle types available on the market. [14]

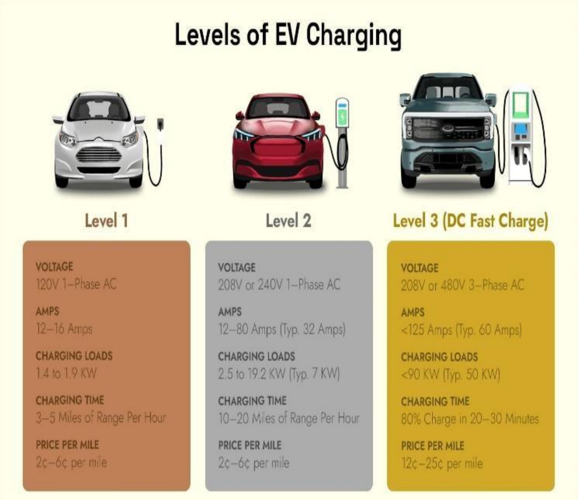

Fig1. Levels of EV Charging. [17]

III. THE SMART CHARGING CONCEPT

Smart charging or intelligent charging refers to a system where an electric vehicle and a charging device share a data connection, and the charging device shares a data connection with a charging operator. Smart charging allows the charging station owner to monitor, manage, and restrict the use of their devices remotely to optimize energy consumption. There are various possible techniques for implementing intelligent charging. Currently, five methods allow for intelligent charging of electric vehicles:-

- Time-of-use pricing (TOU pricing) without automatedcontrol.
- ON/OFF control.
- Unidirectional vehicle control (V1G).
- Bidirectional vehicle-network control (V2G, vehicle-to-grid).
- Dynamic pricing with automated control.

A. *TOU Pricing*

TOU Pricing is the simplest smart charging technique. Based on the current state and available energy of the network, charging prices rise or fall, giving incentives to recharge vehicles at network valley hours, for example at night. The goal of TOU pricing is to avoid overloading the network during peak hours, allowing all users to have a stable and secure service. This technique does not provide direct control on the vehicle charging, so it is not necessaryto integrate the vehicle into the smart grid. It informs the user of the current price of the recharging service, and he/she will decide, according to his/her needs, whether or not to recharge the electric vehicle (implicit demand response) [15].

B. *On/off control*

On/off control involves the integration of the vehicle into the smart grid. The user can carry out the recharging operation at any time. On the basis of the energy demand and the number of loads connected to the network, the recharging service can be temporarily paused or stand-by (on/off). [14]

C. *The unidirectional control (V1G)*

The unidirectional control (V1G) is a direct evolution of the on/off control. In this case, the charging profile can be dynamically adjusted in real time at any value between the maximum and minimum charging rate considering the network load conditions. Therefore, there is no complete shutdown of the service, but the amount of electricity supplied to the charging station and to the vehicle is limited.

D. *The bidirectional vehicle-network control (V2G)*

The bidirectional vehicle-network control (V2G incorporates the same technologies used in the V1G approach, but it allows bidirectional power flow between the EVs and the grid (charging/discharging). [15]

E. *Dynamic pricing with automated control*

Dynamic pricing with automated control optimizes the charging experience, meeting both the needs of the user and those of the smart grid. Obviously, due to the complexity of both hardware and software architectures, the capex andopex of the systems are increased.[15]

IV. IMPLEMENTATION

To be able to implement smart charging, the integration of electric vehicles into the smart grid and a control system are required. This supervisor aims to monitor the status of the network in real time, the energy demand and the available network capacity for charging. In [16], smart charging is implemented aiming to minimize the charging cost taking into account the temperature and "health" of the car battery during the charging operation. Especially in V2G charging with bi-directional energy flow, the battery is stressed, since it is used for non-mobility purposes, and this has significant impact on the battery ageing. In [17] an algorithm is described for the management of a recharging station for fast charging in direct current, in which photovoltaic cells are installed. Three different approaches are discussed in the next subsections for the implementation of smart charging in a smart grid, highlighting the peculiarities and the different methodologies that have been adopted in the related literature:-

A. REINFORCEMENT LEARNING

Reinforcement learning is a machine learning technique that aims to create autonomous agents able to choose actions to be taken to achieve certain objectives through interaction with the environment. The enforcement learning is applied to solve the problem of managing the charging of electric vehicles. In [18] reinforcement learning is implemented to carry out a real-time scheduling of the charging/discharging cycles of electric vehicles. The authors try to find the optimal choices, interacting directly with the system and observing the results obtained based on the decisions of the agent. The agent can thus learn, based on the actions that have produced the best results. Once the electric vehicle is connected to the grid, the agent makes the decision to charge or discharge the vehicle based on the current state of the system. The decisions are made by the agent at hourly intervals depending on the State of Charge (SoC) of the vehicle, the current price of electricity, which depends on the amount of available energy that can be supplied from the electricity grid, and the time of arrival and departure of the car.

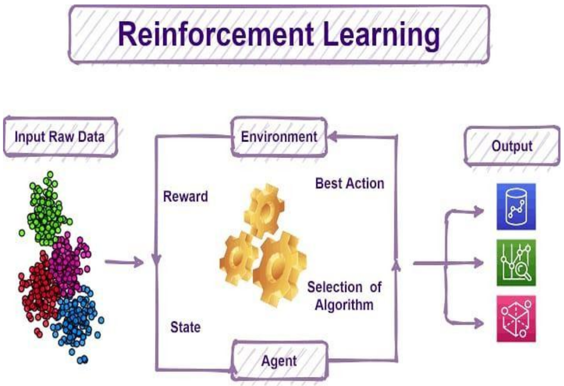

Fig 2. Reinforcement Learning [17]

B. MODEL PREDICTIVE CONTROL

Model predictive control (MPC) is an advanced control technique that allows to control a system while satisfying previously imposed constraints. Predictive model controllers are based on dynamic models of a given process, usually built on the basis of empirical data and statistical methods. The main advantage of the MPC is to be able to optimize the current performance of the system, taking into account the possible future evolutions. The MPC can anticipate future system events and represents a possible approach to the problem of charging electric vehicles. In [19] the MPC is implemented to supervise a charging station integrated in a smart grid. Users make the reservation of the charging slot via an APP, providing the minimum SoC that they want to reach and the time of arrival and departure of the vehicle. The APP shows the user the available slots that meet their requests and based on the choice made by the user, the APP provides the aggregator with the charging schedule of the various slots. Finally, the aggregator, based on the current price of electricity, carries out the recharging operation trying to minimize costs.[18]

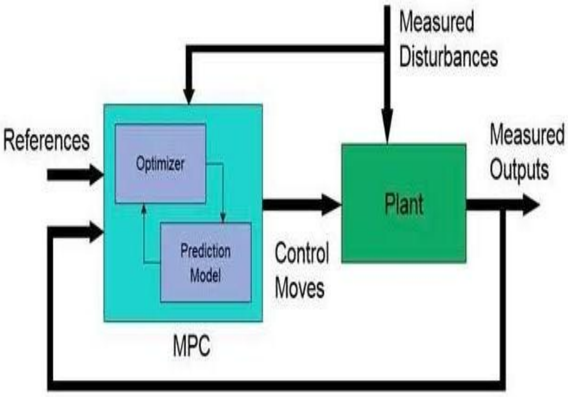

Fig 3. Model Predictive Control Implementation [17]

C. FUZZY LOGIC IMPLEMENTATION

The main advantages of fuzzy logic are the flexibility to multiple fields of application, the robustness and therefore the tolerance to the uncertainty that can be present in the input values, and the simplicity of interpreting the control rules and introducing new ones. In [20] fuzzy logic is used to schedule the charging cycles of electric vehicles based on their priority. The authors of the paper propose a possible algorithm capable of allocating certain time intervals to the recharging of electric vehicles, minimizing the costs of the recharging operation and taking into account the state of the electrical network, in order to avoid possible overloads. The aggregator represents the distributed control center responsible for the collection and processing of information both from the electricity grid and from individual charging stations. Upon arrival of an electric vehicle, the reference charging station updates the aggregator providing the time of arrival of the car, the SoC and the departure time desired by the user. The vehicle's charging priority is determined based on these factors and the time slots (15-minute intervals) dedicated to charging are allocated, taking into account the priority and general status of the network. The system inputs, represented by the SoC(%) and by the total residence time (hours, hr) pass through an interference system together with the fuzzy rules, so as to obtain the charge priority of each vehicle. The algorithm proposed in the paper reduce the high demand peaks by recharging vehicles when power consumption and energy prices are low, effectively optimizing the recharging operation and satisfying both the constraints imposed by the electricity grid and preferences. expressed by users.

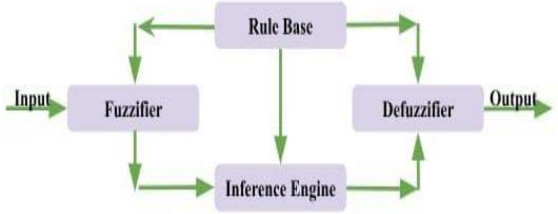

Fig 4. Fuzzy Logic Implementation [17]

D. COMPARISON BETWEEN THREE SMART CHARGING METHODS

The control techniques for charging management minimize operating costs and the constraints imposed by consumers who use the service and by the supplierof the service. Although each algorithm is characterized by different implementation criticalities, the advantages far outweigh the disadvantages:-

- MODEL PREDICTIVE CONTROL

Advantages - Multiple constraints can beimposed simultaneously on the parameters of the being analyzed.

The state of the system can be anticipated. It allows the integration of advanced smart charging techniques.

Disadvantage-A rigorous description of the dynamics of the system is necessary.

- FUZZY LOGIC IMPLEMENTATION

Advantages - Excellent “robustness”. Easy large-scale implementation.

Control laws are easy to understand so to is easy to introduce new ones.

Disadvantages - Simplified description of the system under analysis. Difficulty in integrating, simultaneously, multiple constraints on various parameters.

- REINFORCEMENT LEARNING

Advantages - It is not necessary to define a rigorous model of the system, it is based on empirical data.

Excellent flexibility and adaptability to possible variation of the parameter taken into consideration.

Disadvantages – The agent must be trained to optimize the recharge according to different parameters. [21]

V. 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 smart charging control strategies. [20]

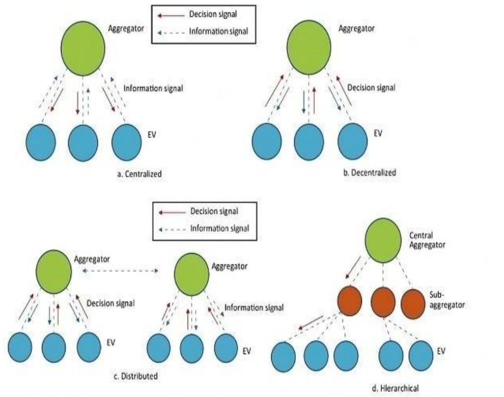

Fig 5. Smart Charging Controlling Strategies [16]

VI. SMART CHARGING (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 mechanisms are real time price, time-of- use, critical peak price, and peak time rebate. 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 asa 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.

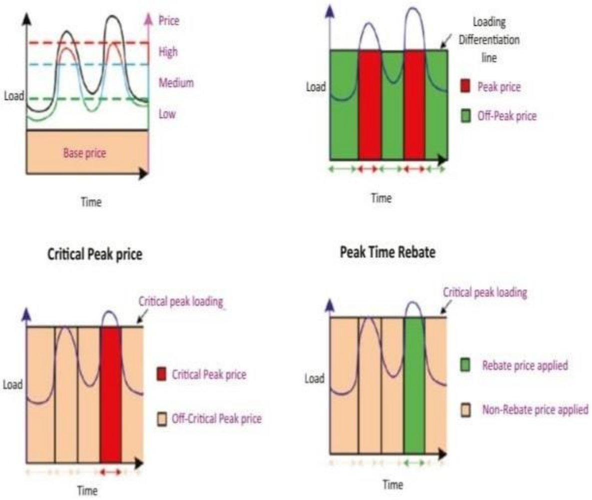

Fig 6. Smart Charging Pricing Mechanism [16]

VII. 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, connectors are an integral part to realize smart charging functions.

A. 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. [19]

B. 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. 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 Snap charge, Juice net, and Charge Point have both mobile and cloud-based platform that provides real-time charging station's status and EV charging status.

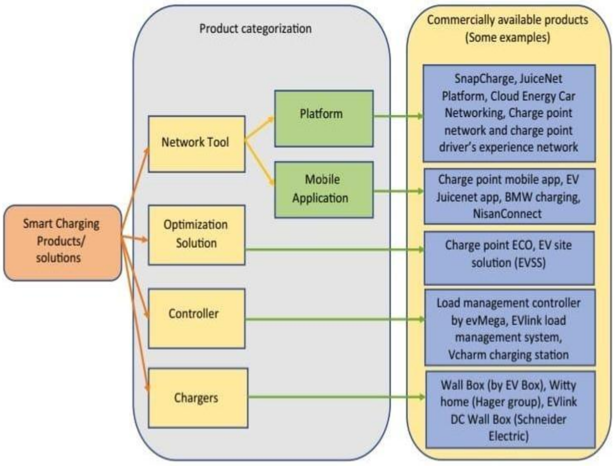

Fig 7. Globally Available Commercial EV Smart Charging Products [16]

VIII. 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 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.

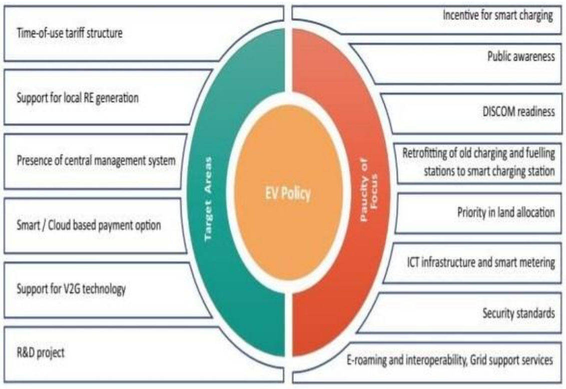

Fig 8. Smart Charging in Indian EV Policies/Schemes/Regulations [16]

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, interventions can be made in the state-wise policies through financial incentives, non-financial incentives, and creating awareness programmes. Somefuturistic broad-level suggestions are mentioned in the subsequent section, which would require further investigation in detail. 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 fueling 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 rebateon 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 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. [18]

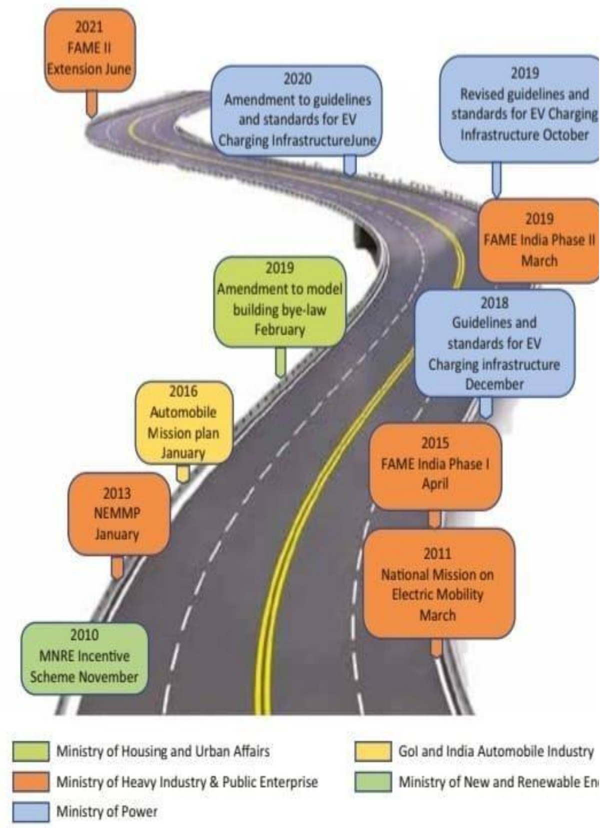

Fig 9. Roadmap of India's E-Mobility Journey [16]

IX. 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 EVsat large.

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