

DSM Solutions for Distribution Networks with Electric Vehicle Integration

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Abstract. Electric vehicles (EVs) are known for being zero emissions and environmentally friendly, making them extremely popular for transportation. In general, electric vehicles are often charged in residential areas. Due to this uncoordinated charging of electric vehicles, the low-voltage distribution network must face many challenges to maintain the new load conditions without blackouts and voltage fluctuations. Failure to properly measure and address these impacts of EVs on the distribution network will result in replacement and reinforcement of the distribution system, which is costly and time-consuming. This study introduces a Demand Side Management (DSM) approach aimed at minimizing overhead in residential distribution systems with electric vehicle (EV) integration. DSM emerges as the optimal strategy for mitigating severe power spikes within the distribution network. The study compares the effects of uncoordinated planned EV loads with those achieved through the implementation of the DSM strategy in a residential distribution system. The analysis encompasses the system's stability and end-user satisfaction as key parameters

1 Introduction

Electric vehicles (EVs) are driven by electric motors and rely on rechargeable batteries or other forms of energy storage for their power. They are becoming crucial in the shift toward a more sustainable transportation system because of their ability to lower greenhouse gas emissions and decrease reliance on fossil fuels [1-2]. Integrating electric vehicles (EVs) into distribution systems presents several challenges. One significant issue is the increased load on the grid, which can lead to peak demand spikes, especially when many EVs charge simultaneously. This can strain existing infrastructure, potentially causing overloads and reducing the lifespan of grid components. Another challenge is the need for substantial upgrades to the distribution network to accommodate the higher power requirements. This includes reinforcing transformers, substations, and distribution lines to handle the additional load effectively. The intermittent nature of EV charging can also create difficulties in load forecasting and management, complicating the task of maintaining grid stability and reliability. Additionally, ensuring adequate and evenly distributed charging infrastructure is essential to prevent localized overloading and ensure convenient access for EV users [3-4]. Many solutions are proposed in the literature to solve the problems due to the integration of electric vehicles like smart charging, V2G, dynamic pricing, Advanced metering Infrastructure (AMI). The traditional approach to planning for electric utilities involved predicting future electricity needs and then determining the best supply-

side solutions to meet those needs. However, as overall demand and load diversity grew, this demand-driven planning became more challenging. Consequently, a few decades ago, utilities began exploring ways to manage and control demand to better align with supply, leading to the development of Demand-side management [5]. Authors [6] provides a comprehensive review of demand response (DR) strategies in commercial buildings. It details various demand response strategies tailored for both large and small non-residential customers, specifically in response to Critical Peak Pricing (CPP), as outlined in a series of technical reports. Demand Side Management (DSM) encompasses various strategies and techniques aimed at optimizing energy consumption and shifting or reducing peak demand. The primary types of DSM include:

1. **Energy Efficiency Programs:** These initiatives aim to reduce overall energy consumption by encouraging the adoption of energy-efficient appliances, lighting, and building designs. Examples include retrofitting homes with better insulation and promoting the use of energy-efficient HVAC system

2. **Demand Response Programs:** These programs incentivize consumers to reduce or shift their electricity use during peak periods. This can involve direct load control by utilities or time-based pricing schemes such as time-of-use rates, critical peak pricing, and real-time pricing

3. **Load Shifting:** This strategy involves shifting energy consumption from peak to off-peak periods. Methods include using thermal storage systems (e.g., ice

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storage for air conditioning) or scheduling energy-intensive processes to operate during off-peak hours.

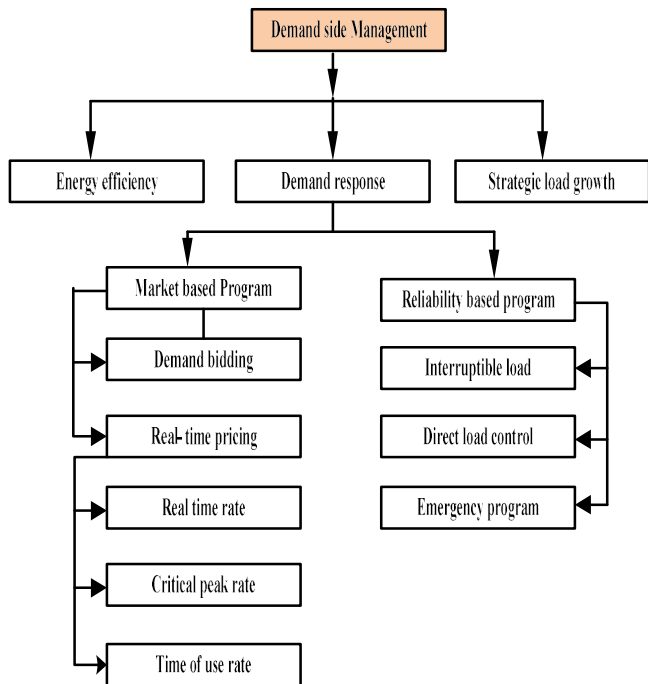
4. Peak Clipping: Peak clipping aims to reduce the maximum energy demand during peak periods. This can be achieved through measures like cycling air conditioners or using backup generators during times of high demand.

5. Valley Filling: This approach focuses on increasing energy use during low-demand periods to flatten the demand curve. Encouraging electric vehicle charging or industrial processes during night time hours are examples of valley filling.

6. Strategic Conservation: Encouraging long-term reductions in energy use through behavioural changes, education, and awareness campaigns. This can include promoting habits like turning off lights when not in use or reducing thermostat settings in winter.

7. Distributed Generation: Involves the use of small-scale power generation technologies, such as solar panels or wind turbines, at or near the point of consumption. This helps reduce the load on the central grid and can provide power during peak periods.

8. Energy Storage: Utilizing technologies like batteries to store energy during off-peak periods and discharge it during peak demand times. This helps in balancing the load and ensuring a reliable supply of electricity.



In this article, we will focus on demand-side management. A review of DSM is presented in the next section.

2 Literature review

The concept of Demand Side Management (DSM) is considered a competent solution to answer various challenges that exist in today's distribution networks.

With their flexibility to change charging time, electric vehicles expand the possibilities for effective DSM. Consequently, controlling electric vehicle charging is a viable solution to shift charging time to off-peak times, thereby reducing voltage fluctuations and transformer load. DSM refers to the planning and execution of these supply activities that aim to influence electricity usage in such a way that they cause desired changes in the timing and size of the supply load and thus change the shape of the load. The implementation of the DSM techniques increases the complexity of the existing power grid because the satisfactory operation of the DSM requires frequent monitoring of the power grid loads and power generators [7]. Demand Side Management (DSM) originated in the late 1970s and focuses on utilizing demand flexibility by involving active consumers. It encompasses the strategic planning and execution of electric utility initiatives aimed at influencing how customers use electricity, thereby achieving desired modifications in the utility's load profile [8]. Three concepts are clearly defined in DSM: energy efficiency (EE), energy conservation (EC), and demand response (DR). DR refers to any intentional changes to electricity consumption patterns by end-use customers, aimed at altering the timing, level of instantaneous demand, or total electricity consumption. These DSM measures are receiving increasing attention due to the added complexity in electric power systems from the integration of distributed generators and variable renewable energy sources. Additionally, the incorporation of information and communication technologies, automation, and control within smart grids, facilitated by advanced metering infrastructure, sensors, and digital network management devices, enables the effective implementation of DSM strategies.

Numerous DSM strategies to utilize the flexibility of electric vehicles (EVs) have been explored in the literature. Recently, managed charging programs have proliferated, growing in scale, complexity, and variety, gaining significant traction. These programs vary in their objectives, associated algorithms and methods, required resources, and costs. However, their main goal remains consistent: to regulate charging power and/or shift the timing of EV charging without interfering with mobility needs. Managed charging of EV's can be achieved through passive or active control mechanisms. It can also be designed for unidirectional (V1G) or bidirectional (V2B, V2G, or V2X) power flow, depending on the requirements. These methods vary in their complexity, communication needs, and resource requirements. Passive managed charging, also referred to as behavioural load control, depends on the actions of customers. In this method, EV users receive a signal encouraging them to adjust their charging behaviour, which they can do manually or automatically. In response to the limitations of passive load control, active management strategies for EV charging are being developed to offer more efficient solutions to address the challenges faced by the grid. There are two strategies for active charging management: centralized control and decentralized control [9-10]. Next-generation Plug-in Electric Vehicles (PEVs) not only support the conventional grid-to-vehicle (G2V) charging mode but

also have the ability to return energy to the grid, a process known as vehicle-to-grid (V2G) technology. The concept and fundamentals of V2G are well explained in literature. Since vehicles are typically driven for only a brief part of the day, V2G-enabled PEVs hold significant potential to provide numerous benefits to the power grid. From the perspective of utility operators, these benefits include peak shaving and load leveling. Providing regulation and other ancillary services (such as spinning reserves), smoothing the intermittent generation from renewable energy sources (RESs), and acting as distributed storage units for backup capacity during unexpected power outages.

It is reasonable to doubt that during the early stages of V2G deployment, before the mass adoption of PEVs, PEV owners might not be keen on allowing their batteries to feed energy back to the grid for use by utility operators. Concerns also include the increased wear on battery cells caused by frequent cycling associated with V2G services. Hence, unidirectional V2G is likely to be implemented first, where V2G functionality is achieved by adjusting charging rates rather than enabling two-way power flows. However, the authors in state that unidirectional V2G can only provide a limited range of services (mainly regulation) and therefore cannot realize all the potential benefits. Regarding the concern about battery degradation, recent work published in concludes that V2G, regardless of the amount provided, results in a loss of less than 10% of battery capacity after several thousand driving days. It is anticipated that with the development and utilization of more advanced battery technologies in next-generation PEVs, bi-directional V2G technology will eventually become more prevalent compared to unidirectional V2G. When bi-directional V2G is enabled, PEVs can be controlled to function either as responsive loads or generation sources, depending on the status of the power grid and the vehicle itself. To achieve the full potential of V2G, an aggregator would act as the central controlling unit, scheduling and coordinating both the charging and discharging of PEVs. The aggregator, representing fleets of PEVs, could participate in various energy markets and earn monetary benefits for the vehicle owners and itself if applicable. Participants would be financially compensated due to the avoided costs from the installation of new capacity, the use of high-cost generation units, and the postponement of network reinforcement from the perspective of utility operators. A detailed cost-benefit analysis for PEV owners considering participation in a V2G-enabled program is provided in, where the authors find that V2G not only enhances grid stability but also offers a significant revenue stream for each participating PEV owner.

2.1 Contribution of the paper

The objective of the paper is to highlight the challenges faced by the distribution system due to the increasing demand for electric vehicles (EVs) and to propose a solution in the form of Demand Side Management (DSM) techniques. The paper aims to emphasize that uncoordinated EV charging in residential areas can strain the low voltage (LV) distribution network, leading

to power outages and voltage fluctuations. The proposed DSM algorithm is described as a method to alleviate these challenges by managing and shifting both household and EV loads, or solely EV loads, to avoid power peaks and ensure the stability of the distribution system. The goal is to maintain distribution system stability while ensuring end-user satisfaction. The paper also seeks to improve user experience by providing real-time monitoring and remote-control capabilities, which will encourage more people to adopt electric vehicles. Through this paper, the aim is to contribute to the transition towards a sustainable and resilient energy ecosystem while facilitating the widespread adoption of electric vehicle

3 Proposed DSM Algorithm

In this Demand Side Management (DSM) algorithm, both residential baseload and electric vehicle (EV) loads undergo a shift. The algorithm proposes a solution that prioritizes EV charging over other residential loads. Residential baseload is categorized into critical, heating, and miscellaneous loads, allowing consumers to adjust their loads to accommodate EV charging. Load priority is assessed hourly during load adjustments. The algorithm's main steps are outlined below.

Step1: Input parameters include baseload and EV profiles, initial State of Charge (SOC), battery charging power, demand limit, charging efficiency, and distribution system data.

Step2: Baseload is segregated into critical, miscellaneous, and heating loads. Power-intensive devices like heaters and cookers are turned off if EV charging is concurrent.

Step3: The algorithm considers the demand limit set by the distribution network operator, assuming it's uniform across residential consumers.

Step 4: To determine the State of Charge (SOC) of each connected electric vehicle (EV), you can follow these steps

(i) Allocate Charging Power: Distribute the available charging power among the connected EV's based on priority, charging profiles and SOC targets.

(ii) Update SOC: using the allocated charging power and charging efficiency, update the SOC of each connected EV over time. Monitor the charging process to ensure SOC targets are met without exceeding battery capacity or causing issues with grid.

(iii) Adjustments: continuously adjust the charging power allocation and SOC updates based on grid conditions and user preferences.

Step 5: The time needed to charge each electric vehicle can be determined by considering the state of charge (SOC) and the active power of the EV charger.

$P_{re} = (1 - SOC) * C$. The charging time for EV=

$$\frac{P_{re}}{P_{ch} * \text{charging efficiency}}$$

Step 6: The algorithm evaluates the constraints of distribution systems and prioritizes the loads each hour accordingly. It ensures the total load selected each hour

remains below the demand limit. The demand limit profile aids residential power consumers in choosing suitable loads to use within the power capacity set by the distribution system operator.

4 Distribution network with electric vehicles

Figure 1 illustrates the typical residential distribution system used in the simulation to evaluate the proposed DSM algorithm. The system includes one 150 KVA distribution transformer, two feeders, and twenty urban residential houses. Feeder 1 serves eight residential consumers, while feeder 2 serves the remaining twelve. It is assumed that EV owners charge their batteries at home. Uncoordinated EV charging can impact the distribution system voltage and overload the distribution transformer. The effect of EVs on the residential distribution network is influenced by various factors such as battery charging capacity, travel distance, road conditions, and the penetration levels of electric vehicles.

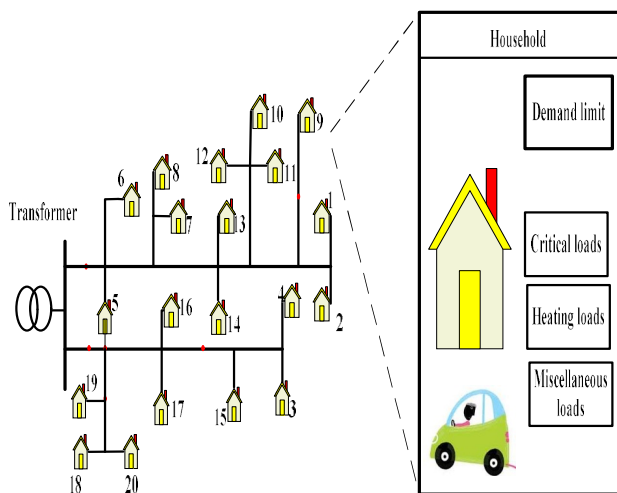


Fig 1: Topology of a typical residential distribution system

4.1 Base load Selection and its classification

Household appliances can be classified as follows

Table 1 classification of household appliances

Type of Appliance	Properties	Examples
Type-1	Non-shiftable	Fridge, stove, rice cooker
Type-2	Shiftable but non-interruptible	TV, Washing machine
Type-3	Shiftable and interruptible	EV's, Energy storage device

We use databases of domestic DLPs (Daily Loads Profiles) to select load data [8].

Table 2 Daily load curve of one house

Time	Load in kw	Time	Load in kw
0	2.77	12	3.24
1	2.77	13	3.24
2	2.77	14	3.24
3	2.77	15	3.24
4	2.77	16	6.93
5	2.77	17	8.09
6	3.24	18	6.93
7	4.04	19	6.93
8	4.04	20	6.47
9	3.24	21	4.85
10	3.24	22	4.85
11	3.24	23	4.04

Table 3 shows the classification of total load into critical loads, heating loads and other loads

Time	Critical load (KW)	Heating load (KW)	Miscellaneous load (KW)	Total load (KW)
0	0.97	1.39	0.42	2.77
1	0.97	1.39	0.42	2.77
2	0.97	1.39	0.42	2.77
3	0.97	1.39	0.42	2.77
4	0.97	1.39	0.42	2.77
5	0.97	1.39	0.42	2.77
6	1.13	1.62	0.61	3.24
7	1.42	2.02	0.61	4.04
8	1.42	2.02	0.49	4.04
9	1.13	1.62	0.49	3.24
10	1.13	1.62	0.49	3.24
11	1.13	1.62	0.49	3.24
12	1.13	1.62	0.49	3.24
13	1.13	1.62	0.49	3.24
14	1.13	1.62	0.49	3.24
15	1.13	1.62	0.49	3.24
16	2.43	3.47	1.04	6.93
17	2.83	4.04	1.21	8.09
18	2.43	3.47	1.04	6.93
19	2.43	3.47	1.04	6.93
20	2.26	3.24	0.97	6.47
21	1.7	2.43	0.73	4.85

22	1.7	2.43	0.73	4.85
23	1.42	2.02	0.61	4.04

4.2 Electric Vehicle Data

Many types of electric vehicles are available on the market, but for simulation we will use the following data

Table 4 EV Data

S. No	Parameter	Value
1	Battery capacity	21 kWh
2	Energy Consumption	0.15 kWh/km
3	Driving distance	140 km
4	The power rating of the Charger	3.3 kW
5	Charger efficiency	93%

4.3 Selection of charging periods

The proposed work involves charging electric vehicle (EV) batteries primarily at home. The process of connecting and disconnecting EVs from the residential system is contingent upon the behavior of EV owners.

EV User 1: A typical family that uses their electric vehicle regularly. They connect their EV to the network from 4 PM to 6 PM and from 10 PM to 5 AM.

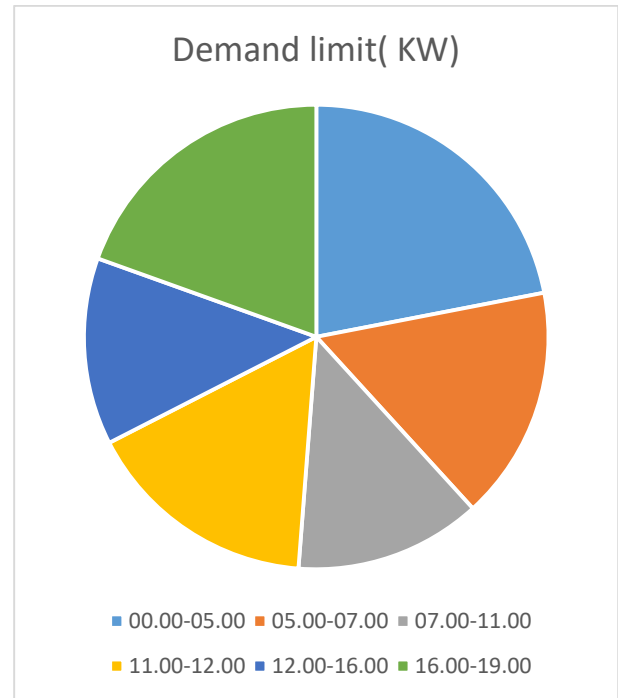
EV User 2: A single person who uses an electric vehicle. This user connects their EV to the network from 4 PM to 6 AM.

EV User 3: An unemployed individual who connects their electric vehicle to the network from midnight to 10 AM and from 2 PM to 5 PM.

EV User 4: A person who works night shifts, connecting their electric vehicle to the network from 7 AM to 7 PM.

4.4 Settings of demand limit

The demand limit profile outlined in Table 5 is integral to the proposed approach, as it empowers residential power consumers to select loads that align with the capacity offered by the distribution network operator. This strategy ensures that consumers operate within the bounds of the system's capabilities.



Notably, the power rating fluctuates depending on the activity level in the industrial zone; during peak industrial activity, the power rating decreases, and conversely, it increases when industrial demand is lower. It's important to note that the maximum rated power capacity of a distribution transformer is capped at 6.75 kW, which serves as the upper threshold for consumer usage. This capacity is achievable within a residential distribution network with a power factor of 0.9, ensuring efficient utilization of available power resources. While the demand limit does influence the load distribution, residential customers retain the flexibility to make choices regarding their specific loads. Within households, there exists a diverse range of appliances, each with its characteristic power consumption patterns. Conventional devices like lighting fixtures, heaters, and cooking appliances typically exhibit constant impedance loads. In contrast, modern gadgets such as TVs, computers, EV chargers, and energy-efficient lighting tend to function as constant power loads. Motor-driven appliances, like air-conditioner compressors, often exhibit complex operational behaviors. Notably, during EV charging, certain high-power-consuming devices like heaters and cookers may be temporarily deactivated to accommodate the increased load demand. This dynamic interplay between different types of loads underscores the complexity of managing energy consumption within residential settings.

4.5 Load priority of users

The initial column lists load priorities, with 1 being the highest priority and 16 being the lowest. The goal of the proposed Demand Side Management (DSM) algorithm is to maximize load usage while staying within the demand limits. This may involve rescheduling or

shifting certain loads when they are disconnected from the system due to reaching the demand limit.

load Priority	Types of loads
1	All the ordinary, shifted heating loads, and EV charging
2	All the ordinary, shifted heating loads, and EV charging
3	All the ordinary loads and EV charging
4	Ordinary heating, shifted heating, Critical loads, and EV charging
5	Ordinary heating, Critical loads, and EV charging
6	Critical, ordinary misc, shifted misc loads, and EV charging
7	Critical, ordinary misc loads, and EV charging
8	Critical and EV charging
9	All the ordinary loads and all shifted loads
10	All the ordinary loads and shifted heating loads
11	All the ordinary loads
12	Ordinary heating, shifted heating, and critical loads
13	Ordinary heating and critical loads
14	Critical, ordinary misc, and shifted misc loads
15	Critical and ordinary misc loads
16	Critical loads

5 Simulation results and discussion

The initial DSM algorithm proposes a solution that prioritizes EV charging over other residential loads. This algorithm sets an equal demand limit for all houses within the distribution system. To validate the algorithm, a single residence is selected and a user profile is simulated, specifically using House3 and EV user profile 1. When residential loads are not categorized into critical loads, heating loads, and miscellaneous loads, the opportunities for EV charging are limited. However, by classifying the loads into these categories, multiple possibilities for EV charging emerge. As per the proposed DSM algorithm, the load will not cross the demand limit. The impact of the initially scheduled EV loads on the distribution system is compared with the results from applying the proposed DSM algorithm to the residential distribution system integrated with EVs. The analysis focuses on network stability and user satisfaction. Although the DSM strategies cannot ensure that all EVs are fully charged within a 24-hour period, they significantly reduce the overall load on the transformer and decrease thermal stress on the conductors.

Hour	Priority	Demand limit	Initial	after	Difference
			scheduling	applying DSM	
0	1	6.75	6.07	6.07	0
1	1	6.75	6.07	6.07	0
2	1	6.75	6.07	6.07	0
3	9	6.75	2.77	2.77	0
4	9	6.75	2.77	2.77	0
5	9	5	2.77	2.77	0
6	9	5	3.24	3.24	0
7	12	4	4.04	4	-0.04
8	12	4	4.04	4	-0.04
9	9	4	3.24	3.32	0.08
10	9	4	3.24	3.24	0
11	9	5	3.24	3.24	0
12	9	4	3.24	3.24	0
13	9	4	3.24	3.24	0
14	9	4	3.24	3.24	0
15	9	4	3.24	3.24	0
16	8	6	10.23	6	-4.23
17	16	6	11.39	6	-5.39
18	8	6	10.23	6	-4.23
19	13	6.5	6.93	6.5	-0.43
20	11	6.5	6.47	6.5	0.03
21	11	6.5	4.85	6.5	1.65
22	7	6.5	8.15	6.5	-1.65
23	7	6.5	7.34	6.5	-0.85

6 Future directions

Future directions for Demand Side Management (DSM) with Electric Vehicles (EVs) could include:

Advanced DSM Algorithms: Develop more sophisticated algorithms that can optimize EV charging schedules based on real-time grid conditions, energy prices, user preferences, and vehicle-to-grid (V2G) capabilities. This would enhance grid flexibility and efficiency.

Integration of Renewable Energy: Explore ways to integrate EV charging with renewable energy sources to reduce carbon emissions and increase sustainability. This could involve smart charging strategies that prioritize renewable energy use.

V2G Expansion: Expand the implementation of bi-directional V2G technology to enable EVs to provide grid services such as frequency regulation, peak shaving, and grid stabilization. This would require further development of V2G infrastructure and regulatory frameworks.

Smart Grid Integration: Integrate EV charging into smart grid systems to enable dynamic pricing, demand response programs, and grid balancing. This would require enhanced communication and interoperability between EVs, charging stations, and grid management systems.

User Incentives: Implement incentives and rewards for EV owners to participate in DSM programs, such as

discounted electricity rates, financial incentives for V2G participation, and access to premium charging services.

Battery Technology Advancements: Continue research and development in battery technology to improve EV battery performance, lifespan, and charging efficiency. This would support faster charging times and reduce concerns about battery degradation.

Policy and Regulatory Support: Advocate for supportive policies and regulations that promote the integration of EVs into DSM programs, ensure fair compensation for V2G services, and address privacy and security concerns related to smart charging systems.

Data Analytics and Predictive Modeling: Utilize advanced data analytics and predictive modeling techniques to forecast EV demand, optimize charging schedules, and identify opportunities for grid optimization and load management.

Collaboration and Partnerships: Foster collaboration between utilities, automakers, charging infrastructure providers, and technology companies to develop integrated solutions for DSM with EVs. This could involve joint pilot projects, research initiatives, and standardization efforts.

Education and Awareness: Increase public awareness and education about the benefits of DSM with EVs, including cost savings, environmental impact, and grid reliability. Encourage consumer adoption of smart charging technologies and participation in DSM programs.

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