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International Journal for Modern Trends in Science and Technology, 8(08): 170-179, 2022

ISSN: 2455-3778 online
DOI: https://doi.org/10.46501/IJMTST0808024
Available online at: http://www.ijmtst.com/vol8issue08.html

A Review on EV Charging Station Infrastructure Integrated with Distribution System and Management of EV Load Using Demand Side Management

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To Cite this Article
Sowmya G and Sureka Manoj. A Review on EV Charging Station Infrastructure Integrated with Distribution System and Management of EV Load Using Demand Side Management. International Journal for Modern Trends in Science and Technology 2022, 8(08), pp. 170-179. https://doi.org/10.46501/IJMTST0808024

Article Info
Received: 15 July 2022; Accepted: 10 August 2022; Published: 16 August 2022.

ABSTRACT

In the literature, numerous electric vehicles (EVs) charging schemes are reported. and shown in practice to encourage the adoption of EVs. This article analyses existing and future electric vehicle charging systems in terms of topologies of power converter and its level of power handling, direction of power flow, and control algorithms of charging techniques. Additionally, this paper provides a critical examination of the DSM deployment on a distribution system that includes EVs. Finally, it discusses the issues that may develop in the future as a result of high EV penetration and the research areas that should be prioritized to mitigate the impacts of EV charging stations and also explore the need of DSM in EV connected distribution system.

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KEYWORDS: *Demand Side Management, Distribution System, Electric Vehicle Charging Station Infrastructure, Power flow*

1. INTRODUCTION

Due to the escalating problems associated with global warming and the fact that transportation is the largest cause of pollution, clean power production and electric vehicles are increasingly attracting the attention of businesses and consumers around the world. The driving factors of the Indian vehicle sector are energy security (reduced reliance on foreign fuel), climate warming goals, environment protection (mostly CO2 emissions), and industrial viability. In 2021, India sold 3,29,190 electric vehicles, a 168% growth over the 1,22,607 electric vehicles delivered last year. According to Indian EV Market, the Indian electric vehicle market will be worth USD 1,434.04 billion in 2021. By 2027, it is expected to be worth USD 15,397.19 billion, which is a compound annual growth rate (CAGR) of 47.09% over the forthcoming years (2022-2027).

EVs rely on the presence of EV chargers on highways prior to EVs for the convenience of charging EV batteries, which has a substantial impact on the adoption rate and utilization of EVs. The developing EV sector represents the promise of emissions free when electric cars (EVs) are fueled by clean energy. Indeed, it is critical to power these electric vehicles as much as possible using renewable sources, as such substantial charging burdens would have had harmful environmental repercussions if they are powered by non-renewable power plants. Whereas the EV charging station with RES aims for desirable impacts, they simultaneously pose questions about the current energy network's ability to handle peak loads at the distribution level. These flaws are likely to result in system failures such as voltage deviation and power congestion. As a result, network losses may increase, network equipment's life may be decreased, end-user equipment may be damaged, supply services may be halted, or, in the worst-case scenario, network outages may occur.

Although the aforementioned difficulties might be addressed by altering the layout of the existing power system, for as by replacing cables with larger ones or increasing the capacity of transformers, However, these are anticipated to be substantial [1]. Also, the EVs can be used as a smart load which can be used as renewable distributed generators (DG) or storage devices. As generation and consumption always should counterbalance for a stable operation of power system, EVs can be recharged and thereby act as a load during high production and light load periods. This stored energy can be used to drive or as a source of electricity during high load or low generation periods [2-3].

Demand Side Management (DSM) is an efficient approach to maximize the use of EV load in order to counteract the negative effects of EV charging stations. To improve system stability, EVs could be used as peak shaving techniques. Aside from EV technological advancement, reliable charging infrastructure is critical to the widespread adoption of EVs.

This study focuses primarily on two main areas. The primary purpose is to discuss potential EV charging infrastructures and standards. The second purpose is to emphasize the need of applying the DSM technique for effective scheduling and utilization of EV load in order to improve system performance and avoid negative distribution system (DS) consequence This paper offers a thorough review of all kinds of EV charging stations with the goal of informing academics about EV charging infrastructure as well as specific types of DSM approaches.

2. EV Compatibility with the Distribution System

Initially, the EV charging station is integrated with the DS, with electricity always flowing from the grid to the EV (G2V). This is referred to as the unilateral method. The concept of smart charging is explored [5], which employs planned approaches in a unidirectional manner. The safety and control tactics related with G2V techniques are discussed in detail in attempt to lessen charging costs and the impact of EV charging stations on DS [6-7].

Figure 1 depicts a simplified illustration of an EV that is connected to the DS. Modelling research on the interaction of electric vehicles integrated with the DS has advanced from a unidirectional pattern in the early stages to a two-way power flow in the present grid [8]. The term "vehicle-to-grid" refers to the technology that enables bidirectional energy transfer between an EV and the grid (V2G). This is accomplished by integrating information and communication technology (ICT) into the electric vehicle charging station. The major goal of having bidirectional mode is to employ EVs as smart loads, charging them during light load periods and discharging them during peak load periods to meet peak demand. This can be done by peak load shaving technique in DSM [9].

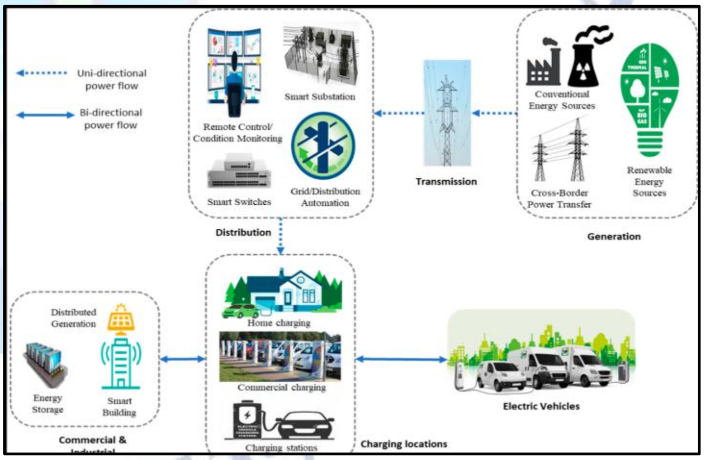

Fig.1: EV Compatibility with the DS [4]

A. International EV Charging Standards

Charging an EV could be done at residence or at a commercial charging station situated in workplaces, Malls, and parking zone, among other locations. According to SAE standards, there are three distinct charging modes for EVs. Alternating current (AC) charging can be performed in modes 1 and 2, while direct current (DC) charging can be performed in mode 3. (DC). Numerous countries in Europe, as well as Japan and the United States, have implemented similar charging modes [10]. The charging standards and various level charging stations have been created in accordance with the charging characteristics and modes specified in Table 1. For residential charging, Mode 1, also known as Level 1 AC Charging, is used. It operates on 120 Valternating current and is created by having a little modification to domestic wiring. Although this is a low-cost charging configuration, it requires a lengthy charging time of 12–16 hours to reach 100 percent SOC. Apart from charging at home, EVs may also be charged at public. Public charging area operate in Mode 2 and provide a relatively rapid charge rate. However, installing infrastructure of Mode 2 charging is costly and has a significant effect on the DS. Commercially, in alternative to the AC charging, a DC charging solution is available. Mode 3 charging is a direct current (DC) fast charging method that utilizes an on-board supply unit. It has a power handling capacity of 80–200 kW and is suitable enough of charging EVs in as little as 30 minutes. However, it has a substantial impact on the DS's maximum loading capability and is the most expensive to build.

3. EV CHARGING STATION INFRASTRUCTURE

For various infrastructures of EV charging stations, providing owners the option of charging their vehicle at home or using public charging stations for a quick charge. The classification of EV charging station infrastructure along with the work carried out so far is discussed as follows:

B. Onboard Charging Technique

On-board chargers (OBC) for electric car batteries can be positioned either on the inside or the exterior of the vehicle (off-board). As a result, OBC are constrained in terms of their size, weight, and volume [11]. As a result, they are often suitable with both level 1 and 2 chargers, which require 4–11 hours and 1-4 hours, respectively, to fully charge the battery. These chargers are available in two modes: constant current or constant voltage, both of which are simple to operate. They are typically capable of unidirectional power transfer; but, depending on the arrangement, bidirectional power transfer is possible. As illustrated in Figure 2, An on-board charger's principal function is to manage the flow of electricity from the utility to the battery. This means that the OBC must adhere to the DS's specifications in the areas where it will be used. The fundamental condition is that no reactive power is injected back into the grid, which is accomplished with a power factor (PF) greater than 0.9. Additionally, the OBC must be compatible with the chargers available, which means it must enable single-phase and three-phase operation.

Two Stage Back to Back Converter Topology: Typically, onboard chargers consist of two stages: a converter that converts AC to DC at the front, and a converter that converts DC to DC at the back. The power factor correction (PFC) module is attached between the two converters to increase power factor and power quality. Controlled or uncontrolled, full or half wave bridge rectifier, the first stage AC/DC converter is available. The converter type can be influenced by the characteristics of power flow, either unidirectional or bidirectional. For example, diodes can be used to provide unidirectional power flow, whereas active switches can be utilized to provide bidirectional power flow [12]. The interleaved boost converter is gaining popularity in the PFC converter. Interleaved boost converters are just two boost converters functioning in tandem with 180 degrees of phase difference between them [13]. The fundamental goal of this interleaving is to improve the power of the output current by lowering the disruption in the input current. This will allow for the interleaving to be successful.

Table I. Various Charging Methods with their Characteristics

Charging Modes	Charging ports	Charging Station Capacity	Power Supply	Charging Time (Hrs)	Pros	Cons
1	Domestics	120V-AC, 12-16A & 1.4-1.9 kW	1-Phase	6-10	cheap setup. Less effect on DS.	Rate of charging is slow. Long charging

						duration.
2	Public and domestic	240V-AC, 80A & 19.2 kW	1/3 Phase	1-3	Quick charging interval. Energy-saving.	High setup cost. High effect on DS.
3	Public	480V-DC, 80-200A & 20-120kW	3-Phase	0.5	A very quick charge time. More efficient.	High setup cost. High effect on DS.

The second stage DC-DC converter is commonly employed as a resonant power converter, followed by the PFC module. due to the possibility of simultaneously achieving a greater switching frequency and a smaller switching loss [14]. Among allthe resonant converters, the LLC configuration is getting a lot of attention because of its many benefits over other resonant configurations, like: (1) the capability to switch at zero voltage (ZVS) or zero current (ZCS), (2) a transformer with high frequency makes it possible to isolate the grid and the EV, (3) a broad range of output voltage is conceivable, and (4) the filter at the output side is just a capacitive one [15].

Single Stage Converter Topology: When the rectifier and the buck-boost converter are joined, a single stage battery charger is formed. This architecture of charging scheme is utilized when price and allocation considerations are crucial [11]. Indeed, a one stage battery charger eliminates the need for several high - cost parts such as dc-link capacitors and inductors [18], which are necessary in a 2-stage charger. The disadvantage is that 1-stage chargers with an insulated converter have a low ratio of conversion, limiting its usage to a broad output voltage range. If, on the other hand, a high frequency isolator is used, likes in the OBC architecture presented in [19], the low frequency signals created due to AC to DC conversion passes through the transformer, resulting in a high magnetizing current. Additionally, a significant multiple passive diodes and active semiconductor devices may be required to provide PFC [18], increasing the configuration's complexity.

Multifunctional OBC: The final type of OBC proposed is the multifunctional OBC. Certain components of this sort of battery charger are shared to achieve many objectives. This way, increased efficiency of fuel can be achieved with a simple, lighter design. According to [20], While the vehicle is in drive mode, the proposed multipurpose battery charger might charge the auxiliary battery using the primary battery, thereby operating as both an OBC and a low-voltage dc-to-dc converter (LDC). In [21], a similar configuration, depicted in Fig. 3, is offered with the similar responsibilities.

C. Off-board Charging Technique

Off-board chargers are essentially DC fast chargers that are mounted externally to the EV due to their high-power capacity. Off-board charging systems are typically consisting of two stages: an AC/DC rectifier that interfaces with the DS and a DC/DC power converter that interfaces with the EV battery. Depending on the converter architecture, either of these stages can handle both bidirectional and unidirectional power transfer.

Unidirectional Converter: In off-board chargers, the Vienna rectifier is the most popular unidirectional AC/DC converter [22–23]. It has a number of advantages, including low voltage burden on individual switches and great efficiency. The primary restrictions, however, are the limited reactive power management and the requirement for balancing the dc-link voltage. [22] proposes a 25-kW capacity off-board charging station prototype model comprised of a single-switch Vienna rectifier, as illustrated in Fig. 4, and four parallel connected dc/dc modules with three-level.

The phase shifted H bridge power converter [24] is another form of unidirectional DC/DC converter used in unidirectional off-board chargers, the schematic of which is shown in Figure 5. This type of converter offers numerous benefits, along with a high-power density, low magnetic distortion, and great efficiency, making it an ideal option for inclusion in rechargeable batteries [25].

Bi-Directional Converters: The 3-phase LCL filter connected active rectifier is most extensively used bidirectional AC/DC converters, the schematic of which is shown in Fig. 6. In [27], the front-end ac–dc converter is accomplished using a three-phase three level neutral-point-clamped (NPC) converter. This power converter was used to boost density of the power and to minimize current harmonic distortion. Additionally, it enables the establishment of a bipolar direct current bus suitable for the deployment of partial-power converters. However, the NPC results in a power imbalance and, as a consequence, complexity in balancing of voltage across the capacitors on the DC bus.

The other topology to offer bidirectional power flow which is gaining more popularity is DC/DC power converter. This is because of the potential of modern wide-bandgap (Gan/SiC) semiconductor devices, which have permitted significant increases in converter efficiency and power density [28]. Resonant dual active bridge [29] and multilayer dual active bridge [30] is designed as primary isolated DC/DC converter to provide bidirectional power flow.

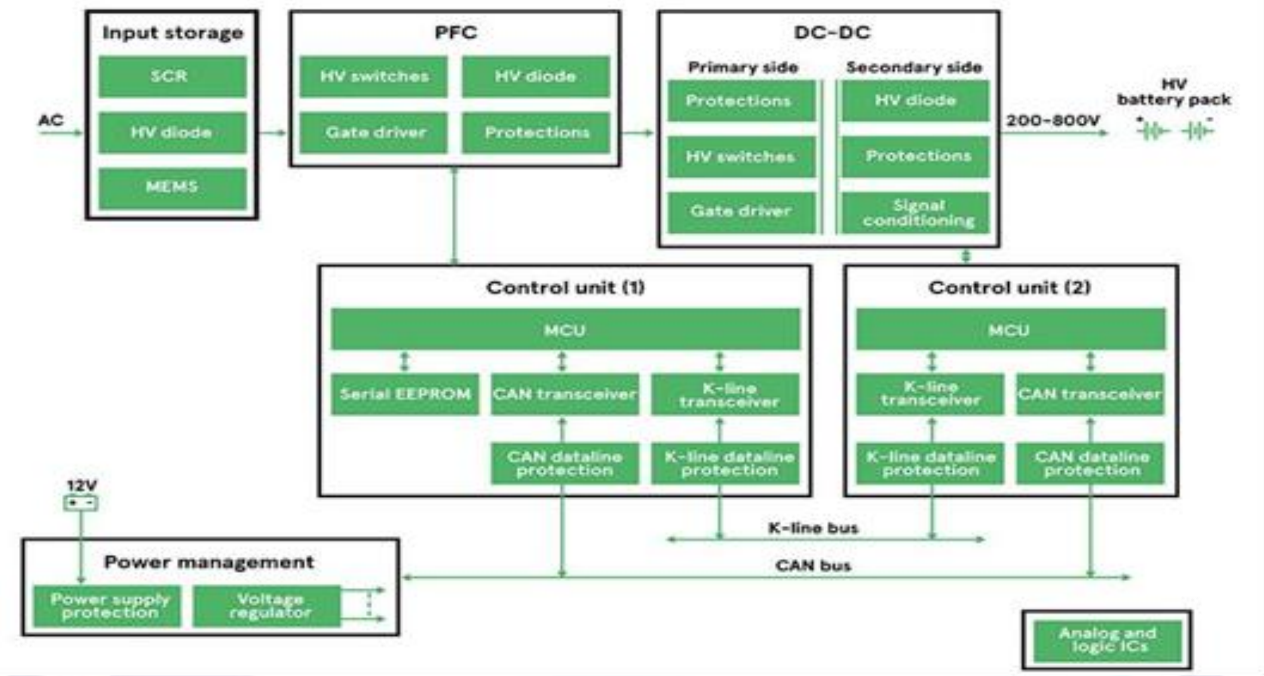

Fig. 2: OBC Configuration with Controller Unit

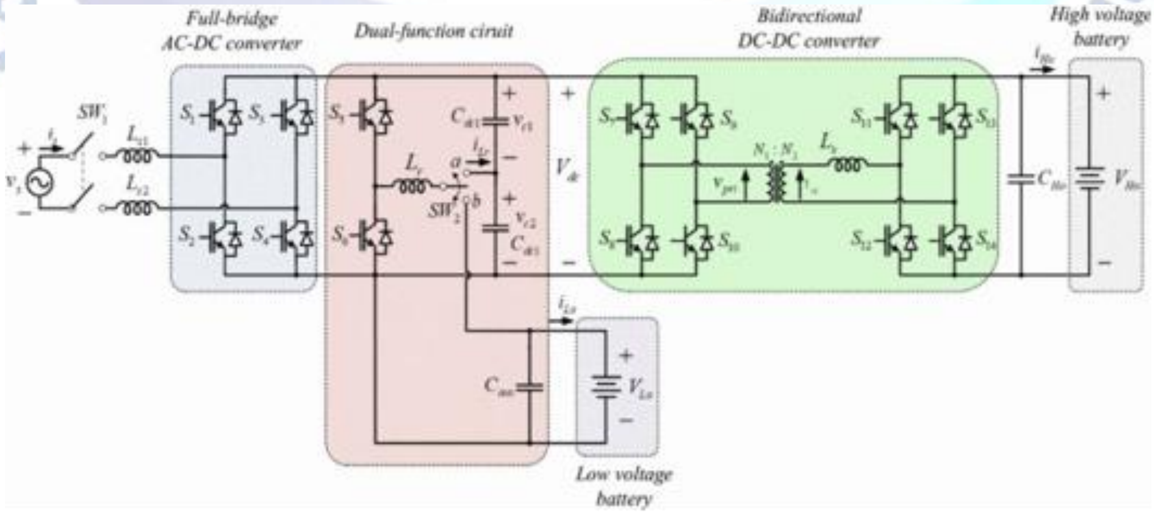

Fig. 3: Multifunctional OBC Approach

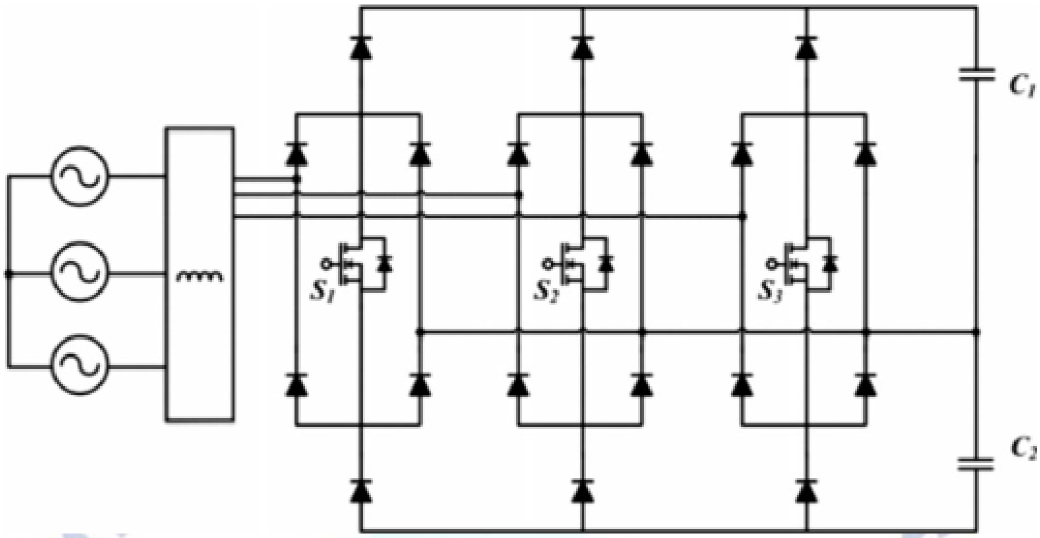

Fig. 4: Vienna Rectifier Configuration

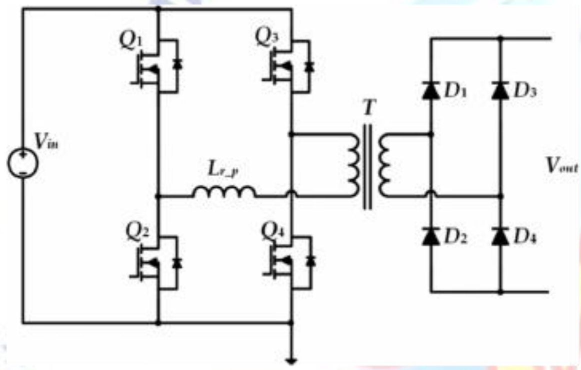

Fig. 5: Full bridge Rectifier with Phase Shift

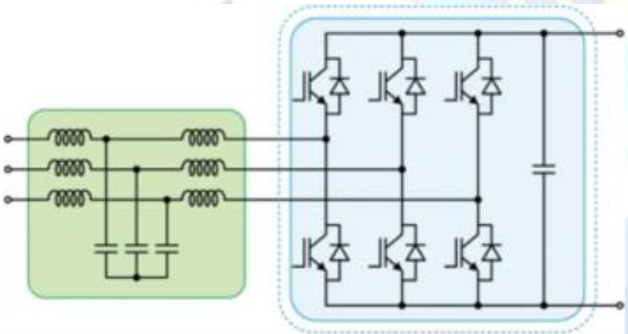

Fig. 6: Three Phase Active Rectifier with LCL interface [26]

D. Fast Charging Technique

With the global prevalence of EVs increasing, there is a need for a charging infrastructure capable of replacing existing oil stations. A fast charging station (FCS) is capable to charge the battery of EV to 80 percent within half an hour of reduction, but to reduce the charging time to 30 minutes from 7–8 hours, FCS require a lot of power from the grid, which is why they are typically linked to the MV system [31-32], although some FCS are proposed to be connected to the LV grid as well [33]. Connecting these charging stations involves a significant capital expenditure and risks overloading the distribution network. Another crucial factor to consider is the voltage drop that the interconnection of FCS may generate along distribution network lines, which must be less than 10% according to EN50160.

According to [34], rapid charging stations' impact on the MV network can be reduced by the implementation of energy storage systems (ESSs), which can reduce peak power consumption and supports extra system functions. Additionally, ESS can boost the level of voltage in the event of an undervoltage in the lines; however, this function requires the deployment of a voltage regulations.

Renewable energies can also be added into the FCS to further mitigate the FCS's grid effect [35]. Solar PV can charge the EV batteries during regular operation, keeping the MV grid from becoming overburdened. Instead, EV batteries can be recharged by the grid at night when solar energy isn't available. There are moments when electric vehicles can help the grid. As a result, the grid's stability will never be compromised by EVs charging at high pulse power.

4. DSM Techniques in EV Connected DS

Electric vehicles must be supplied by the existing distribution network; alternatively, the electrical distribution network must be upgraded by fulfilling critical system requirements. Due to the uncertainty inherent in EV charging / discharging processes, they have a limited impact on the functioning of the electric grid. These uncertainties, combined with a variety of driving behaviors, make it difficult to evaluate the consequences of EVs on the low voltage distribution network with precision. Lack of coordination or haphazard charging of EVs can significantly wreak havoc on the electrical distribution system, resulting in dangerous voltage swings, decreased system efficiency and economy, and an increased risk of power outages due to network congestion.

Demand Side Management (DSM) is the most effective way for mitigating the effect of EVs on the residential distribution grid. The benefits of DSM and synchronized charging of EVs are contingent upon user involvement in load shifting paradigms to accomplish objectives like as reducing peak demand, flattening usage patterns, and improving billing methods. The DSM approach was proposed following the 1973 energy crisis in the United States of America. A three-layer model, consisting of a utility layer, a demand response aggregator layer, and consumers layer, is highlighted in [36] for attaining multilayered DSM foresight. DSM is a critical component of smart pricing because it enables the system to operate efficiently by optimizing electricity usage and minimizing costs by modifying the load curve as illustrated in Figure 7, there are a total of six primary ways for shaping load: load shifting, peak cutting, strategic expansion, and valley filling.

DS integrated with photovoltaic system can be utilized to compensate for energy shortages in the grid. Due to the stochastic nature of sun radiation photovoltaic generating, the power system's frequency and voltage fluctuate. Storage is critical in this setting. EV is utilized as a DSM technique to mitigate solar PV variability [37]. In [38] the residential area is used as a proxy for local users to forecast the energy consumption of families with plug-in electric vehicles one day in advance (PEVs), and the charging expense and discharging revenue of PEVs are unknown across societies. Utilizing a Bayesian game strategy, the optimal scheduling of energy usage amongst communities is achieved.

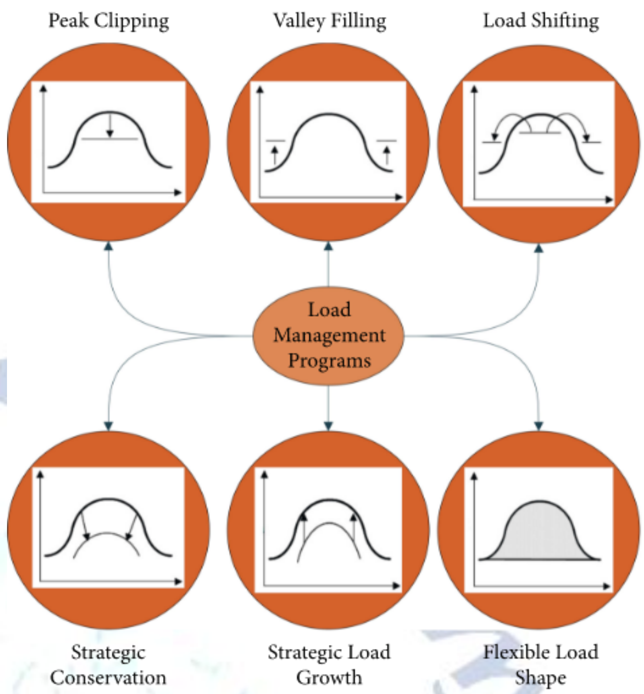

Fig 7: Demand Management Programs

In [39], a DSM technique was developed to alleviate the strain on the DS caused by EVs. The DSM approach is used to prevent the most heinous peaks power. There have been two DSM algorithms proposed. Two states have been defined for the proposed DSM algorithms. Both residential and EV loads are transferred in the first state. Only EV loads are transferred in the second state. While the DSM techniques do not fully charge all of the network's vehicles within 24 hours, they do significantly reduce the total demand on the DS and temperature strains on the live wire.

According to a review of the literature on DSM for EVs, the constraints most usually used are (i) the EV's charge level (ii) the PEV's limitation on discharging and charging (iii) Energy system limitations (iv) Energy battery limitations The DSM methods can be implemented by following approaches:

A. Optimization Algorithms: Numerous researchers have adopted a variety of bio-inspired optimization approaches, including particle swarm optimization (PSO) and its improved technique, genetic algorithm, bacterial foraging optimization (BFO), artificial bee colony (ABC), chicken swarm optimization (CSO), Cuckoo search optimization (CSO), and Hybrid Bat Algorithm cost-effectively achieve a balance between power usage and user comfort [40-42].

B. Time of Use (TOU) Pricing: Rates are defined for each period under the ToU pricing model. It benefits both the utility and the user by lowering total costs, since peak rates are greater and off-peak rates are lower.

C.Game Approaches: The DSM method is developed using a mixed-strategy game to address multi-objective issues of distribution system integrated with EVs.

5. Challenges and Future Trends

This section discusses some of the difficulties raised in recent study and suggests future research directions. The increasing number of EVs will increase both overall load on the system as well as the maximum load demand. As a consequence, the system's overall performance may be affected, necessitating the augmentation of generation capacity. To accommodate a high level of EV penetration, capacity expansion and facility upgrades in current generation, transmission, and distribution systems must be designed holistically, taking both technological and financial benefits into account. The integration DERSs play a vital role in supporting EV demand only when enough care has taken towards synchronization of DERs and its impact on DS performance.

Convenient charging is critical for easing range anxiety on long-distance trips and boosting widespread adoption of EVs. The long-term placement of charging infrastructure within an area determines the number, size, and location of infrastructure required to meet EV charging demand, which is a difficult optimization problem.

Extensive research has been conducted to expand DSM optimization strategies, as illustrated in the previous section; nonetheless, there is still much opportunity for improvement. Customers' resistance to adopting and engaging in DSM programs must be addressed, which can be accomplished through the development of consumer awareness initiatives that encourage consumers to participate in the DSM system.

A substantial amount of study is necessary to accurately assess the charging demand and power demand relationship at the residential level. Apart from power prices, there are a variety of other variables that affect the electricity use of one EV client vs another.

A critical aspect of the DSM challenge is the collaborative approach used by multiple devices. It has the potential to improve stability, power distribution and efficiency by reducing circulating currents. This subject can be researched further.

6. Conclusions

The infrastructure for electric vehicle charging and the timing of EV charging have been intensivelyresearched in recent years from a range of perspectives. This article summarizes published research on EV charging infrastructure and DSM approaches used in DS integrated with EV. The first section of this paper discusses the various topologies of EV charging stations, their power ratings, and characteristics. We reviewed onboard and offboard charging techniques using various power converters. The high-power DC charging station, often known as a fast charging station, is composed of many level converters that have a negligible impact on the DS. The second section of this paper will emphasize the importance of DSM in DS coupled with EV. It discusses several DSM techniques and also consolidates the various DSM approaches identified in the literature survey in order to satisfy multiple purposes. Finally, the article discusses the obstacles and future trends in the subject field, which is beneficial for the researcher and academician.

Acknowledgment

We gratefully thank the Visvesvaraya Technological University, Jnana Sangama, Belagavi-590018 for the support extended to this research work.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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