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Vehicle to Grid (V2G) for Peak Shaving: New Trend, Benefits, and Issues

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Abstract: Use of Electric Vehicles (EVs) or Plug-In Electronic Vehicles (PEVs) has gained the potential attention for traveling and transportation purposes. Since, as compared to the electric potential in transportation systems, EVs have also gained potential and can be transformed in a way to one of the supporting entities for grid systems. With this concept, Vehicle-to-Grid (V2G) is not only supporting the smart grid services, rather it can serve the harmonics reduction, frequency, voltage regulation, peak shaving and valley filling too. The use of V2G technology and its services specifically are used for peak shaving and one of the great concerns. These services offer various environmental, economic and implementation advantages. In this paper, we discuss the existing literature on V2G and peak shaving. In addition, we also discuss the benefits, shortcomings and probable solutions with conclusive findings. This review will help new researchers in the field of V2G for peak shaving.

Keywords: *Electric vehicles, Vehicle -to- Grid, Peak Shaving*

1. Introduction

Conventional sources for electricity generation, renewable and non-renewable have been discussed very extensively in the literature. Conventional sources have harmful effects for the environment, are greater in number or sustain most of our daily electrical load and demands [1, 2]. The renewable energy sources have great potential and rapidly becoming major contributors for the national grid. Furthermore, from the consumers' point of view, our daily use of gasoline and diesel-powered automobiles on the road causes emissions of CO2 gases. Since, these vehicles make up a large number in total, the production and sales of Electric Vehicles (EVs), Plug-in EVs (PEVs) and Hybrid EVs (HEVs) have greatly increased, this has been a major contributing factor to reduce the greenhouse effect and global warming [3-6].

Then again, since all these EVs are battery powered, and consume a great amount of energy, they might become an extra liability for the current grid system in times to come. No doubt, it helps in making our environment better, yet with the increase of electric load, electricity demands would also be elevated. With the inclusion of EVs at a large scale, this can also cause voltage regulation issues, distribution system issue and increase load uncertainties. Further discussing the electricity issues; demand uncertainty, load regulation, peak load forecasting and energy demand forecasting are the few of the electricity issues to mention. The energy demands are increasing day by day and so is the peak demand. To cater the issue, not only a stronger distribution and generation system is required, rather it should be efficient and intelligent one in order to consume all the sources to the optimal level. Hence, only by using conventional energy sources, all the energy demands cannot be addressed. It is necessary to inculcate renewable energy sources and use them effectively. By doing so, not only the issue of voltage regulation can be addressed but also, the load demand profile can be softened making the energy demands bearable for the grid system [7, 8]. For all, the renewable energy sources, have issues of their own. Their power production is highly uncertain and is very much environment/weather dependant. Also, their solutions are costly, taking when battery bank is added in the solution. Batteries add up much of a price to the overall solution too as well as require maintenance with replacement after some time. Adding a large battery backup system, speaking of having a gird level backup system, is clearly not feasible.in addition to that, charging these bulk of batteries is again an issue.

One feasible solution includes, using the batteries of EVs already there on the road for storage of electricity and suppling the stored energy back to the grid at the time of peak load, in turn softening the load curve. Addressing the issue of EVs being an extra liability for the gird, the charging of these EVs is aimed to be done via renewable energy sources. For instance, through the solar panels, installed in the parking lot where all the vehicles are parked. During the day, when a peak demand is forecasted, the energy stored in these EVs can be extracted and supplied to the grid. Benefits offered by this technique include; cost effectiveness, less CO_2 emissions and improved efficiency [9, 10].

Despite their advantages, integrating EVs with the gird has its own challenges. For peak shaving purposes, their possible challenges are as follows:

1. EV availability is a great challenge. As only then, energy can be extracted from their batteries is when they are parked and yet, EVs have not been widely deployed.
2. There is a requirement to have controlled and monitored discharge operation from many EVs. Although, there lies a natural reluctance for the vehicle owner to allow the extraction of energy.
3. As the grid is not available everywhere, there can be a challenge to deliver the energy extracted from the EVs to the grid, covering a lot of distance. This can cause power loss and a decline in overall system efficiency.

Extending the discussion on the idea, many techniques, solutions and modelling have been explored in the literature against the idea of Vehicle to Gird (V2G), as mentioned above. As stated in the literature, EVs consume less than 5% for transportation purposes, hence there exists quite a bracket to use these storage devices for other purposes too, such as providing abrupt power the grid. Also, these EVs can be the solution for grid issues, for not only peak shaving, but also for valley filling, frequency regulation and voltage regulation.

2. Literature Review

Regarding V2G for grid services, there lies an extensive application, modelling, case studies and obviously simulations. Many have addressed the effective and efficient uses of V2G and its services covering reviews, voltage regulation, valley filling, softening of load curve, peak shaving, frequency regulation, reactive power compensation and even, acting as a spinning reserve.

For the V2G systems to be implemented, there exist many control schemes in the literature. Generally, the control can be centralized and decentralized as mentioned by N. Erdogan et.al [3]. For the centralized control scheme, the aggregator is responsible for the determination of discharging points for each PEV. For this control scheme, a bidirectional communication and data takes place to decide the direction of power flow i.e., from V2G to grid and vice versa. Taking about the decentralized control scheme, the PEV is independent to decide its discharging scheme. The decentralized scheme has its own advantages in terms of implementation ease and improved user convenience. Figure 1 shows a typical centralized and decentralised control scheme as mentioned in.

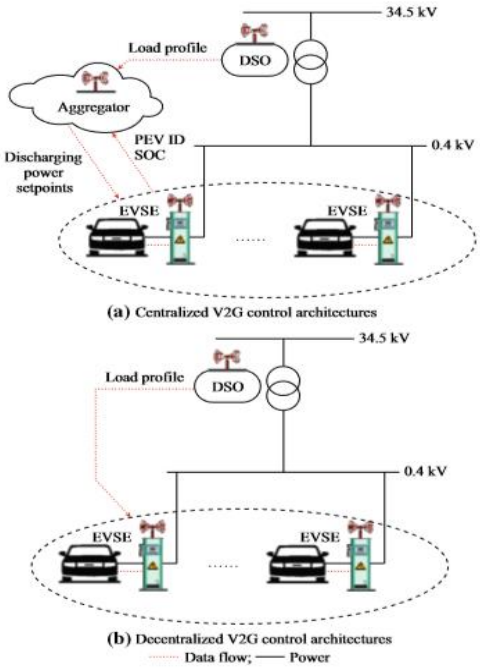

Figure 1. Centralized and Decentralized Control Architectures

With mathematical formulation, [11] discusses possible scenario of V2G implementation within in regional smart grid. Being an optimization problem, double layer optimal charging has been proposed to reduce computational complexity due to the increase in scale of PEVs and charging posts. For the possible scenarios, it discusses the following ones:

1) Recording the Charging Posts

To have a record of the charging posts (CP) being available or not and being public or private for that matter is necessary.

$$CP = [CP_{ID}, CP_{LOC}, P_{CP}^{max}, Flag] \quad (1)$$

CP_{ID}, identity number of CP,
CP_{LOC}, location of CP,
P_{CP}^{max} , maximum allowed power,
$Flag$, being public or private CP (0 or 1)

2) Registering PEVs

$$EV = [EV_{ID}, EV_{Mod}, BAT_{typ}, BAT_{cap}, SOC_{upper}, SOC_{lower}] \quad (2)$$

EV_{ID}, identity number of PEV,
EV_{Mod}, model of PEV,
BAT_{typ} ,battery type installed,
BAT_{cap}, battery capacity,
SOC_{upper} , allowed upper limit of battery SOC,
SOC_{lower} , allowed lower limit of battery SOC

The central control centre (CCC), should also have an idea of type of PEV being connected. For every PEV involved, CCC creates a data set of each as mentioned in (2).

3) Proposing request for joining V2G Operation

To model the request generated by EV to join the V2G operation, following information factors have been considered:

- Estimated latest moments of EV connection and disconnection from grid respectively.
- The charging post location at which the EV will be connected to.
- Estimated battery SOC, when it will be connected to the grid.
- Required battery SOC, when the EV will be disconnecting from the grid.

4) Request confirmation and data preparation

Right after the EV owner submits the joining request, an attempt is made to include the EV to the charger post by CCC based on availability of a vacant post. Then a data set is created based on time allocation to each post with the desired allocation plans.

Pinto, et al. [12] represents a bidirectional charger for V2G and Vehicle to Home (V2H) application. When connected with the gird, the charger enables an exchange in energy amount PEV and grid. For the case when PEV is connected to the gird, the charger uses the energy to charge the batteries, although they don't use it as a permanent energy storage device. In the case, grid requires excess energy, the charger converts the batteries as voltage sources and delivers the energy back to the grid. As mentioned earlier, the V2G system is designed to be economical, [13] focus on the same motive. It presents an estimation mechanism to enhance the flexibility of the system which further assists in developing a contract between the grid operator and aggregator, also estimating the profit margin.

To make the solution further eco-friendly, [14] F. Fattori focuses on methods through which PVs and EVs can coexist and supply energy to the grid. The solution is to use both smart charging and V2G concepts with the inclusion of linear optimization model named, Electric Vehicles Learning Static Model. Considering EV and V2G constraints with vehicle requirements and load demands, has presented a control algorithm for peak shaving and valley filling. Further analysis over the constraints have been conducted using computer simulations. The literature concludes the findings by commenting as if the availability of EVs is substantial enough, other peak shaving and valley filling techniques can be exempted and V2G system can single handedly serve the purpose and energy demands. For a few additional constraints mentioned in the research by Z. Wang and S. Wang [15], they have been mentioned as follows:

Constraints on the power of EVs which are involved in V2G will be:

V2G will be: (3)

$|y_i(t)| \le a_i \qquad a_i > 0$

$|y_i(t)| \le b_i \qquad b_i < 0$

$$|y_i(t)| \le |z_{i(t)} - x_{i(t)}|$$

Where,

a_i : total charge available from grid
b_i : total discharge available from EVs
$y_i(t)$: Available power for peak load from V2G
$z_{i(t)}$: target load value
$x_{i(t)}$: forecast load value

Constraints on power of EVs will be:

$$0 \le C_{ij}^c \le C_{cm}$$
$$0 \le C_{ij}^d \le C_{dm}$$
$$-I_{cm} \times V_{ij}^c \le P_{ij} \le I_{dm} \times V_{ij}^d \qquad (4)$$

Where,

j : vehicle code
C_{ij}^{c} : charge ratio
C_{ij}^{d} : discharge ratio
C_{cm} : available maximum charge ratio
C_{dm} : available maximum discharge ratio
V_{ij}^{c} : charge voltage
V_{ij}^{d} : discharge voltage
I_{cm} : charge current within maximum charge ratio
I_{dm} : discharge current within maximum discharge ratio
P_{ij} : available power of EV

Constraints on battery pack capacity of EVs will be:

$$\Delta Q_{ij}^{max} = (SOC_{max} - SOC_{min})Q_e$$
$$0 < \Delta Q_{ij}^{c} \leq (SOC_{max} - SOC_{ij})Q_e$$
$$0 < \Delta Q_{ij}^{d} \leq (SOC_{ij} - SOC_{max})Q_e \quad (5)$$

Where,

ΔQ_{ij}^{max} : maximum available capacity of battery pack
SOC_{max} : maximum value of SOC
SOC_{min} : minimum value of SOC
Q_e : rated capacity of EV battery pack
SOC_{ij} : real time capacity state
ΔQ_{ij}^{d} : available discharge capacity at SOC_{ij}
ΔQ_{ij}^{c} : available charge capacity at SOC_{ij}

Constraints from the user as set parameters will be:

$$SOC_{min}^{'} \leq SOC_{ij}^{'} \leq SOC_{max}^{'} \quad (6)$$

Where,

$SOC_{min}^{'}$: lower limit of SOC set by user
$SOC_{max}^{'}$: upper limit of SOC set by user

With the inclusion of EVs in the general market and with an increase in their use by the masses, it is expected to have an increased electrical load demand. For the very same purpose, [16] analyses the merits and demerits of the deployment of EVs for V2G system. The concerned literature also mentions different charging strategies for EV batteries and their impact on electrical distribution networks. It further mentions that the economic benefits of V2G system greatly depends in the charging/discharging strategies. The benefits include, cheaper electricity, less voltage variations and load surges with better stability, efficiency and reliability of distribution network.

Addressing the same perspective, as mentioned in [16, 17] proposes an energy management system for intelligent car parking area. The system proposed is claimed to be able to control the charging & discharging of many EVs. Multiple constraints and customer preferences have also been taken in account in the literature. Constraints include, battery charging limit, arrival and departure time of vehicle, desired charging and discharging price. With the inclusion of V2G system, EV's owners can generate revenue as a by-product too. With the same objective to address, i.e. charging/discharging control scheme, as in [17, 18] does the same but with the following problems in view:

- Variation and stochasticity in the load demand
- Conflict between EVs charging demand and provision of service for regulation
- Privacy issues occurring due to the scheduling of EVs

In the mentioned literature, the above three issues have been addressed with real time control of EVs. Yilmaz and Krein [17] comprehensively review the possible impacts of V2G systems on multiple distribution systems and utility interfaces. The literature covers a wide range of factors regarding V2G and its applications such as its technological requirements, costing, current and expected challenges with strategies for both individual PEVs and PEV fleets. Major contributions by the authors include a wide range of V2G concepts with services and benefits, components and current technologies covering power flow and finally, charging/recharging strategies. Authors in [17] mention the charging and discharging of EVs and their type of connection, i.e. being unidirectional or bidirectional, depends on multiple factors such as:

- Geographical location
- Number of EVs connected in a specific region
- Their charging currents and voltages
- Instantaneous battery status and battery capacity
- Duration of battery charging

Authors conclude that factors such as impact of EVs, emission benefits and economic costs greatly depend on the way the charging and discharging of these EVs is done. Without a controlled circuitry/system they just charge and discharge like any other load. For when the same process is performed using smart charging and coordinated charging, it greatly reduces the negative impact battery has on the grid as a load, can help the shifting of load, load peaks can be avoided and most importantly benefit the EV owners in terms of returns.

Other researchers such as [19] have focused on supplementary frequency regulation (SFR) keeping the EV charging demand in preview. For large number of EVs to be connected, an aggregator is required for control. It communicates with automatic generation control (AGC) and EV charging stations for the matter. For the EV aggregator two aspects are taken in account (Figure 2):

- Calculation of total Frequency regulation control (FRC) & V2G power
- Finalizing a V2G strategy as per regulation requirements, demanded from EV stations.

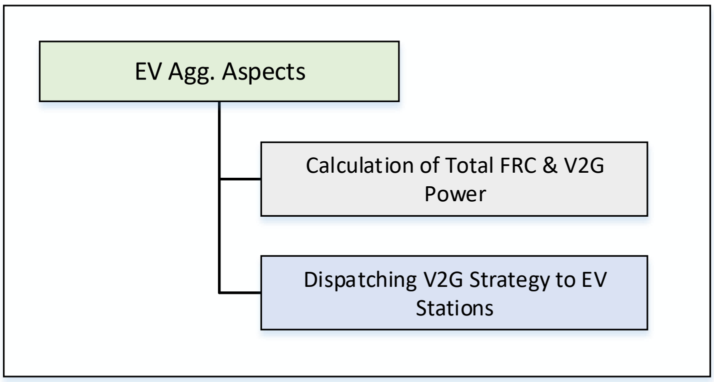

Figure 2. Considered Aspects by EV Aggregator

Liu, et al. [19] have proposed both methods and strategies for both aspects with modelling done as per the practical interconnected grid system in China. Following have been their proposition outcomes:

i. The fluctuation of area control error (ACE) and frequency in the system has greatly been reduced.
ii. Effective control and regulation of up/down tasks can help maintain the desired battery state of charge (SOC) requirements.

Quoting another review paper in [9] author reviewed smart gird integration with EV. They extensively discuss the correlation between smart grid and EVs as to enable EVs to contribute to the gird and its services, advance communication, smart metering and effective control system is required. Although there are promising results mentioned in the literature showing reduced battery degradation with Lithium ion (LFP) batteries, yet still the topic is a matter of great concern and further research in the domains of battery lifetime extension and cost-benefit analysis is very much required, as suggested in the concerned review paper.

Integration of renewable energy with EV is an aspect and application discussed for long [9]. The use of renewable energies today has won the vote of many due to the production of clean energy. Yet these renewables are not yet treated as a sustainable source of energy due to electricity production unpredictability. Our cent percent energy cannot be relied on these renewables as they are totally dependent of environmental and weather conditions themselves. Yet, integration of these sources such as wind and solar, with EVs can be an intelligent solution. The excess energy produced by them can be stored in PEVs and then be used for peak load shaving and valley filling.

2.1 EVs Integration with PV Solar Energy

Production of energy through solar has been very popular since the late 1800s and still today, the efficiency of solar cells is being done via latest technology. Solar panels are now a day, found connected in the form of arrays to provide electricity in abundance. With the integration of EVs, they are most likely to be used for charging and grid supporting purposes. A very common example of such is the use of solar panels in wide and spacious parking lots.

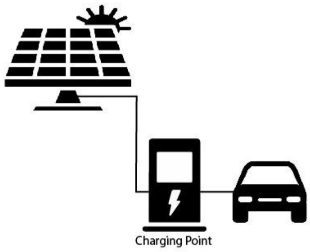

Figure 3. Solar Panels for charging EVs

A major benefit these solutions offer, is the reduction in CO2 emissions, which in turn slows down the overall greenhouse effect. The past literature has produced reviews, cost benefit analysis, generation scheduling schemes, investigation of large PV penetration with PEVs and even designing of bi-directional converter [20, 21], presenting the benefits of integration a renewable energy and storage source. Clearly, rather than developing large and costly battery banks to store the excess solar power is not a feasible and economical solution at grid level.

2.2 EVs Integration with Wind Energy

Like PV, wind energy is another renewable energy source that has been the attention of many due to its inherent feature of producing clean energy. Talking in terms of integration of wind energy production and PEVs, the applications and literature is somewhat the same as that of solar energy. Frequency regulation, comparative analysis of isolated power grid, use of EVs to provide regulation with wind energy and assessment of wind and EVs for a viable use for the gird, are a few of the researches done in the literature lately.

Table 1. V2G Services & Contributions

Issue Discussed	Proposition/Methodology	Ref	Contribution/Research Outcome
Exploration of Energy Management Techniques for PHEV	Dynamic programming for cost-consciousness. State independent four-threshold feedback policy for reduction of computational complexity.	[5]	Optimal PHEV charging scheme for load flattening.
Reduction of cost and emissions in the presence of wind & PV for MG	EVs for peak shaving and responsive loads for compensation of wind & PV uncertainties.	[8]	• Simultaneous scheduling of EVs and responsive loads. • Presentation of two stage model for calculation of expected costs.
Feasibility of V2G implementation with smart grid	Double Layer Optimal charging (DLOC) strategy to solve computational complexity.	[11]	A comparative study confirming the effective impact of DLOC
Hardware Design of Bidirectional charger	Buck and Boost conversion • G2V Operation mode • V2G Operation mode • V2H Operation mode	[12]	Development of a bidirectional charger with simulations and operation mode based results.

Estimation of sizeable profits based on capacity estimation of V2G system	Queuing network and smart charging mechanism	[13]	• Queuing network model for V2G regulation services • Regulation of various contracts by the separation of Regulation Up/Down ques • Designing smart charger for EVs
Integration of PV, EVs, Smart Charging and V2G	A comparative analysis of uncontrolled and controlled charging under smart charging and V2G	[9, 14]	• High penetration of EVs under uncontrolled charge can increase the load peaks • Flexibility can be experience under smart charging in the presence of non-mouldable generation technology
Impact & Charging Techniques Analysis of EVs over distribution Networks – Review	NA	[16, 17]	• Smart metering and intelligent communication required for effective V2G implementation. V2G does have an impact on battery life, yet is economical for end user. • Smart charging/discharging lessens daily cost and improves technical performance
Improvement of energy management systems for EVs parking lot	Optimization done under system constraints and weighing factors with customer useable requirements	[18]	New controllable energy management system for charging/discharging of large number of EVs considering system constraints & end user preferences
Dealing with variation in regulation demand. Assessment of potential conflicts between EVs charging requirements and load regulation services	Multi-level Architecture for V2G	[22]	Control the power variation of the grid during coordination mode.
With respect to given charging demands, V2G for SFR	Area specific simulations and modelling done for V2G strategy effectiveness and control.	[19]	• V2G strategy proposed to dispatch regulation commands from aggregator to EV charging stations. • Proposition of FRC calculation method considering frequency regulation and charging demands

In this paper, we aim to present a review over the contributions V2G can offer for the distribution grid in context of peak shaving.

3. Vehicle to Grid for Peak Shaving

This section reviews the problems with using V2G as a mode for peak shaving with its use and effects of V2G technology. We have mentioned the methods and solution techniques present in the literature.

3.1 Benefits of Peak Load Shaving

The benefits of peak load shaving extent beyond the cost benefits. Generally, their benefits can be categorized into three main groups i.e., benefits for grid operator, end user and lastly reduction in carbon emissions. For the grid operator, an improved power quality is first and foremost benefit peak shaving has to offer. The issue of balancing power generation with load demand has been an issue since day one. In a scenario when demand increases by the electrical generation, it increases the stress on the overall grid system and in worse scenarios can result in a total blackout. Different peak shaving techniques generate an efficient load demand profile which ultimately improves the power quality.

With the peak electrical loads reduced, the percentage of load factor also increases making, cost per unit of electricity cheaper. Since, the demand profile is made sustainable, the overall load on the transmission and distribution system also reduces. This in-turn reduces the I2*R losses, increasing the system's efficiency. For the end user, participating in V2G system will result in financial compensation in terms of electricity cost reduction. The most benefit the end user will experience will be during the peak hours of energy demand due to high electricity cost for that specific time interval.

With a reduction in the use of conventional power generation plants due to the inclusion of V2G technology, the peak demands will be deduced hence, the burning of fuel will be reduced too. The emission of harmful gases will greatly be reduced to make the environment better.

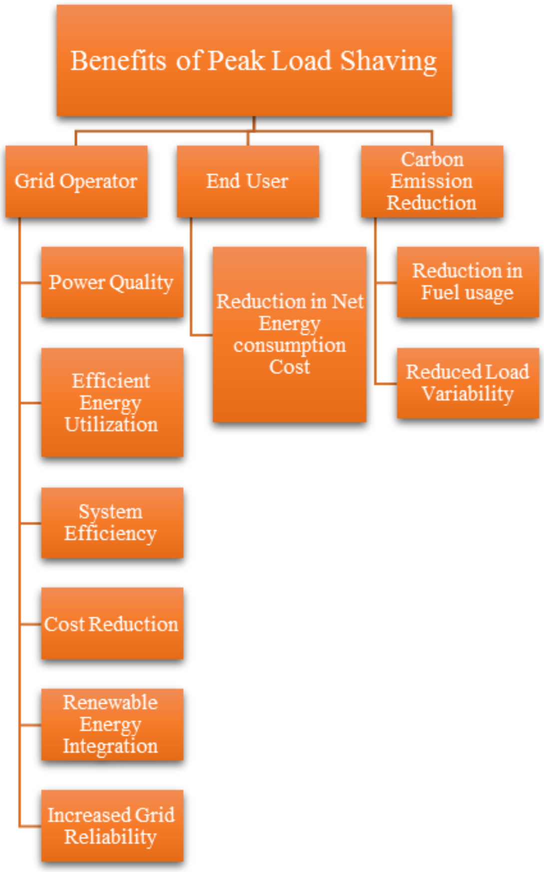

Figure 4. Benefits of Peak Load Shaving

3.2 Benefits of V2G for Grid System

V2G technology offers its advantages especially when it comes to grid support as discussed above. To highlight a few, are enlisted as follows in Figure 5:

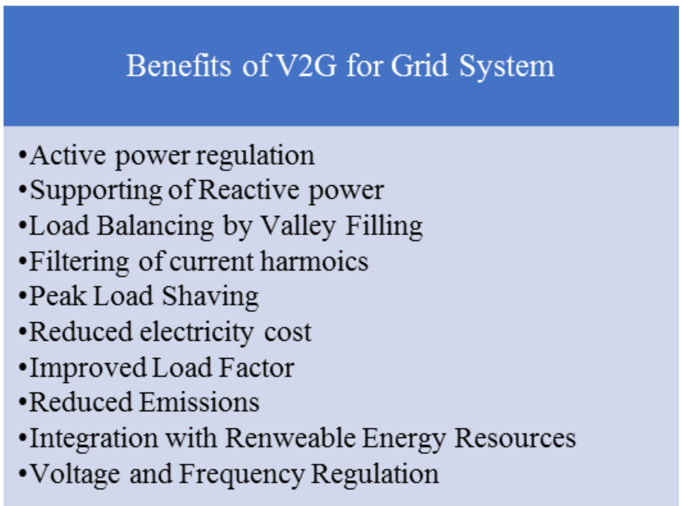

Figure 5. Benefits of V2G for Grid System

3.3 Current Issues – V2G Implementation for Peak Shaving

Using V2G technology for peak shaving does have benefits including cost effectiveness and being environment friendly. Yet it has some shortcomings too as discussed below.

The effective performance of peak shaving algorithms greatly depends on the number of PEVs connected to the system along with other factors. Also, their attachment and detachment are highly unpredictable making it mandatory for the implemented system to have dynamic, efficient and smart charging/discharging of PEVs. Synchronizing the charging and discharging of a large number EVs is an issue.

Battery life degradation is yet another issue for V2G technology. As PEVs will serve their role as grid supporting entities too, their conventional use will exceed beyond it. Therefore, their charging and discharging will greatly increase causing a possible issue of their early degradation and decline in performance.

3.4 Proposed solutions and techniques in present literature

In literature [1], the battery capacities have been used to ensure effective peak shaving. That has been done by ensuring, proper communication and coordination with respect to load profile and PEV battery characteristics, connected to the grid. The optimal solution has been established by first assessing the performance of proposed algorithm and then a two staged control V2G scheme has been presented. The proposed two staged control as mentioned in [3] has been described as follows:
The first stage involves estimation of required level of peak shaving and the time for V2G service based on forecasted data. While the second stage involves the calculation of discharging rates for PEV batteries based on battery capacities and load profile level.

Making peak shaving and active power losses minimization as the main constraints, [23] presents a model-based solution for charging and discharging management of PEVs. The authors have also taken in account many other issues in their proposed model such as daily load variations, per hour variation in electricity prices and different PEV penetration levels. To make matters user friendly for the end user, the proposed model also presents three charging and discharging time zone schemes namely Red, Blue, & Green time zones (1800-2200HRS;2200-0100HRS;0100-0800HRS respectively). Being somewhat similar to [15, 23] presents V2G control algorithm for peak shaving and valley filling with an objective function considering main constraints. In the under-discussion literature, following constraints have been taken in account:

- EVs' net power available for V2G system
- Two-way current direction control for EVs
- Capacity of each EV's battery pack
- User requirements and needs

An effective utilization of PEVs' batteries is very necessary as their use is most beneficial at the middle section of peak demand as compared to its significance at the beginning and ending sections [24]. Peak shaving index (PSI) is a quantitative measure that takes in account of battery capacity, power demand and duration of power demand give the PEV an estimation for how much deficient load is to be supplied.

4. Conclusions

With the advancement in automobile industry, the use of vehicles, especially electric vehicles, has grown beyond transportation. It is possible today, EVs can participate in contributing and serving as an energy reserve for the distribution gird system. Vehicle-to-Grid technology has its own advantages covering a wide range of. From frequency harmonics reduction to compensation of power deficiency, V2G technology proves to be energy efficient, emission free and cost-effective solution for both, the grid operator and PEV/EV user. Although there are few short comings and research challenges it still, V2G still serves to be a promising solution for the years to come. Particularly for peak shaving applications, V2G system is one cost effective solution. The main attraction to the suggested solution is financial benefit to the EV/PEV owner. The owner can meet the most out of his vehicle during peak hours. In-turn, the grid system faces lesser stresses, voltage and frequency regulation issues. To the issues regarding application of V2G systems as a solution for peak shaving, there exist feasible, practically possible and effective solutions, hence voting in the favor of it as a possible solution.

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