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A Review on Charging Strategies of Plug-in Electric Vehicles

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Abstract—The Charging and Discharging strategies and optimal scheduling of Plug-in Electric Vehicles (PEVs) are very active area of research in which several hundred papers are published each year. The main goal of this area of study is to optimize the charging and discharging of PEVs in a way to reduce the power losses on the power grid, and reduce total operation cost. These studies have developed several techniques for optimizations, and they have proved that the coordinated charging and discharging have many benefits to the power grid, aggregators and PEV owners. While the uncoordinated charging may cause severe problems to the grid such as increasing the peak demand, increasing the power losses and operation costs, increasing voltage deviation, reducing grid stability, and it may overheat transformers and could destroy them or reduce their lifetime. This paper gives a general review on the domain of charging and discharging strategies of PEVs, their advantages and barriers; optimal scheduling; different types of charging rates; different pricing mechanisms; different management techniques; different optimization techniques, their main objective functions and constraints; and many others.

Keywords-*Charging and Discharging Strategies; Coordinated charging; Optimization Techniques; Electric Vehicles; Power Grid.*

I. NOMENCLATURE

PL/CS: Parking Lot or Charging Station for charging and discharging PEVs
PSO: Power System Operator, also called utility,

II. INTRODUCTION

A. Motivation and Background

The world is encountering a reduction in fossil fuel reserves for the next few decades, the worldwide production of oil is expected to expire in 53.3 years, the natural gas in 55.1 years, the coal in 113 years [1]. The energy consumption is increasing each year [2], and the CO2 emission is also increasing [2], 32.190Gt (Gega ton) of CO2 are produced in 2013, compared to 15.515Gt in 1973 [3]. The global temperature of Earth is increasing each year and it is predicted to rise to 3.6^{0}C by 2040 compared to 2014 [4].

The fuel oil consumption in transportation sector overpassed 63.8% in 2013 with respect to the whole consumption in the world according to IEA [3]. The natural gas consumed by the transportation sector overpassed 6.9% in 2013 [3]. While the electricity used for the transportation sector didn't reach 1.5% in the whole world, which is negligible compared to the oil consumed in the sector [3].

All these reductions in the worldwide reserves have encouraged researchers, organizations and governments to shift their source of energy to renewable energy sources such as wind, solar, geothermal, etc. And to introduce Electric Vehicles (EV) as an alternative solution to the Internal Combustion Engine (ICE) which is used in most of the vehicles. The share of renewable sources in total power generation is expected to rise to 33% in 2040 [4], and the market production and demand of EVs are increasing every year, they have reached 740,000 vehicles in 2014 [5], and it is expected to reach 20 million EVs in 2020 according to IEA [6].

The utilization of EVs has many benefits, the most important ones are: they support the penetration of renewable energy sources which is the future of smart grid [7-33], [34], [35], [36], [37], [38], [39], reduce the consumption of fossil fuel [40], [41], [42] and reduce the emission of harmful gases such as CO2, NOx, SO2, etc [43], [12], [24], [39], [37], [41], [44], [45], [46], [47], [48], [42], [40], which have bad impact on the nature and the public health, they are considered as small portable power plants [49], and they provide power regulation to the grid [32], [31], [50], [51], [12], [52], [41]. Therefore, many studies have been done to integrate electric vehicles into the power grid in a healthy way, in order to benefit from their integration. It is important to mention that the uncoordinated penetration of EVs may cause several problems to the power grid, therefore, many studies have been done to control the penetration of many EVs into the power network, which will be discussed in this paper.

Beside the many advantages of PEVs, they have also limitations such as: (i) Chargers without state-of-the part power electronics may inject harmonics into the power grid [53], [41], [54], [55], [56], some institutions provide standards to limit the harmonic injection such as IEEE [57], [58], SAE [59], and IEC [57], [60]; (ii) PEVs are facing resistance from automotive and oil sectors [61], [41]; (iii) Current and/or voltage three phase imbalance for all strategies except if they applied phase switching which is presented at the end of this paper [62].

B. Literature review

A Plug-in hybrid Electric Vehicle (PHEV) consumes energy from two sources, the fossil fuel, and the battery, while the Full Battery Electric Vehicle (BEV) is supplied only by a battery which can be charged from the power grid [63]. In this paper, both types are lumped together with Plug-in Electric Vehicle (PEV). PEVs are connected to the grid the most of the time in a day, over 90% [64], [65], [31], [49]. PEVs reduce

CO2 emission and other harmful gases compared to conventional Internal Combustion Engines (ICE) vehicles [66], [40], [67], [40], they improve the noise levels and the urban air quality [40]. Paper [40] [49], [68] has demonstrated that PEVs charged from conventional power plants such as coal-based plant, are producing more CO2 and harmful gases compared to a normal ICE vehicles, hence, the penetration of PEVs should be followed by the integration of renewable energy sources, hydropower plants, and nuclear plants in order to reduce the emission of such harmful gases. It is important to mention that the advantage of the PEV over the ICE cars is that the efficiency is much higher in which the fuel/electricity is transformed into mechanical works. The charging of PEVs could be done at home [69], [70] in a Charging Station (CS) [71], [72], [73], private or public Parking Lot (PL) [74], [75], on the side of roads and highways where chargers are located, etc [69], [70].

A PEV can have a unidirectional charger in which it can absorb energy from the power grid but it can't inject energy into the power grid [70], while a PEV with bidirectional charger can absorb and inject energy from/to the power grid [41]. Researches demonstrated that coordinated smart charging/discharging of PEVs is much more efficient than uncoordinated charging [76], [40] and the used optimization techniques reduce the power losses on the power grid, and reduce the operation cost of the whole system, in addition, aggregators such as Parking Lots (PL), Charging Stations (CS), and Power System Operators (PSO) also called Utilities, and individual PEVs are benefiting from these coordination [41], [43], [77], [78], [79], [80], [81], [82], [83], [70], [84], [85], [86], [87], [88], [47], [89], [90], etc. Coordinated smart charging/discharging minimize the PEV impact on the power grid [41], [61], [67], [91], [37]. PEVs can be also used to support the integration of renewable energy sources such as wind turbines [38], and solar power plants, and mitigate the variability of these resources in order to reduce their negative impact on the power grid [7-33], [34], [35], [36], [37]. The PEVs are used to reduce the consumption of CO2 and harmful gases [24], [48], [39].

The uncoordinated charging may affect negatively the power grid even with small penetration level [92], while a high penetration level using coordinated charging may not affect it negatively [69].

Tesla Motors suggested a battery swap (also called battery exchange) technology in which the PEV can swap its depleted battery with another one with high SOC for a few seconds [93], [94], but this technology wasn't interesting to many of its clients, therefore, it was stopped [95]. Other papers discussed the same topic [96], [97].

Many review papers were done on the impact of the integration of PEVs on the power grid [45], [41], [56], other review papers were done on the battery charger topologies [56], others on the charger power levels [56], others on the infrastructure for PEVs [56], others on the unidirectional and bidirectional chargers [56], and power flow [41]. Some papers mentioned the charging strategies but they are not detailed and lack of important definitions and information [56], [41], others on the optimal scheduling methods [45]. There are lack of information in these review papers in which (i) a complete list of different charging and discharging strategies of PEVs doesn't exist, (ii) the advantages and barriers of each strategy are not described completely, (iii) the different type of charging rates are not mentioned, (iv) the pricing mechanisms for PEVs are not mentioned, (v) the papers mentioned few optimization techniques which are used, while other important techniques are not mentioned, (vi) there are hundreds of different methods of charging and discharging and most of them are not related to each other's, therefore, it is suitable to put them into strategies in order to facilitate to the researchers how each strategy works and what strategy should be chosen in his study, (vii) there are different charging rates used for the charging/discharging schedules, therefore it is important to categorize them in order to show the readers what kinds of different charging rates are used.

Hence, it is suitable to write a review paper that treats in more details the types of charging and discharging strategies and much other important information that help researchers to find pertinent data and methods for their studies. All these information will be studied in this paper.

C. *Contributions*

The contribution of this review is that it gives a general view on (i) different charging and discharging strategies, their definitions, their advantages and barriers, and categorizing them into many different categories, some categories are newly defined in this paper, (ii) different optimal scheduling, and optimization techniques used for PEVs are defined, their main objective functions and main constraints are also presented which will help the reader to choose on which problem he should work, (iii) different charging rates are newly categorized and defined, (iv) different pricing mechanisms are defined, many of them are not used in the PEVs in which this paper recommend to use them for future work, (v) different management techniques are defined. Moreover, future works and recommendations are presented at the end of each section in which the authors give their recommendations and propose future works which may help the development of new methods and improve the research in the domain.

D. *Paper organization*

Section 3 presents a literature review of the different charging and discharging strategies, their advantages and barriers, different charging rates used for PEVs and their standards, pricing mechanisms, Energy management, unidirectional or bidirectional power flow regulation, optimization techniques and their objective functions and constraints, mathematical model of the arrival and departure time and SOC, and finally the impact on the infrastructure. Section 4 presented different phase strategies for charging. And finally a conclusion is presented in section 5.

III. LITERATURE REVIEW ON OPTIMAL CHARGING AND DISCHARGING STRATEGIES

Many papers have only studied the charging mode, and many others have studied both charging and discharging modes. A detailed classification of these studies doesn't exist in the literature to the best of the authors' knowledge. Therefore, it is found suitable to classify and categorize these papers according to many criteria as described in the following subsections.

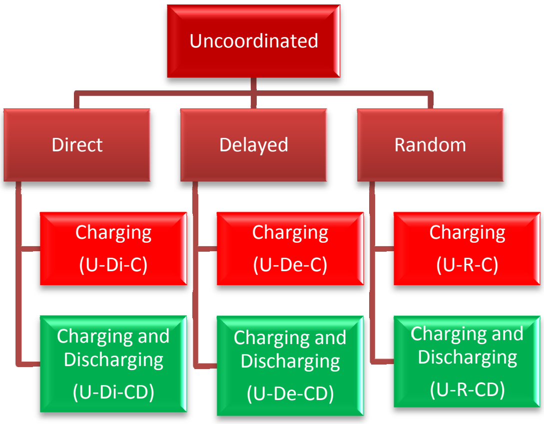


Fig. 1: Different Uncoordinated Charging Strategies.

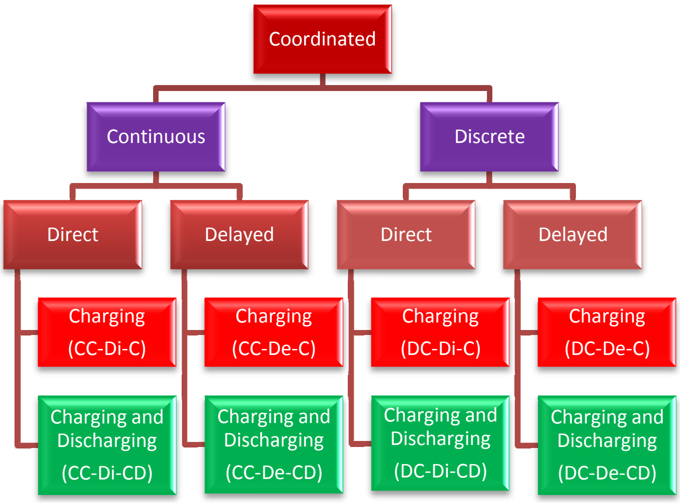


Fig. 2: Different Coordinated Charging Strategies.

A. Uncoordinated Charging and discharging

A.1. Strategy 1: Uncoordinated Direct Charging

Uncoordinated Direct Charging (U-Di-C) is defined as the charging process (also called mode) of a single or a fleet of PEVs which are automatically charging when they are connected to a Power Grid (PG) until they are fully charged or disconnected (Fig. 3). The charging mode is done without schedule or even without taking into account other users on the same bus, and without following a pricing mechanism. Some papers studied this strategy and compared it to other strategies such as [98], [78], [82], [83], [99], [100], [63], [63], [70], [40], [101]. The impact of this strategy is presented in Table I.

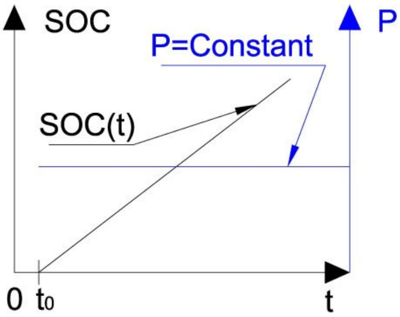


Fig. 3: The PEV is plugged-in at time t_0, and the charging mode starts at the same time, the charging rate could be constant or variable.

A.2. Strategy 2: Uncoordinated Direct Charging and Discharging

Uncoordinated Direct Charging and Discharging (U-Di-CD) is defined as the charging and discharging modes of a single or a fleet of PEVs which are instantly participating in the charging and discharging modes when they are connected to the PG until they are fully charged or disconnected (Fig. 2). Since it is subjected to the owners' desire, they are charging and discharging independently without any coordination between them. The impact of this strategy is presented in Table I. This strategy has not been studied yet to the best of the authors' knowledge.

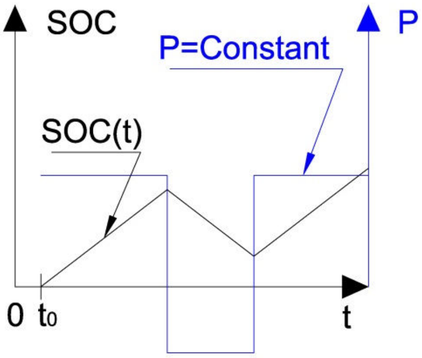


Fig. 4: The PEV is plugged-in at time t_0, and the charging mode starts at the same time, the charging rate could be constant or variable.

A.3. Strategy 3: Uncoordinated Delayed Charging

Uncoordinated Delayed Charging (U-De-C) is defined as the charging mode of a single or a fleet of PEVs which is delayed for a certain period of time (i.e. the charging is delayed to the off-peak period, usually to the evening) when it is connected to a PG until PEVs are fully charged or disconnected (Fig. 5). The purpose of this delay is to reduce the charging during on-peak time and charge the PEVs during off-peak time. But the charging coordination between different PEVs is not implemented, thus, it may create another peak during off-peak time. Therefore, it could have negative impact on the PG as stated in Table I. some papers studied this strategy such as [99], [102].

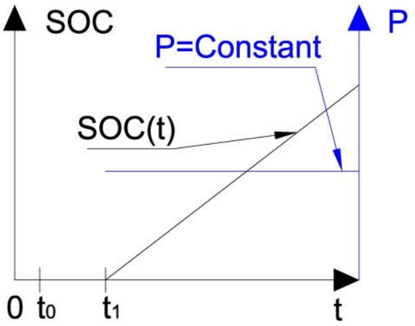


Fig. 5: The PEV is plugged-in at time t_0, and the charging mode starts at time $t_1 > t_0$, the charging rate could be constant or variable.

A.4. Strategy 4: Uncoordinated Delayed Charging and Discharging

Uncoordinated Delayed Charging and Discharging (U-De-CD) is defined as the charging and discharging modes of a single or a fleet of PEVs which is delayed for a certain period of time (i.e. the charging and discharging modes are delayed to the off-peak time, usually to the evening) when PEVs are connected to the PG (Fig. 4). The purpose of this delay is to reduce the charging during on-peak time and charge the PEVs during off-peak time, the discharging may happen during on-peak time or during off-peak time, but in uncoordinated manner. Because it is uncoordinated, it may create another peak during off-peak time even when some PEVs are discharging. Therefore, it could have negative impact on the network as stated in Table I. this strategy has not been studied yet to the best of the authors' knowledge.

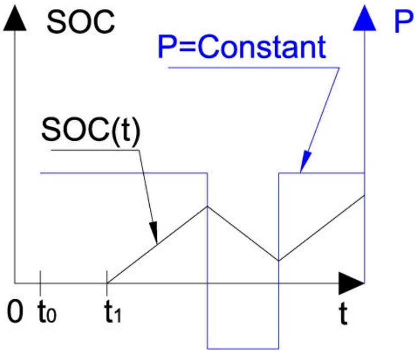


Fig. 6: The PEV is plugged-in at time t_0, and the charging and discharging modes start at time $t_1 > t_0$, the charging rate could be constant or variable.

A.5. Strategy 5: Uncoordinated Random Charging

Uncoordinated Random Charging (U-R-C) is defined as the charging mode of a fleet of PEVs distributed randomly during a certain period of time. This type of charging is similar to the uncoordinated delayed charging, but the difference is that in the second case, the PEVs are not distributed randomly during a certain period of time. Some papers studied this strategy such as [103], [104], other papers mentioned it such as [69]. Paper [98] studied a similar type of charging called "random schedule" in which the distribution of charging PEVs is done randomly during a certain period of time. The impact of this strategy on the PG is described in Table I.

A.6. Strategy 6: Uncoordinated Random Charging and Discharging

Uncoordinated Random Charging and Discharging (U-R-CD) is defined as the charging and discharging modes of a fleet of PEVs distributed randomly during a certain period of time. This strategy is similar to the strategy 5 (U-R-C), but the difference is that the discharging may occur during on-peak or off-peak time. The strategy has not been studied yet to the best of the authors' knowledge.

B. Coordinated Charging and Discharging

The coordinated charging and discharging strategies are widely studied in the last recent years, they are the best strategies which could be implemented to PEVs in which the charging and discharging modes are coordinated and optimized in a way to turn the bad impacts of the penetration of PEVs into good impacts on the PG. Most of these studies have concentrated on the concept Grid-To-Vehicle (G2V) in which the charging mode is only considered, and other have concentrated on both concepts Vehicle-To-Grid (V2G) and G2V in which a bidirectional power flow is considered, and both charging and discharging modes are used. The main goal of these strategies is to reduce the power losses, reduce the total operation cost, reduce the peak load, etc as will be stated in Table I. There are also other concepts such as Vehicle-To-Vehicle (V2V) [105], Vehicle-To-Home (V2H) or Home-to-Vehicle (H2V) [105], etc. But all these concepts have the same goals as the V2G and G2V. Usually these strategies use optimization techniques to optimize the charging and discharging schedules of PEVs.

B.1. Continuous Coordinated Charging and Discharging

B.1.1. Strategy 7: Continuous Coordinated Direct Charging

Continuous Coordinated Direct Charging (CC-Di-C) is defined as the charging process of a single or fleet of PEVs which are charging continuously during a certain period of time (i.e. ≥1 hour) without being interrupted, and they are charging directly when they are plugged to a power grid, in addition, the charging mode of a single PEV or a fleet of PEVs is coordinated in a way to avoid the charging during on-peak time and fill valleys during off-peak time. Some papers studied this strategy such as [98], [82], [83] [43], [103], [63], [70], [106], [40]. Fuzzy Coordinated Direct Charging is included in this strategy in which it uses the Fuzzy reasoning. Some papers used the fuzzy reasoning such as [100]. Real-time coordination is also included in this strategy [103].

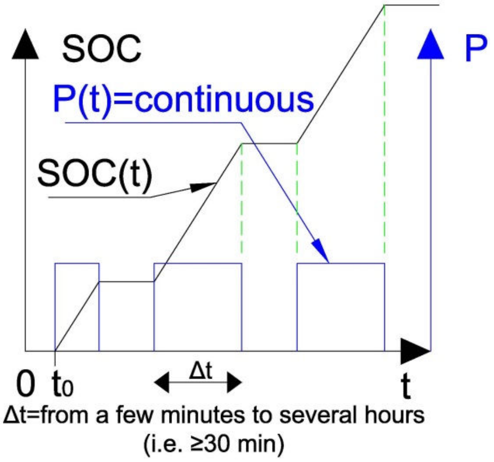


Fig. 7: Continuous Coordinated Charging. The period of a continuous charging is from a few minutes to several hours. The period is not decomposed into several intervals as the discrete coordinated charging does.

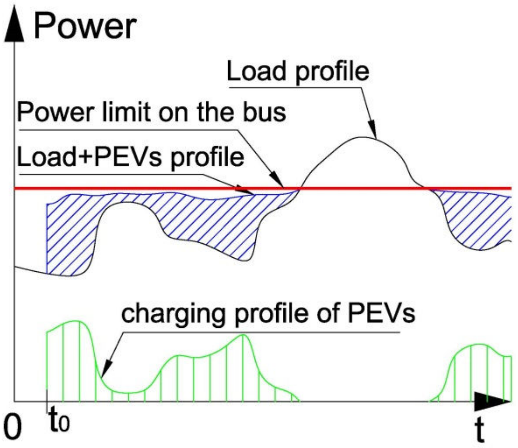


Fig. 8: Coordinated Charging. Black curve represents the load profile on the bus without considering the charging of PEVs, blue curve represents the total load on the bus including the charging of PEVs and the initial load, the green curve represents the charging power of PEVs, the red curve represents the power limit of the bus.

In figure 6, Strategies 7 (CC-Di-C), 9 (CC-De-C), 11 (DC-Di-C), 13 (DC-De-C) allow PEVs to charge during off-peak time, and fill valleys. But the problem is that the PEVs are not participating in reducing the peak load caused by the load on the bus which may overpass the power limit imposed by the bus, transformer, or PSO, therefore, the peak load is always presented on the bus causing many problems as discussed in the Table I.

B.1.2. Strategy 8: Continuous Coordinated Direct Charging and Discharging

Continuous Coordinated Direct Charging and Discharging (CC-Di-CD) is defined as the charging and discharging processes (modes) of a single or fleet of PEVs which are charging/discharging continuously during a certain period of time (i.e. ≥1 hour) without being interrupted, and they are charging/discharging directly when they are plugged to a power grid, in addition, the charging/discharging modes of a single PEV or a fleet of PEVs are coordinated in a way to avoid the charging during on-peak time and fill valleys during off-peak time, in addition the discharging occurs during on-peak time, and when the electricity price is high. Some papers studied this strategy such as [81], [12], [107].

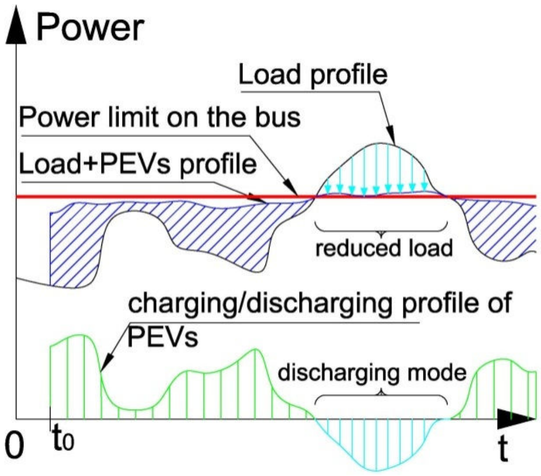


Fig. 9: Coordinated Charging and discharging. Black curve represents the load profile on the bus without considering the charging/discharging of PEVs, blue curve represents the total load on the bus including the charging/discharging of PEVs and the initial load, the green curve represents the charging power of PEVs, the cyan curve represents the discharging power of PEVs, the red curve represents the power limit of the bus.

In figure 7, Strategies 8 (CC-Di-CD), 10 (CC-De-CD), 12 (DC-Di-CD), 14 (DC-De-CD) allows PEVs to charge during off-peak time, fill valleys, and discharge during on-peak time and when the price of energy is high, therefore, reduces the peak demand (as depicted in cyan color in figure 7). Hence, the total load respects the limits imposed by the bus, transformer, or PSO. The coordinated charging and discharging strategies are the best between all methods and they are highly recommended to be implemented in smart grid system.

B.1.3. Strategy 9: Continuous Coordinated Delayed Charging

The Continuous Coordinated Delayed Charging (CC-De-C) is defined as the shifted charging of PEVs after they are connected to the grid for many reasons, the most important reasons are (i) reducing the congestion on the network; (ii) charging when the electricity price is low [108]; (iii) valley-filling [108], [109]. Some papers studied this strategy such as [83], [108], [70], [109], the first paper used this method is [110].

B.1.4. Strategy 10: Continuous Coordinated Delayed Charging and discharging

The Continuous Coordinated Delayed Charging and Discharging (CC-De-CD) is defined as the shifted charging/discharging processes of PEVs after they are connected to the grid for many reasons, the most important reasons are (i) reducing the congestion on the network, (ii) charging when the electricity price is low, (iii) discharging when the electricity price is high, (iv) discharge when the total power is higher than the limit imposed by the bus, transformer, or PSO. Some papers studied this strategy such as [83].

B.2. Discrete Coordinated Charging and Discharging

B.2.1 Strategy 11: Discrete Coordinated Direct Charging

The Discrete Coordinated Direct Charging (DC-Di-C) is defined as the charging during discrete intervals for a certain period of time, the width of the interval depends on the designer, it could be from several seconds to several minutes, and it could be equally or not equally distributed. For each interval, the charging occurs for a limited number of PEVs, and the same PEVs could not be charged in the next interval, the charging partition of PEVs depends on many factors such as their numbers, their initial and final SOC, and their arrival and departure time, etc. The purpose of this method is to extend the charging mode to a larger period in order to reduce the impact of PEVs' high penetration on the grid. Some papers studied this strategy such as [85], [78], [80].

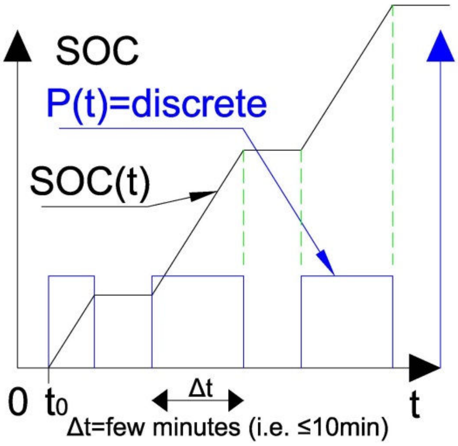


Fig. 10: Discrete Coordinated Charging. Black curve represents the $SOC(t)$, and the blue curves represent the $P(t)$. The period of charging is decomposed into several intervals in a discrete way for each PEV, and the duration of each interval is from few seconds to few minutes.

B.2.2. Strategy 12: Discrete Coordinated Direct Charging and Discharging

The definition of the Discrete Coordinated Direct Charging and Discharging (DC-Di-CD) is similar to (DC-Di-C) in addition the discharging mode is applied. The purpose of this method is to extend the charging and discharging mode to a larger period in order to reduce the impact of PEVs' high penetration on the grid. This strategy divides the period of time into many intervals, and for each interval, the charging/discharging occurs for a limited number of PEVs, therefore, the peak demand is reduced and prolonged to a wider period of time. To the best of our knowledge, this strategy hasn't been studied yet.

B.2.3 Strategy 13: Discrete Coordinated Delayed Charging

The Discrete Coordinated Delayed Charging (DC-De-C) is defined as the shifted charging process of PEVs after they are connected to the grid for many reasons as stated in strategy 9 (CC-De-C). But this time the discrete coordination is used, and the charging process is delayed to a larger period of time. This strategy has not been used yet.

B.2.4 *Strategy 14: Discrete Coordinated Delayed Charging and Discharging*

The Discrete Coordinated Delayed Charging and Discharging (DC-De-CD) has the same definition as the (DC-De-C) in addition the discharging mode is applied. This strategy has not been used yet to the best of the authors' knowledge.

B.3 Future Work and recommendations

Strategies 1 (U-Di-C), and 2 (U-Di-CD) are not recommended even if there are very few PEVs on a certain bus. Some modifications could be done to improve these strategies such as controlling and limiting the charging power rate in a way to limit the bad impact on the power grid and distribution grid. Strategies 3 (U-De-C) and 4 (U-De-CD) are recommended when a small amount of PEVs are presented on a certain grid, even with this small amount, the risk of bad impact on the power grid (and distribution grid) is also highly presented, therefore, it is mandatory to limit the number of PEVs or to shift to coordinated charging. Strategies 5 (U-R-C) and 6 (U-R-CD) are similar to strategies 3 and 4, in real life the distribution of PEVs is not random on a certain bus, therefore, these strategies are meaningless and they could not be used. Strategies 7 (CC-Di-C), 9 (CC-De-C), 11 (DC-Di-C), 13 (DC-De-C) are recommended when the base load doesn't overpass the limits imposed by the transformer, bus, or PSO, they are good methods for charging and scheduling PEVs, but these strategies can't reduce peak demands on the bus or transformer. Therefore the strategies with coordinated charging and discharging are recommended in this case which are 8 (CC-Di-CD), 10 (CC-De-CD), 12 (DC-Di-CD), 14 (DC-De-CD). Strategy 8 (CC-Di-CD) includes the Fuzzy Coordinated Direct Charging and Discharging, this type of charging has not been used yet, this paper recommends to use this strategy for its many advantages. Strategy 12 (DC-Di-CD) has not been studied yet, this paper recommends to study such kind of strategies for their many advantages as will be stated in Table I. Strategy 13 (DC-De-C) has not been studied yet to the best of the authors' knowledge, it is recommended to use this strategy if only coordinated charging is required. Strategy 14 (DC-De-CD) has not been studied yet to the best of the authors' knowledge, it is highly recommended for smart grids, the advantages and barriers of this strategy is mentioned in Table I.

C. Advantages and Barriers of the mentioned strategies

In general, each strategy has its advantages and limitations, the same study may have different impact according to the nature of the load on the bus or transformer. Paper [76] suggested to divide the load on the grid into three categories, residential, commercial, and industrial, in which the penetration level of PEVs has different impact for each category, but in general the optimization algorithms can work for each load category, and minimize the cost of charging and minimize the losses. The limitations of the optimization techniques for each load category are only presented in the final SOC in which the PEV owner will obtain at the end of the charging process, and it could be lower than his requirements. It is important to mention that the most of the studies don't limit the penetration level of PEVs, therefore, this leak in the modeling could create bad impacts on the power grid even when optimization techniques are used, and all these limitations and advantages are presented in Table I. From Table I it can be concluded that the strategies 8 (CC-Di-

CD) and 11 (DC-Di-CD) are the best among all other strategies.

High penetration level may affect negatively the power grid even when coordinated charging is applied [103], [69], therefore, this paper recommends that the penetration level should have an upper limit.

TABLE I. ADVANTAGES AND BARRIERS OF DIFFERENT CHARGING AND DISCHARGING STRATEGIES

Description: “S”: Simple, “Vs”: Very Simple, “C”: Complex, “Vc”: Very Complex “L”: Limited, “N”: No, “Y”:Yes, “M”: Might be	S1: U-Di-C	S2: U-Di-CD	S3: U-De-C	S4: U-De-CD	S5: U-R-C	S6: U-R-CD	S7: CC-Di-C	S8: CC-Di-CD	S9: CC-De-C	S10: CC-De-CD	S11: DC-Di-C	S12: DC-Di-CD	S13: DC-De-C	S14: DC-De-CD
Complexity of Charging [63], [85], [78], [80], [56], [41]	Vs	S	Vs	S	Vs	S	C	Vc	C	Vc	C	Vc	C	Vc
Topology of power electronics circuits: Charging uses only diode bridge, unidirectional converter, and unidirectional power flow [56], [41]. While charging and discharging use semiconductor devices such as MOSFET, IGBT, GTO from low to high power respectively, bidirectional chargers, and bidirectional power flow [56], [41], [111]	S	C	S	C	S	C	S	C	S	C	S	C	S	C
Require control and digital communication between PEV, chargers, aggregator (PL/CS), and the power network [41], [112], [113], [111], [32], [114], [65], [102], [115], [63], some institutions provide specifications and requirements on this topic such as IEEE, SAE [116], [117], and National Electric Infrastructure Working Council [118], [119],	N	N	N	N	N	N	Y	Y/ Vc	Y	Y/ Vc	Y	Y/ Vc	Y	Y/ Vc
Require complex data collection and storage from PEVs, aggregator, power network, and other parties [63]	N	N	N	N	N	N	Y	Y/ Vc	Y	Y/ Vc	Y	Y/ Vc	Y	Y/ Vc
Response time is very short for ancillary services compared to other conventional power generators (diesel generators, wind turbines, nuclear reactors, and hydropower stations), therefore, PEVs can replace other regulation service units [109], [120]	N	N	N	N	N	N	L	Y	L	L	L	Y	L	L
Battery might:														
degrade during regulation service [109], [121], [122] , [123], [41]	N	Y	N	Y	N	Y	N	M	N	M	N	M	N	M
increase cycling wear [124], [125], [121]	L	Y	L	Y	L	Y	N	M	N	M	N	M	N	M
reduce its lifetime and storage capacity [41], [126]	L	Y	L	Y	L	Y	N	Y	N	Y	N	Y	N	Y
Transformer might (due to high power demand from Base Load only “1”, or from PEVs+Base Load “2”, or from both “3”):														
• Reduce its lifetime [43], [127],	3	3	3	3	3	3	1	N	1	1	1	N	1	1
• Overheat, shutdown, insulation may break-down, increase losses, reduce its efficiency [56], [41], [128], [104], [129], [130], [103], [131], [132], [62], [99], [133],	3	3	3	3	3	3	1	N	1	1	1	N	1	1
• Overpass its limit [134], [104], [70], [41], [135], [69], [99], [85], [78], [80] the same for cables and distribution infrastructure,	3	3	3	3	3	3	1	N	1	1	1	N	1	1
Ancillary services are provided [32], [64], [114], [12], [81], [15], [41]:	N	N	N	N	N	N	L	Y	L	L	L	Y	L	L
• Improve grid stability [56], [136],[12], [137],	N	N	N	N	N	N	L	Y	L	L	L	Y	L	L
• Frequency regulation* [47], [109], [64], [51], [47], [41], [138], [139], [15], [22], [81], [140], [120], [141], [142], [143], [41], [109], [144],	N	N	N	N	N	N	L	Y	L	L	L	Y	L	L
• Voltage regulation [100], [103], [56], [12], [52], [103], [145], [146], [41], [136],	N	N	N	N	N	N	L	Y	L	L	L	Y	L	L
• Harmonic regulation	N	N	N	N	N	N	N	Y	N	Y	N	Y	N	Y
• Support the integration of RES [32], [12], [24], [48], [39], [37], [41], [35], [147], [15], [38]	N	N	N	N	N	N	L	Y	L	L	L	Y	L	L
• Improve grid stability [56], [136],[12], [137],	N	N	N	N	N	N	L	Y	L	L	L	Y	L	L
• Spinning reserve participation [64],[12], [140], [120], [141], [142], [143], [41]	N	N	N	N	N	N	N	Y	N	L	N	Y	N	L
• Energy Storage (also called small portable power plant), it injects power to the grid [51], [125], [12], [41], [49], [56],	N	N	N	N	N	N	N	Y	N	L	N	Y	N	L
• Improve power quality[100], [103], [56], [12],	N	N	N	N	N	N	L	Y	L	L	L	Y	L	L
• Improve grid efficiency and reliability [137], [41], [37], [41],	N	N	N	N	N	N	L	Y	L	L	L	Y	L	L
• Active and Reactive power flow regulation [100], [103], [12], [85], [78], [80], [69]	N	N	N	N	N	N	L	Y	L	L	L	Y	L	L
• Improve generation dispatch [148], [41]	N	N	N	N	N	N	L	Y	L	L	L	Y	L	L
• Replace large-scale energy storage systems [41],	N	N	N	N	N	N	N	Y	N	L	N	Y	N	L
• Black Start of a part of the distribution grid	N	N	N	N	N	N	N	Y	N	L	N	Y	N	L
*usually there are three types of control for frequency regulation defined by the Union for the Coordination of Transmission of Electricity [149], [150]														
Emission of CO2, NOx, SO2, etc and fossil fuel are reduced from :														
• PEV	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
• Conventional Power plants only if PEVs are charged from RES* [49], [109], [43], , [47], [45], [39],	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y
• During peak demand [12], [41], [91], [151], [152], [153], [24], [48], [39]	N	N	N	N	N	N	N	Y	N	L	N	Y	N	L

*Generally speaking, when PEVs are supplied by conventional power plants, the emission of harmful gases in much higher than conventional vehicles, therefore, the power plants produce more harmful gases and consume more energy, hence, the charging of PEV should be done using RES, or power plants where fossil fuel is not used (i.e. Nuclear power plant, hydropower plant, etc)														

Continue Table I

Description: “S”: Simple, “Vs”: Very Simple, “C”: Complex, “Vc”: Very Complex “L”: Limited, “N”: No, “Y”:Yes, “M”: Might be	S1: U-Di-C	S2: U-Di-CD	S3: U-De-C	S4: U-De-CD	S5: U-R-C	S6: U-R-CD	S7: CC-Di-C	S8: CC-Di-CD	S9: CC-De-C	S10: CC-De-CD	S11: DC-Di-C	S12: DC-Di-CD	S13: DC-De-C	S14: DC-De-CD
Operation cost are reduced: • Power plants [49] • Grid [100], [103], [109], [12], [49], [41], [91], [151], [152], [24], [48], [39] • PEV charging/discharging processes [56], [41], [49], • Reduce dependency on small/micro expensive power units [49] • Turn off some generators during on-peak time by providing energy to the grid using V2G [49], [12],	N N N N N	N N N N N	N N N N N	N N N N N	N N N N N	N N N N N	L L Y N N	Y Y Y Y Y	L L Y N N	L L Y L L	L L Y N N	Y Y Y Y Y	L L Y N N	L L Y L L
Power and Energy Losses are reduced in the grid [100], [103], [41], [99], [12],	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y
• Load shifting of PEVs charging process [125], [109] • Peak shaving [56], [154], [155], [41], [69], [107] • Shift the hourly generation portfolio [12], [100], [103] • Load balancing by valley filling [156], [157] [68], [41], [158], [159]	N N N N	N N N N	Y N N N	Y N N N	N N N N	N N N N	N N N Y	N Y Y Y	Y N N	Y L L	N N N	N Y Y	Y N N	Y L L
Generate revenue from ancillary services [64], [31], [50], [160], [161], [41], [81],[12], [49],	N	N	N	N	N	N	N	Y	N	L	N	Y	N	L
Minimize load variance [162]	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y
• Cost of chargers, power electronics circuits and infrastructure are high [56], [41], [56], [64], [24], [163], [164], [41], [165], [69] (it includes on/off-board smart meters [156], [37], [31], [111], on/off-board chargers, data infrastructure, sensors [111], etc.) • Infrastructure needs upgrade to support PEVs [100], [103], [41] • Avoid additional investment on the infrastructure due to coordinated charging [166]	N N N	Y Y N	N N N	Y Y N	N N N	Y Y N	N N Y	Y Y Y	N N Y	Y Y Y	N N Y	Y Y Y	N N Y	Y Y Y
• A large number of PEVs participate in the charging mode [41] • Increase the penetration level of PEVs without violating the constraints on the power grid [167],	Y N	Y N	Y N	Y N	Y N	Y N	L Y	L Y	L Y	L Y	L Y	L Y	L Y	L Y
Priority of charging/discharging is considered (not all papers in these strategies) (reference??)	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y
• Charging occurs instantly [41], [70], • Charging may be delayed depending on the constraints of PEVs and the grid [104], [41], • The management of charging/discharging becomes difficult for a large number of PEVs because the period of charging/discharging is extended, thus, reducing the management reliability and dissatisfy many clients, [85], [78], [80], • Arrival and departure time of each PEV is considered	Y N N N	Y N N N	N Y N N	N Y N N	Y N N N	Y N N N	Y M N Y	Y N N Y	N Y N Y	N Y N Y	Y M Y Y	Y N Y Y	N Y Y Y	N Y Y Y
• Reduce network congestion [99] • Reduce load factor [41], [61], [162], [48]	N N	N N	N N	N N	N N	N N	Y Y	Y Y	Y Y	Y Y	Y Y	Y Y	Y Y	Y Y
Optimize time and power demand [76]	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y
Bad impact on the network (due to high power demand from Base Load only “1”, or from PEVs+Base Load “2”, or from both “3”):: • Decrease the efficiency of the distribution grid [70], • High peak demand and power consumption in certain periods, even during off-peak time [56], [41], [103], [70], [76], [63], [99], [168], • System may lose its stability (Voltage and frequency violations) [56], [104], [69], [62], [85], [78], [80], [41] • Uncontrolled load [104], [41], [69], [167] • Power and Energy losses are increased [56], [41], [69], [62], [70], • Network congestion is increased [62], • Reliability is reduced of the power grid [41], [69], • Shortage in the power grid in which the demand on a certain bus exceeds the power supply and cause a severe voltage drop [169],	3 3 3 3 3 3 3 3	3 3 3 3 3 3 3 3	3 3 3 3 3 3 3 3	3 3 3 3 3 3 3 3	3 3 3 3 3 3 3 3	3 3 3 3 3 3 3 3	1 1 1 1 1 1 1 1	N N N N N N N N	1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1	N N N N N N N N	1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1
Charging is delayed to a later time [41], [102]	N	N	Y	Y	N	N	N	N	Y	Y	N	N	Y	Y

IV. OTHER IMPORTANT DEFINITIONS USED BY PEVS

A. Charging rate used for the mentioned strategies

There are mainly three classifications for the charging rate (also called charging power, power rate, and charger power level) used in the mentioned strategies to charge/discharge a single or a fleet of PEVs: (i) Constant charging/discharging rate; (ii) multilevel constant charging/discharging rate; (iii) variable charging/discharging rate. The charging rate could be limited to a maximum value in which the PEV can't charge the battery with a power greater than the required one of a given SOC and time as mentioned in [106], in order to reduce the life loss of the battery, for example if the maximum power rate for a SOC=0.6 is 10kW, therefore, the charging rate could not overpass 10kW for the specified SOC. In addition, the charging rate could be determined by the PEV owner, Charger, Standard, Battery constructor, available power on the grid or transformer, limit of the transformer, bus or circuit breaker, and the SOC.

There are three main categories for charging/discharging a fleet of PEVs, (i) the PL/CS could charge/discharge all vehicles with the same charging rate [43], (ii) each group of PEVs are charging/discharging with the same rate, (iii) each PEV is charged with its own charging/discharging rate [109].

A.1. Constant Charging/Discharging Rate for a single or fleet of PEVs

The charging/discharging rate is considered constant during the whole charging/discharging modes of a single or fleet of PEVs and can't be changed. There are only 3 power levels for this method $P(t) = (-P, 0, +P)$, and a process can use one to three levels. The negative power is for the discharging mode, the zero is for the idle mode, and the positive power is for the charging mode. In case of many PEVs, all (or part) of them are charging or discharging at the same time. In another meaning, the fleet of PEVs can charge or discharge at the same time, but it is not possible to find some PEVs charging while others are discharging. Therefore, the $SOC(t)$ is of the first order as depicted in the following figure. There is a standard SAE J1772 that determines the levels of charging [170], [171]. This standard is mainly used in USA, but in Europe and other countries there are other standards, and it is useful to mention that some manufacturers have their own standards such as Tesla Motors. Some papers used this method such as [78], for charging mode only [103], [100], [69], [43], [172], [162], [101], [48].

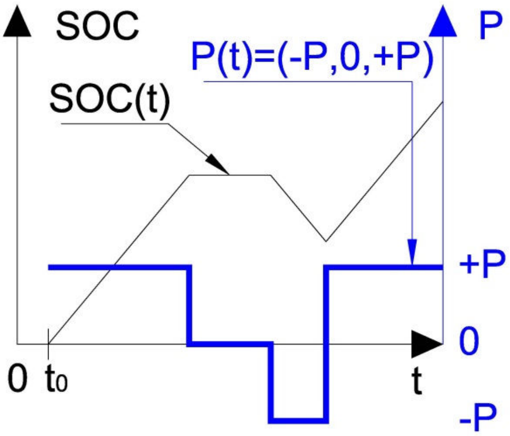


Fig. 11: Constant Charging/Discharging rate for a single PEV.

A.2. Multilevel Charging/Discharging rate for a single or fleet of PEVs

It has the same definition as the previous one, but this time PEVs are able to charge/discharge at different constant levels. Moreover, the process of charging and discharging can happen at the same time, in another meaning, some PEVs are charging while others are discharging. Some papers used this method such as [78].

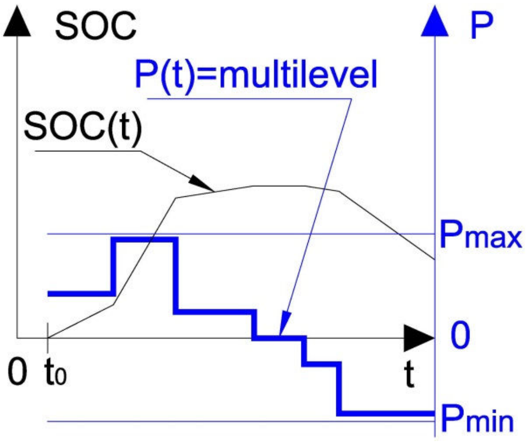


Fig. 12: Multilevel Charging/Discharging rate for a single PEV.

A.3. Variable Charging/Discharging rate for a single or fleet of PEVs

The charging/discharging rate is considered variable during the whole charging/discharging modes of a single or fleet of PEVs, it should be within a certain limit ($P_{min} \leq P \leq P_{max}$). The power curve can be represented using a piecewise function, and the SOC is nonlinear because the power is not constant. The aggregator (PL/CS, etc) is able to control the charging/discharging rate of each PEV. In another meaning some PEVs are charging at level 1, others at level 2, others at level 3, and others between level 1 and 2, etc. Moreover, some PEVs may discharge at the same time with different charging/discharging rates. Some papers used this method such as [78], [82], [108], [12], [70], [109], [173], [107], [106]. Some papers calculate how to obtain the charging rate at each instant such as [174]. Usually the charging rate could be determined with optimization techniques in which the PEV owner puts a higher limit for the charging rate and the algorithm chooses the appropriate power to charge the PEV.

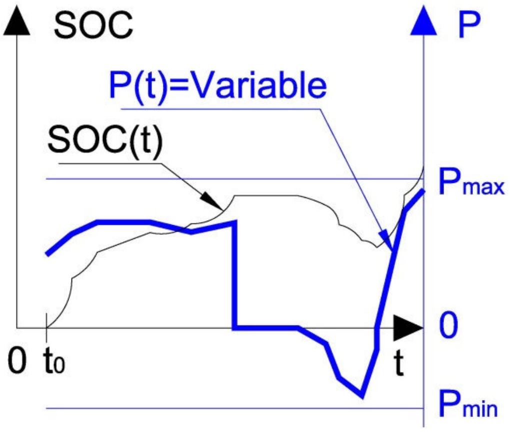


Fig. 13: Variable Charging/Discharging Power level.

A.4. Charging Rate's impact on the power grid

Mainly there are three levels of charging according to SAE J1772 [175], [176], and other standards such as [177], [178], [41], they are presented in the following table. (Not all countries adopt these standards, for example: the level 1 in North America is for a voltage equal to 120VAC, while in Europe it is 230VAC, etc).

TABLE II. DIFFERENT LEVELS OF CHARGING PEVS ACCORDING TO [177], [178] AND SAE J1772 STANDARD

Levels of Charging	Recommended vehicle Type	Approximately charging time	Voltage	Peak Current	Power And Used Strategies (.)
AC Level 1 (SAE J1772)	PHEV (ONBC) BEV(ONBC)	(≈7 hours)*[1] (≈17 hours)*[2]	120V AC (residential outlet)	12A-16A	1.4kW-1φ → 1.92kW-1φ (a)→(f), [41], [177], [178]
AC Level 2 (SAE J1772)	PHEV (3.3kW ONBC) BEV (3.3kW ONBC) PHEV (7kW ONBC) BEV (7kW ONBC) PHEV (20kW ONBC) BEV (20kW ONBC)	(3 hours)*[1] (7 hours)*[2] (1.5 hours)*[1] (3.5 hours)*[2] (22 minutes)*[1] (1.2 hours)*[2]	208-240V AC (residential or public charging equipment)	Up to 80A	Up to 19.2kW- Sφ (g)→(j) [41]
AC Level 3 (SAE J1772)	PEV (PHEV & BEV)	No standard	No standard	No standard	>20kW 1φ and 3φ No standard. (g)→(j) [41]
DC Level 1 (SAE J1772-2009)	PHEV (20kW OFFBC) BEV (20kW OFFBC)	(20 min.)*[3] (1.2 hours)*[2]	200-450VDC (non-residential outlet)	80A	Up to 36kW (g)→(j) [41]
DC Level 2 (SAE J1772-2009)	PHEV (45kW OFFBC) BEV (45kW OFFBC)	(10 min.)*[3] (20 min.)*[4]	200-450VDC (non-residential outlet)	200A	Up to 90kW (g)→(j) [41]
DC Level 3 SAE J1772	BEV only (OFFBC)	(<10 min.)*[3]	200-600VDC (non-residential outlet)	400A	Up to 240kW (g)→(j) [41]
DC Level 3 (CHAdeMO)*[5]	PEV (OFFBC)	10-30 min. for full charge	480-500VDC (non-residential outlet)	≥100A	≥50kW No international standards. (g)→(j) [41]
DC Level 3 (Tesla Supercharger)*[6]	PEV (OFFBC)	≈20 min. for full charge	480-500VDC (non-residential outlet)	≥100A	≥50kW No international standards. (g)→(j) [41]

Where, *[1] is the needed hours to charge a battery with SOC from 0% to 100%. *[2] is the needed hours to charge a battery with SOC from 20% to 100%. *[3] is the needed hours to charge a battery with SOC from 0% to 80%. *[4] is the needed hours to charge a battery with SOC from 20% to 100%. *[5] CHAdeMO technology is also known as DC fast charging, there is no international standards for this level of charging, therefore some electric vehicles may work using this type of charging and others may not. *[6] Tesla Supercharger works only for Tesla Model S Electric Vehicle, and it doesn't work for other PEVs. PHEV is a Plug-in Hybrid Electric Vehicle. BEV is a Battery Electric Vehicle. PEV is a Plug-in Electric Vehicle including BEV and PHEV. ONBC is an On-Board charger (charger located inside the PEV). OFFBC is an Off-Board Charger (charger located outside the PEV). Sφ is a split phase or Single phase three wires. 1φ and 3φ stand for single phase and three phases respectively. Remark: cold weather may lengthen the needed time for charging.

A.5. Batteries Used in PEVs

The batteries are divided into two major groups, the first one is the non-rechargeable batteries, and the second one is the rechargeable batteries [179], [180]. The rechargeable batteries are used for PEVs, and each type has its advantages and limitations, many factors are considered for the choice of the battery in PEVs including but not limited to, the price of the battery, the lifetime of the battery, the charging and discharging power limits, the temperature of use, the energy density of the battery, the weight, etc. The most important types of batteries used for PEVs are: Lead-Acid, Lithium-Ion, Nickel Metal Hybrid (NiMH) [76], Nickel-cadmium (NiCd), Lithium-Ion-Polymer [180]. And the non-rechargeable batteries are used for other applications such as Zinc-Carbon, Alkaline-Manganese, Lithium Iron Disulfide (Li-FeS2), Lithium-thionyl chloride (LiSOCI2 or LTC), Lithium manganese dioxide (MnO2 or Li-M), Lithium sulfur dioxide (LiSo2), lithium-metal [179].

TABLE III. MOST PEVS USED IN STUDIES

Name	Battery Capacity	Battery Type	Electric Range
General Motors Chevrolet Volt [181], [182]	16kWh	Lithium-Ion	35 miles
Nissan Altra [106], [183] The production of this vehicle was stopped	29.07kWh	Lithium-Ion	120 miles
Nissan Leaf [181], [184]	24kWh 30kWh	Lithium-Ion	100 miles 107 miles
Tesla Model S [185]	85kWh	Lithium-Ion	265 miles
Tesla Model X [186]	90kWh	Lithium-Ion	257 miles
Tesla Roadster [181],	53kWh	Lithium-Ion	245 miles
Toyota Plug-in Prius [181]	4.4kWh	Lithium-Ion	15 miles

A complete list of electric vehicles available in the market could be found in [187], [188], [189].

Future work and recommendation: it is known that every battery type has a particular charging/discharging power profile which could be variable during charging/discharging modes. Actually all studies on the charging/discharging modes of PEVs were made considering a constant power profile of the charging/discharging modes of the batteries [162]. Therefore, the results may not be accurate enough using optimization techniques, hence, this paper recommends that the charging/discharging power profiles of PEVs should be considered in order to give more accurate results. We also recommend setting a standard for the discharging mode similar to the charging mode, in this way the PL/CS will limit the discharging of PEV in order to reduce their life loss. In addition, this paper recommends to include the following power limits in the study of PEVs: (i) limits imposed by PEV owner, (ii) Charger, (iii) Standard, (iv) Battery constructor, (v) available power on the grid or transformer, (vi) limit of the transformer, bus or circuit breaker, (vii) the SOC, (viii) and charging power profile of the battery.

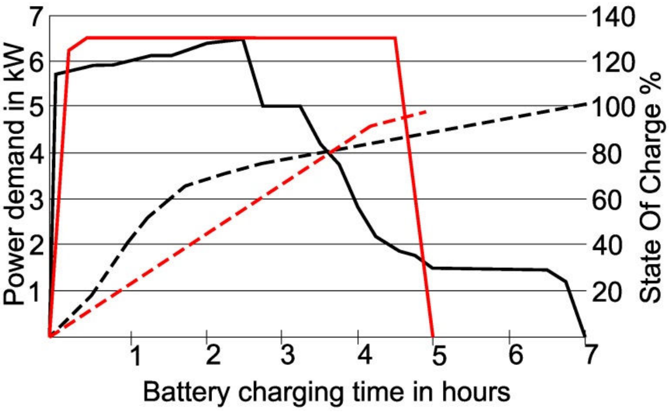


Fig. 14: A comparison between two types of PEVs, (i) General Motors EV1 which uses the lead-acid battery (black curves), (ii) Nissan Altra which uses Lithium-ion (red curve) [106]. The solid curve represents the charging rates in kW (black for Nissan, and red for GM), and the dashed curve is for the SOC (black for Nissan, and red for GM) [76].

In the above figure, it is remarked that the charging power profile of the Nissan Altra is approximately constant, while for General Motors EV1 is variable and decreasing with the increasing of the SOC, therefore, after 5 hours of charging it is possible to introduce another PEV for charging which is not considered in the current studies for optimization techniques. And the limitation of the charging level should be respected in the constraints part of the optimization problem.

B. *Price Mechanisms*

The Price Mechanisms play an essential role in the coordination of charging and discharging of PEVs and their optimization techniques, in which the market price determine if the PEVs will be charged or not, and how many PEVs will be available for charging and discharging. Many incentive programs where developed to encourage PEV owners to charge when the tariff is low and during off-peak time, and to discharge or to stay in the idle mode when the tariff is high or during off-peak time. Most of optimization techniques used the market price to minimize the cost of charging, increase the benefit from the discharging mode, and minimize the total operating cost of the power grid. The mentioned strategies might or might not follow the market price curve predicted by the aggregator or a market agent, the unit of the tariff is usually in \$/kWh. The pricing mechanism could also use optimization techniques in order to determine the price at each instant [190], but many pricing mechanisms don't use the optimization techniques [107], [76], [80], [76], [191], therefore, the pricing is based on the previous data or determined by an aggregator, market agent, PSO, or even the government. The market price might have different forms such as (i) real-time non-linear bidding price in which the PEV owners bid instantly if they want to charge or not at this price [82], [192], [81], [49], [24], [173], [193]; (ii) day-ahead bidding price in which the consumers and suppliers submit day-ahead supply and demand energy price during next day [39], (iii) real-time price in which the price varies by time but there is no bidding from PEV owners [76], [194], [195], [48] (iv) predefined price in which the price is predefined before a certain period of time such as before several hours, at the beginning of the day, or even before one day or more [107], [48], the price could be fixed for a long period of time such as in China [106], (v) fixed price in which the tariff is fixed all the time regardless of the time of use, it has the same price whatever is the power consumption, this category is most probably used in residential buildings where the PEV owner charges his vehicle at home, but usually this is not the case of the most of PL/CS, because a variable price may increase their profit [80], [76], [101]; (vi) time-varying market energy price depends on the demand, it increases when the demand increases, and decreases when the demand decreases [108], [100], ; (vii) forecasted price in which the price is forecasted based on previous data or available data before a certain period of time, [43], [196], [81], [12], [103], [197] including day-ahead market price [12], [198], [197], [43]; (viii) linear price in which the price has a linear function [80], [199], [193]; (ix) dynamic price in which the price is varying dynamically [80], [199], [173], [197], [193]; (x) Time-Of-Use (TOU) electricity rate in which it divides the tariff into three main blocks, on-peak price, flat price (high off-peak price), and valley price (low off-peak price); the on-peak price is higher than the off-peak price, the main advantage of this method is that it motivates consumers to modify their power demand to off-peak time, TOU includes peak-valley prices, seasonable prices, wet-flat-dry prices, etc [76], [200], [106], [191], [190], [201], [202], [203], [167], [102], [101]; (xi) Catalog price in which the price of electricity is divided into several categories such as commercial, general industry, large industry, commercial, etc. and each category has its own tariff, i.e. 0.1$/kWh for commercial area, 0.2$/kWh for industrial area, etc [191]; (xii) progressive pricing mechanism in which the price of electricity increases when the consumption overpasses a certain limit, i.e. 0.1$ for the first 100kWh, 0.2$ from 101kWh to 200kWh, 0.3$ above 201kWh, etc some countries use this kind of pricing such as Lebanon and China [191]; (xiii) Stepwise Power Tariff (SPT) (also called progressive electricity price [190]) is a kind of nonlinear price in which the tariff increases when the power consumption of a user increases, the price increases in steps (divided into N steps), i.e. 0.1$ for 0-100kWh, 0.2 for 100$^+$-200kWh, 0.3 for 200$^+$-300kWh, etc [190], [204], [205], [206], [207]; (xiv) Nodal price in which it combines the technical constraints and economical objectives and they are reflected on the price at each node [42]. The advantage of following the realtime price is to minimize the cost of charging of PEVs [208], maximize the discharging tariff (in case the discharging process is applied), maximize the profit of a PL/CS; avoiding the peak hours [199]; reducing the peak-to-average ratio [199]; reducing the total cost of the system operation including generators and network [199].

Studies can be divided into two strategies, (i) studies that assume the pricing of electricity is known and their methods of charging/discharging are based on this assumption, such as [43], [108], [90]; (ii) studies that generate the price of electricity in order to coordinated the charging/discharging or PEVs, such as [192], [191], [190], . In general generating a price curve is done by the aggregator such as PL/CS, market agent [209], PSO, or by the government such as in China [106].

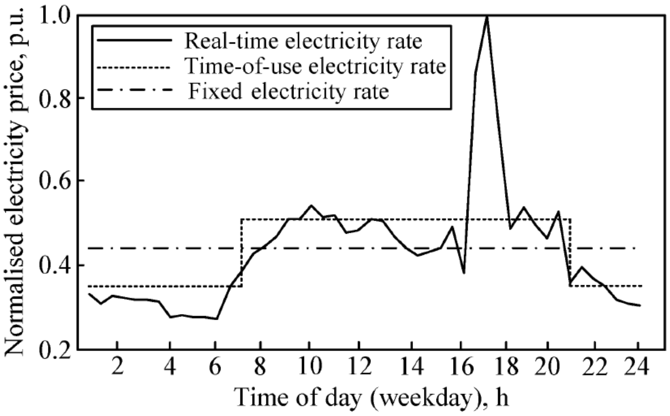
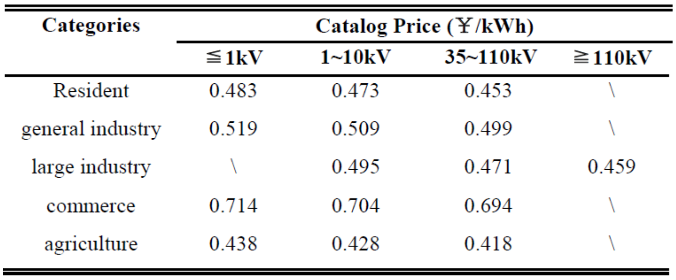


Fig. 15: A sample of pricing energy for PEVs charging and discharging, this figure represents three different prices, (i) Real-time price, (ii) Time-Of-Use price (iii) and Fixed price [76], .



Categories	Catalog Price (￥/kWh)			
	≦1kV	1~10kV	35~110kV	≧110kV
Resident	0.483	0.473	0.453	\
general industry	0.519	0.509	0.499	\
large industry	\	0.495	0.471	0.459
commerce	0.714	0.704	0.694	\
agriculture	0.438	0.428	0.418	\

Fig. 16: Catalog Price example [191].

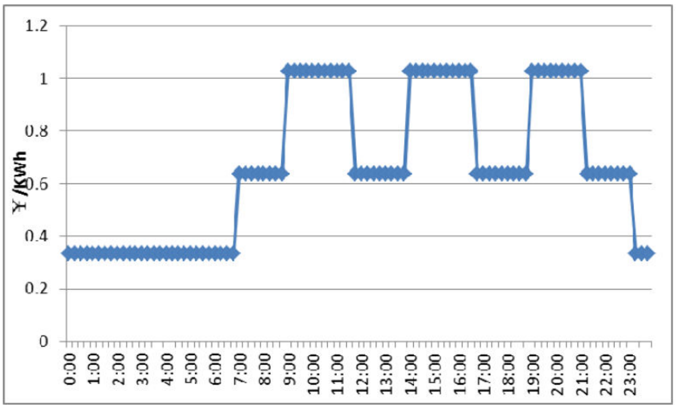


Fig. 17: Time Of Use Price example [191].

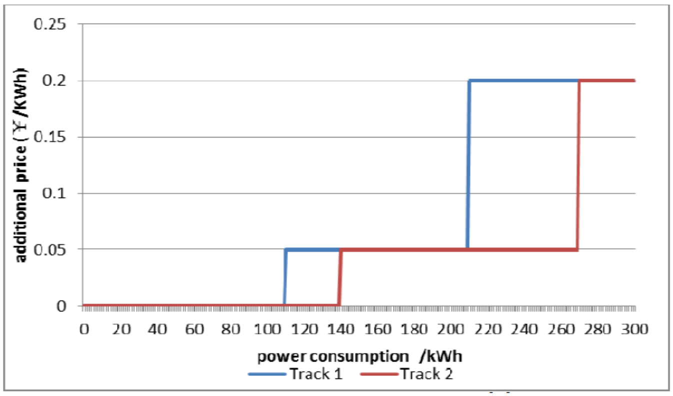


Fig. 18: Progressive Pricing Mechanism example [191].

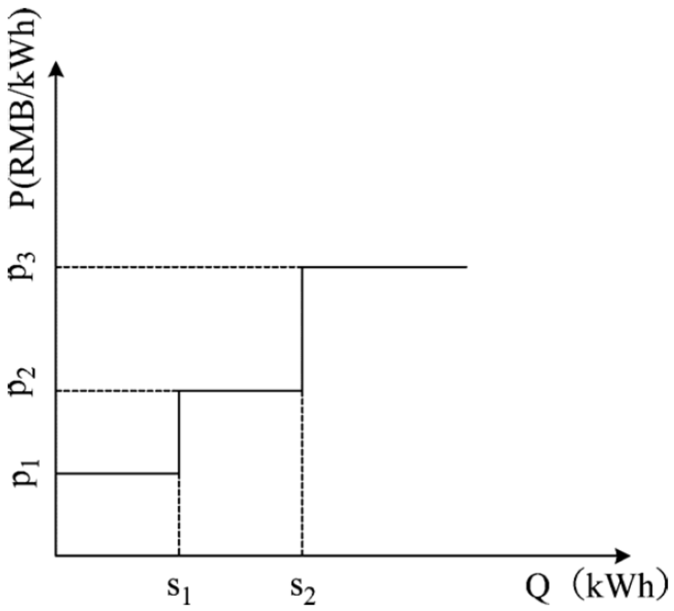


Fig. 19: Stepwise Power Tariff [190].

Future work and recommendations: the pricing mechanism is the most important part of the charging/discharging of PEVs in which the PL/CS and PEV owners decide whether charging, discharging, or staying in the idle mode of their PEVs and every instant. Many Pricing mechanisms are not used for PEVs such as the Stepwise Power Tariff, Progressive Pricing Mechanism, and many others. These methods could have benefits to both PL/CS and PEV owners, therefore, this paper invites scholars, researchers and scientists to apply these methods of pricing and compare them to other used methods in order to know which pricing mechanism could have the highest benefits.

C. *Limitation of the Priority of charging and discharging*

The most of the papers don't consider the priority of charging/discharging of PEVs in a PL/CS, while other papers consider the priority based on a tariff paid by the PEV owner [69], [100], [103], the tariff is decomposed into three zones, high, medium, and low tariffs, if the PEV owner pays a high tariff, he gets immediately charging of his PEV even during on-peak period, while a low tariff may retard the period of charging.

Future work and recommendation: This paper recommends to apply the priority of charging/discharging PEVs at each instant, and to have a mathematical model for this priority in which it could be introduced in the constraint part of the optimization problem. Therefore, the clients with the highest priority will get the highest satisfaction services.

D. *Charging/Discharging schedule for a single PEV or a fleet of PEVs*

The previous strategies of charging and discharging modes could use a single charging/discharging schedule for (i) each PEV in a fleet of PEVs, or (ii) for a fleet of PEVs at the same time [12].

E. *Coordinated charging and discharging management*

The coordinated charging/discharging management of a single or fleet of PEVs could be done by (i) the aggregator (PL/CS) and it is called centralized charging/discharging schedule [12], [80], [210], [81], [211], [70], [114], [42], [63], [209], in which the aggregator has the full control of charging/discharging schedules of its PEVs respecting the constraints imposed by the PEV owners such as the final SOC, arrival and departure times etc. the aggregator use a single optimization technique to schedule the charging/discharging of PEVs [63], [41], [42]; or (ii) by each PEV owner and it is called decentralized charging/discharging schedule [82], [108], [80], [196], [211], [210], [166], [212], [109], [48], [158] in which the owner takes the responsibility to optimize his charging/discharging profile based on a price curve [41], [166], [212]. In the last case, the PEV could also be charged at home (usually at level 1 [41], [70]) without needing an aggregator.

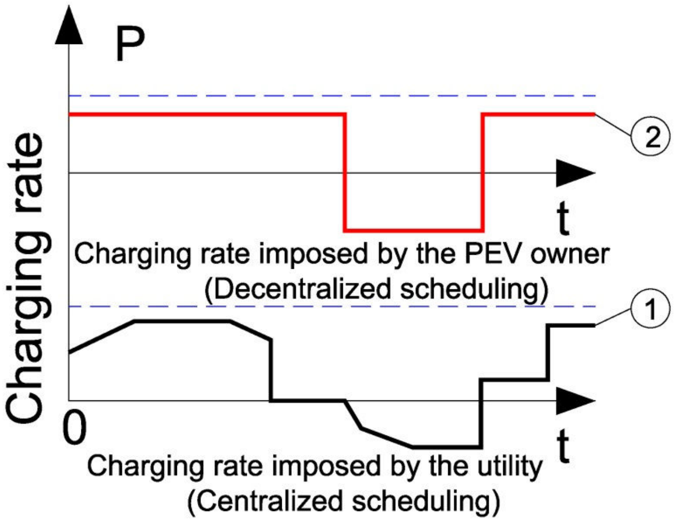


Fig. 20: Different charging/discharging schedules, (1) is for Centralized scheduling where the aggregator imposes charging rates on its PEVs, (2) is for Decentralized scheduling where the user (PEVs owner) imposes his charging rate.

TABLE IV. COMPARATIVE TABLE FOR THE ADVANTAGES AND BARRIERS OF EACH CONTROL METHOD

Scheduling Method	Advantages	Impediments and barriers
Centralized	• The overall charging cost of all PEVs is minimized [80], [12], • Satisfaction factor of the aggregator (PL/CS) is very high, • Power losses are minimized on the feeder or power network [81], [12] • Maintain the feeder within its operating constraints [81], [12],	• The charging cost of each PEV is not minimized, • satisfaction factor of the user is not very high, i.e. his final SOC may not attain his expectation, and the cost of charging/discharging is not minimized, • The amount of data increases significantly when the number of PEVs increases [42] • Large infrastructure to handle the data [42] • very complex structure [42]

Decentralized	• The charging cost of each PEV is minimized [80]. • Satisfaction factor of the PEV owner is very high. • Smaller infrastructure compared to the Centralized method for the same number of PEVs, • The Structure is less complex compared to the Centralized for the same number of PEVs,	• The overall charging cost of all PEVs is not minimized • satisfaction factor of the aggregator is not very high, in which the total [100], [211], [213]. • Power losses are not minimized on the feeder or power network [100], [211], [213], • The feeder may not be maintained within the operating constraints such as voltage violation, [100], [211], [213],

F. *Static and Dynamic charging/discharging*

The charging/discharging can be static or dynamic; in static charging the PEV owners should submit their schedules in advance before starting the charging/discharging modes such as their arrival and departure times, while in dynamic charging the PEV owners are allowed to plug in/out their PEVs at any time and the aggregator keeps calculating the optimal scheduling [100]. The advantage of the dynamic charging is that it offers more flexibility for the PEV owners, the disadvantage is that it requires additional computing time and it is more complicated [100].

G. *Predifined and real-time Coordination*

The Predefined Coordination is defined as the coordination of charging/discharging schedules of PEVs before they are plugged-in, in this case, the algorithm will find the optimal charging/discharging schedules of PEVs based on their supplied data, the most of papers used this type of scheduling. The Real-time Coordination is defined as the coordination of charging/discharging schedules of PEVs instantly after they are plugged-in, in this case, the algorithm will find the instant optimal charging/discharging schedules of PEVs based on their supplied data, some papers used this method such as [100], [103].

H. *Deterministic and Stochastic Load Profile and Energy Source*

The load profile is essential to calculate how much PEVs should be plugged-in at the same time, and it is used in the optimization techniques. However, the load profile could be deterministic [48], in which it is determined before starting the optimization techniques, the programming part is called Deterministic Programming. Or stochastic in which it has a stochastic profile and the optimization techniques could be used, and it is called Stochastic Programming [70]. The same for the energy source (such as PV, Wind turbine) in which it could be stochastic [39], or deterministic [24].

I. *Unidirectional or bidirectional power flow regulation*

The unidirectional power flow regulation (UPFR) supplies power to the PEV, and it is not possible to inject power into the grid from the PEV [41], [56], [70]. The bidirectional power flow regulation (BPFR) is defined as the power injected form the grid to the PEV (G2V) and from the PEV to the grid (V2G) [41], [56].

The UPFR uses diodes which are cheaper than the BPFR which uses MOSFET for low power, IGBT for medium power and GTO for high power [56].

If charging mode is only used, it is always unidirectional power flow regulation; if charging and discharging modes are used, they are bidirectional power flow regulation. But some studies such as [81], [39] only used unidirectional power flow regulation for the discharging process as a first step, in order to study its impact on the network before spreading the bidirectional power flow regulation. The hardware and software of bidirectional power flow regulation is much more complex than the unidirectional [81], [56], [214], the first is much heavier [56], more complex [56], it needs more space [56], it has a higher cost [56], its control is more difficult, and it has more constraints to be respected [56]. Moreover the infrastructure is much more complicated, and it should be updated. But the advantage of the bidirectional over the unidirectional power flow regulation is that it can participate in the voltage and frequency regulations on the power grid, the same for the active and reactive power regulations, etc. Its advantages are presented in Table I.

J. *Optimization techniques*

The optimization technique is very useful for the management of charging/discharging a single or fleet of PEVs on the same bus or transformer, it allows the power grid to optimize the integration of PEVs, and produce several benefits to the power grid. The optimization technique needs an objective function such as minimizing the total operation cost on the network, or reduce the total power losses, etc. The objective function could be a single objective function or multi-objective function [45], Constraints are also important to determine the availability of the solutions within the required limits.

In the linear programming the objective function and the constraints are linear, while for non-linear programming the objective function and/or some of the constraints are non-linear; the same concept is applied for other programming problems. The dynamic programming splits the optimization process into many time intervals and search the optimal solution at each time interval independently of other time slots [45], [215].

The optimization techniques are very helpful for the PSO in which it optimizes the penetration of generation sources, therefore, optimizes the total cost of operation, and minimizes the losses on the power grid, it is also important for the bus and transformer in which the penetration of PEVs respect their limits, and reduce the heating and overloading of the transformer. They are also important to the PL/CS in which the optimization maximize the revenue of the PL/CS, and minimize the charging cost respecting all constraints imposed by the PEV owners and the power grid. The optimization techniques is also important for the PEV owner in which incentive programs are used to encourage him to participate in the charging and discharging modes [45], [47], therefore, the cost of charging is minimized and the revenue from the discharging mode is maximized.

Some programs can be used to solve the optimization problem such as Microsoft Excel, MATLAB, LINGO, and AMPL (it has a free demo version for students) [216], and its solvers are: CPLEX [12], [38], Gurobi, Xpress, BARON, LGO, CONOPT, KNITRO, MINOS, SNOPT, GAMS [217], etc, a list of solvers is presented in [218],

The objective function and constraints have the following form

Objective function:

$$Minimize: Function(X) \tag{1}$$

Subject to:

$$A_{Ineq1}X \leq B_{Ineq1} \tag{2}$$

$$A_{Ineq2}X \geq B_{Ineq2} \tag{3}$$

$$A_{eq}X = B_{eq} \tag{4}$$

$$LB \leq X \leq UB \tag{5}$$

Where, X is a matrix of elements of the objective function, A_{Ineq1} , A_{Ineq2} , B_{Ineq1} , and B_{Ineq2} are matrices for the inequality equations of the constraints, A_{eq} and B_{eq} are matrices for the equality equations of the constraints; LB and UB are the lower and upper bounds of the X matrix.

There are different optimization techniques used by all papers to optimize the charging and discharging of PEVs in a PL/CS or even at home, these algorithms are categories into two main categories, (A) the first one is the conventional mathematical optimization methods such as (i) Linear Programing [43], [77], [78], [79], [80], [81], [109], [48]; (ii) Quadratic Programing [80], [82], [83], [70], [84], [70], [219], [63]; (iii) stochastic/deterministic dynamic programming [85], [86], [87], [70]; relaxed dynamic programming [88], [47]; (iv) Lagrange relaxation [85]; (vi) binary linear programming [78]; (vii) mixed integer linear programing [98], [80], [12], [85], [46], [39]; (viii) mixed-integer quadratic programming [90]; (ix) mixed-integer non-linear programming [210]; (x) stochastic programming [99], [39]; (viii) mixed-integer linear stochastic programming [39]; Maximum Sensitivities Selection optimization approach [103], [100], Game theory [220], [221], [45]; Queuing theory [222], [223]. (B) Meta-heuristic algorithms are also used for optimization problems [45], they are powerful optimization tools and can be used for both single and multi-objective functions [45], they are categorized into two categories, the first one is population-based methods in which they use population of solutions in order to find the optimal one, and the second one is trajectory-based methods in which they use solutions to trace a trajectory or path to the optimal solutions as the iterations continue [45], [224], the algorithm keeps updating solutions until finding the optimal one, this category is well known for its fast convergence and fast computational time compared to the traditional methods of optimization. The trajectory-based methods includes, (i) Hill-Climbing [225], (ii) Simulated Annealing (SA) [226], while the population-based methods includes (i) Ant Colony Optimization (ACO) [227], (ii) Biogeography-Based Optimization (BBO) [228]; (iii) Covariance Matrix Adaptation Evolution Strategy [229], (iv) Differential Evolutionary [230], (v) Estimation Distribution Algorithm (EDA) [231], [232]; (vi) Genetic Algorithm (GA) [89], [233], [234], Integer-Code GA [235], Lagrangian relaxation and GA [236], Non-Dominated Sorting GA II [237], a hybrid combination of Ant Colony Optimization (API) and Real Coded Genetic Algorithm (RCGA) called GA-API [238];(vii) Harmony Search (HS) [239], (viii) Particle Swarm Optimization (PSO) [49], [240], [241], binary PSO [242], [49], Balanced PSO [49], Evolutionary PSO [243], New PSO [244], Integer PSO [245], Hybrid PSO [246], Interior Point Based PSO [247], Quantum-Inspired PSO [248]; Teaching-Learning Based Optimization (TLBO) [249].

Many papers suggest their own optimization technique such as [106] in which they proposed a new Heuristic Algorithm for charging PEVs.

Future work and recommendations: many of these algorithms such as Differential Evolutionary, Biogeography-Based Optimization, Covariance Matrix Adaptation Evolution Strategy, etc. are not widely used in optimization technique for PEVs, therefore, it is recommended to use them as powerful tools to find the optimal solution and their fast computational time. It is also recommended to compare them with other techniques.

K. Important constraints and objectives to be considered in the study of charging/discharging schedules

There are several constraints and objectives which should be taken into account in the studies in order to design a good method for charging/discharging modes. The constraints and objectives are at many levels, (a) country level, (b) power network level, (c) bus level, (d) fleet of PEVs level such as parking lot, and charging station etc, (d) and PEV individual level. Paper [42] decomposes the objectives into three main categories, (i) Technical objectives in which it includes: minimization of energy losses, increase robustness, minimization of voltage deviation, support the integration of RES, balancing power supply and demand, reducing peak power demand, etc, (ii) Economical objectives such as minimizing the cost of charging (iii) Coupled Techno-Economical objectives in which it combines the two previous aspects influencing the total energy price to be paid by a client.

a- Country level: the main constraints are (i) limitation in the investments. The main objectives are (i) reducing the CO2 and harmful gases emissions [43], [12], [24], [39], [37], [41], [44], [109], [43], [39], [40], [49]; (ii) reducing the total operation cost [12], [41], [109], [42]; (iii) reduce the system average interruption duration and frequency indices [43], [250], (iv) reduce the utilization of fossil fuel from fossil plants [12], [109], and from PEVs [40], [41], [42]; (v) maximize the satisfaction of the clients [42], (vi) increase the integration of renewable energy [37], [38]; (vii) increase the penetration level of PEVs [76], [70], [115], [251], [252], [149], [253], [160], [109]; maximize social benefit [254], [42].

b- Power network level (also called Utility, or Power System Operator): the main constraints are (i) maintain the stability of the network, (ii) maintain the voltage and frequency within the required limits [83], [41], [69], [254]; (iii) maintain the harmonics within the required limits, (iv) maintain the current and voltage on the transmission lines within the required limits [83], [254]. The main objectives are: (i) reduce harmonics, (ii) reduce power loss [70], [41], [69], [70], (iii) minimize grid operation costs [12], [41], [42], [49]; maximize load factor [41], [61], [70], [162], minimize system demand [69], [107], reduce peak load [107], minimize load variance [162].

1. Renewable energy sources: the main constraints are: (i) minimum and maximum generation capacity limits [12]. The main objectives are (i) mitigate the variability of the renewable energy sources on the network [12], (ii) reduce the consumption of fossil fuel from non-renewable energy sources [12], [37], [39], (iii) reduce the operation costs of renewable energy sources including startup and shutdown costs [12], [39].
2. Transmission line level: the main constraints are: (i) respect the capacity of the transmission lines [12], and the power transfer limit [254]. The main objectives are (i) reduce transmission losses [12], [69]
3. Power plants (also Called Power Supply Enterprises [190]): the main constraints are: (i) minimum and maximum generation capacity [12], (ii) minimum and maximum reactive power that can be generated by a generator [12], [254]. The main objectives (i) minimize the operation costs including startup and shutdown costs of generators and other units [12], (ii) turn off generators (diesel) when the demand is not high [12],

c- Bus level (also called Distribution System Operators [63]): the main constraints are (i) respecting the limits of the transformer or substation such as its current and voltage capacity, temperature limits, its rated load, etc [43], (ii) maintain the voltage and frequency within the required limits [83], [69], [254], (iii) maintain the stability on the bus, maintain the total demand power below a peak demand level [69]; maintain the power factor within a certain margin. The main objectives are: (i) reduce the instability on the bus, (ii) regulate the power flow (active and reactive power) [12], (iii) reduce harmonics, (iv) reduce power loss and energy loss [12], [70], [69], [42], (v) reduce the unbalanced power flow between phases [62], reduce the heat in the transformer in order to reduce its life loss [43], minimize system demand [69], minimize voltage deviation [42].

d- Aggregator level (such as PL/CS, also called the Charging Service Provider [63]): the main constraints are (i) respecting all constraints imposed by the PEV individual level and the bus level, in addition (ii) following the pricing schedule [82], (iii) arrival and departure time of all PEVs [78], (iv) charging/discharging rate of PEVs (also called power rate) is limited between a maximum and minimum values [83], [12]; (v) initial and final SOC of all PEVs, (vi) respecting voltage and frequency constraints on the bus [83], [69], [254], [47], (vii) batteries capacity limits [83], [12], (viii) maintain the line currents and voltages of the infrastructure within the required limits [83], (ix) maximum energy of PEV fleet that can be supported, (x) power limits imposed by the bus level, (xi) storage capacity limits of all PEVs [12], maximum and minimum charging/discharging rate of all PEVs [12], number of PEVs that can be supported in the PL/CS; efficiency of the charging/discharging modes [12]; on/off-board charger constraints such as unidirectional/bidirectional power flow and maximum power rate [41]. The main objectives are: (i) maximizing the profit from both charging and discharging modes [83], [39], (ii) maximizing the number of clients in a day, (iii) control the power flow (active and reactive power) [12], (iv) prevent to introduce harmonics into the grid and participate in reducing harmonics on the bus, (v) reduce the unbalanced power flow between phases [62].

e- PEV individual level: the main constraints are (i) follow pricing schedule or not [82], (ii) arrival and departure time [78], (iii) initial and final SOC, (iv); (v) battery capacity limits [83], (vi) maximum and minimum energy limits of the battery [12], (vii) minimum and maximum charging rate limits imposed by the PEV owner [12], (viii) charging/discharging/idle modes [12], (ix) starting location and destination [12], respecting the on/off-board charger capacity [41], (x) charging and discharging efficiency [49]. The main objectives are (i) minimizing the operation and charging costs [83], [12], [107], [106], [42], [39], (ii) maximizing the benefit from the discharging mode (if applicable) [12], [107], [45], [47], (iii) obtain the desired final SOC [107], [173], (iv) satisfy the PEV owner [173], (v) reduce the impact on the battery lifetime, for charging mode [173], for discharging mode [107], (vi) minimize the utilization of fossil fuel or gasoline used by PHEVs [40].

Optimization techniques require one or more objective functions and constraints, in which the solution will be available in a region respecting all constraints. A sample of optimizing problem is presented in the following figure:

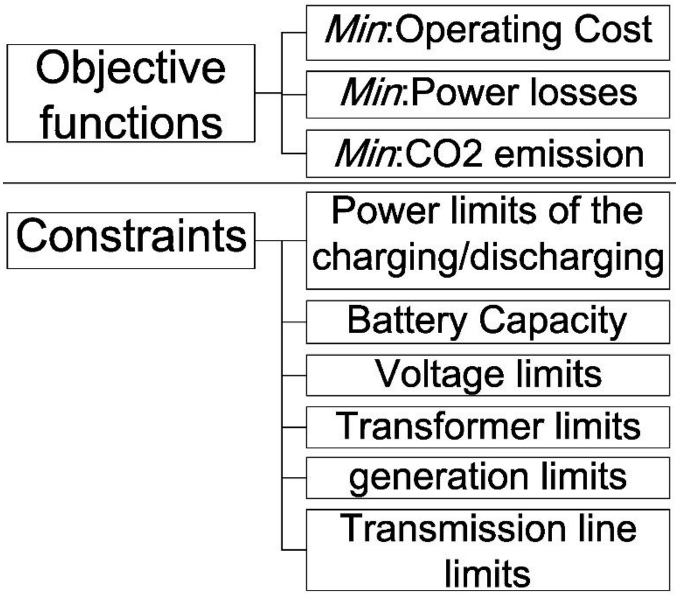


Fig. 21: Sample of main objective functions and constraints to be considered in the optimization.

Future work: this paper suggests including in the constraints part the following:

a) minimum and maximum SOC limits (i.e. 20 and 99%), in which the charging/discharging modes can't occur outside these limits,
b) The sufficient SOC for the departure (i.e. 80%), in which the owner is satisfied, it is not necessary to be fully charged,
c) annual growth rate of power demand on the bus [254], on the network, and the annual growth rate of PEVs on a certain bus,

L. Stochastic or deterministic model of the number of PEVs on a certain bus

Usually, the most of the studies consider stochastic models of the number of PEVs on a certain bus during a day, such as [43]. But it is possible to have a deterministic model if the arrival and departure time and SOC of all PEVs are known. The deterministic model is more accurate for a parking lot, or charging station, in order to price the energy and manage the charging/discharging of the PEVs on a certain bus on the PG. Papers [43] worked on this topic but it considered only that the arrival and departure time of PEVs are predetermined.

M. Arrival and Departure Time of PEVs in a PL

The arrival and departure time of PEVs in a PL could be (i) forecasted, in which the PL is able to know how much PEVs will be presented at each instant in the day ahead or for the next few hours [43]; (ii) deterministic, in which the arrival and departure time are known according to the connected PEVs at the same instant of their arrival, (iii) random [109], in which the time is considered as random therefore the distribution of PEVs during a day has approximately the same probability, (iv) stochastic [109], [106], in which the distribution of PEVs during a day has a stochastic form, and the Probability Density Function is used, (v) uniformly distributed between a certain period of time in a day [107].

N. SOC of PEVs in a PL/CS

The initial and desired SOC of PEVs could be (i) forecasted, the information of the initial SOC of PEVs are transmitted to the PL before a certain period of time (i.e. before one day, or at least several hours before charging/discharging processes), therefore, the PL knows how much demand on energy will be presented at each period in a day; (ii) deterministic, the information of the SOCs is known instantly when PEVs are connected to the grid, (iii) random [109], in which the SOCs are considered as random, (iv) stochastic [109], [106], in which the SOCs have a stochastic form, and the Probability Density Function is used, (v) uniformly distributed between two values [107].

O. Impact of charging/discharging modes on the infrastructure equipment

The impact of charging/discharging modes on the infrastructure equipment depends on many factors such as the number PEVs which are charging/discharging at the same time (also called penetration level) [56], [104]; the actual capacity of the infrastructure [56], [135], [255], including the capacity of the transformer, cables, metering, civil works, engineering works, and the whole system before the integration of PEVs; the charging rates of PEVs [56], [256], [257] (shown in Table II); the arrival and departure time of all PEVs; the initial and final SOC of all PEVs; the energy capacity of PEVs; unidirectional or bidirectional chargers and infrastructure [56]; number of chargers; participation in the discharging process of PEVs; limits of the stability of the system; limits of losses in the system; actual load on the feeder (transformer) before introducing PEVs; investment limitations for improving the infrastructure [56], [165]; degradation of the system's performance and lifetime [132];

There are mainly three definition of the penetration level of PEVs on a certain bus, (i) Papers [76], [106], [258], [40] define the penetration level of PEVs on a bus as the ratio of the number of PEVs and the total number of vehicles on the same bus, (ii) another definition is that the penetration level on a bus is considered as the number of PEVs over the total number of customers presented on the bus, (iii) in power systems the penetration level is defined as the power absorbed by PEVs at instant "t" over the total power absorbed at the same instant on the same bus. Many papers studied different penetration levels of PEVs such as [100]. Some papers found that a high penetration level of PEVs may affect negatively the power grid, even when applying the coordinated charging and optimization techniques [69].

Future work and recommendation: the penetration level should be limited to a certain percentage, therefore, an excessive study should be done to find what is the maximum allowed penetration level of PEVs on a certain, transformer, and bus.

P. Battery Swap Concept

The Battery Swap system (also called Battery Exchange System) is a concept in which an electric vehicle swap its battery by a new one fully charged in a PL/CS. Many studies were made on the concept of battery swap [96], Tesla Motors introduced this concept for Model S vehicles in 2013 [95], [259], and built a battery swap station in California, this station became operational in January 2015 [95], the interesting part of the project is that the station is able to swap out batteries in less than two minutes, but this concept had been stopped for many reasons such as, the battery swap is costly, the drivers should make an appointment to use it, and the most of the users prefer to charge batteries using superchargers which is available for free. Another advantage of the battery swap system is that the batteries will be owned by a company such as Tesla Motors and the cost of the PEV will be reduced, because the price of the battery is not included in the price of the vehicle, the company has the complete control of the recycling of batteries [96].

Future work and recommendations: The battery swap system is very useful for both drivers and PL/CS in which the drivers will obtain a very fast service, and the PL/CS will have enough time to charge the standby batteries during off-peak time. Therefore, reduce the stress on the power grid and the batteries, and reduce the charging rate on the batteries, hence increase their lifetime (reduce their life loss). Another important factor is that the standby batteries in the PL/CS will participate in the power flow regulation even when vehicles are not presented in the PL/CS. Our recommendation is that the PL/CS increase the cost of supercharging the PEVs in a way to be in the same price range of the battery swap. This paper suggests the using of incentive programs for the battery swap such as High Charging Rate-High Price (HCR-HP), this will encourage the drivers to use the battery swap concept more than supercharging.

V. THE NUMBER OF PHASES USED TO CHARGE/DISCHARGE PEVS

Many manufacturers have designed their PEVs to support charging using single phase or three phase connections. The organization “Society of Automotive Engineers” (SAE) developed a standard named SAE J1772 in which it defines how the plug receptacle (charging plug) of the PEV should be designed [170], [171]. Mainly there are two concepts of charging/discharging, the first one has a fixed charging phase, and the second one has a switched charging phase.

A. Fixed Charging phase

The fixed charging phase is defined as the charging mode of PEV using a single phase that doesn’t switch to another single phase in a three phase system. The most of charging stations, parking lots, and individual charging points are using this method. The disadvantage of this method is that if a large number of charging PEVs are connected on the same phase, the total load is unbalanced and may cause problems on the PG and the transformer could be overheated and damaged.

B. Switched Charging phase

The switched charging phase is defined as the charging mode of PEV using a single phase that is able to switch to another single phase in a three phase system. This method is used to balance the total load in a charging station, parking lot or any fleet of chargers located at the same bus and transformer. Some papers used this method such as [62].

The main advantages of this method are: (i) reducing the distribution transformer loading [62]; (ii) improving the voltage profile on all phases [62]; (iii) reducing the current amplitude on the most loaded phase [62]; (iv) improve the current profile [62]; (v) balancing the load [62]; (vi) protect the infrastructure of the PL/CS from overloading.

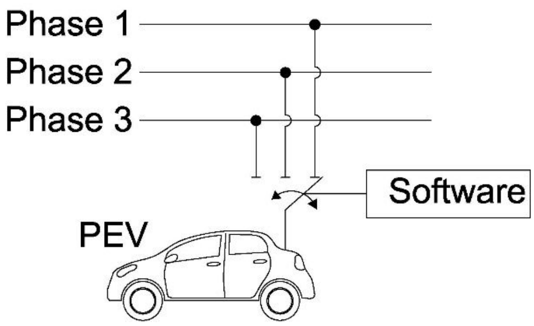


Fig. 22: Switched Charging Phase is controlled by software.

VI. CONCLUSION AND FUTURE WORK

This paper presents a review on different charging and strategies of the electric vehicles. It shows that Strategy 1 and 2: These strategies are not recommended to be implemented when the number of PEVs on a bus is large enough to cause negative impact on the power network. Strategy 3 and 4: These strategies are not recommended to be implemented when the number of PEVs on a bus is large enough to cause negative impact on the power network. They may only be used when the number of PEVs on a bus is not too large. Strategy 7: The current papers that study this strategy don’t fix a power limit on the bus, therefore, even during the charging mode at off-peak time, the total load power on the bus (initial load + PEVs charging power) may overpasses the power limit imposed by the Power System Operator (PSO) on the bus. Hence, it is recommended to consider the limits of the bus, which ensure that the total power doesn’t exceed the power limit.

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