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Cost Benefit Analysis using G2V and V2G Integrating Solar Energy

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Abstract
Energy storage has a vital role to play while integrating solar energy in to local grids. EVs as energy storage device , if used properly , may lead to enhanced capacity utilization of solar power plants and flatten the load curves and reduce the over generation. EV can be charged when there is an over generation and discharge as per the need. In this paper it has been demonstrated that by scheduled charging and discharging of EVS (G2V and V2G) the load curve flatten and the net charging cost also decreases. The actual time data of a power utility has been used to show it effectiveness.

Keywords: Electric vehicles, Vehicle-to-Grid (V2G), Grid-to-Vehicle (G2V), Convex optimization, Smart grid

INTRODUCTION

High level integration of renewable energy into the local grid leads to over generation; thereby reducing the benefits of adding more and more solar and may even lead to negative capacity values[1]. To overcome this, energy storage devices shall be employed; storing energy when it is surplus and feeding it back to supply system during the peak load condition. There is an additional advantage of flattening the load curve [2]. Battery energy storage system has been traditionally used for such applications [3]. More and more advanced batteries are commercially available and are used for power system level applications which are kept at power distribution stations and are available at all the times.

With the increase in Electric vehicle in near future, which uses battery for storage of energy, Electric vehicle is a good option for distributed Energy Storage System. Since, Electric vehicle are generally moving and there charging and discharging adds to the complexity of power system operation. The unscheduled charging of Electric vehicles lead to inefficient operation of our power system. However, scheduled charging will assist in better planning of distribution system, reduction in cost and efficient operation [4]. Nonetheless, the Electric vehicle as energy storage device may be used as regulation reserves as well as operating reserves. It provides fast frequency response and load balancing, ramping, load following, renewable capacity farming, electrical energy time-shift and voltage support [5].

Due to growing concern on environmental issues such as the introduction of EVs in our electric system will change the load profile completely. It will increase overall demand of electric energy which would require new power plants. So an optimal

Charging scheme must be adopted for coordinated charging [6]. Moreover, EV can also help in peak shaving by providing energy when demand it at its peak. The discharging of battery to the grid is known as Vehicle to Grid (V2G). So EVs can be charged when the energy demand is less and discharged during peak hours when demand is high. It is beneficial for both grid operators and EV owners as it reduces the burden on grid during high demand and EV owners can provide power to the utility during high demand at higher rates. By applying any of the schemes which helps in scheduled charging and discharging of an electric vehicle, system profile can be flattened to some extent which results in reduction of the capital costs and operational costs [7]. Three schemes have been devised for the optimal scheduling of charging and discharging to reduce the overall charging cost. In System Level optimal scheduling scheme, charging and discharging of all the EVs during day time is considered and charging power is optimized to get minimum cost. But this scheme is not practical because it requires data related to the future loads and arrival time of different EVs and their charging period in advance. While in Group Level optimal scheduling scheme, only ongoing EV sets are considered. This scheme works in an independent way and scalable to large EV population and different EV arrival. In equal allocation scheme, the allocated power of an electric vehicle is based on electricity price on the previous day in any interval and the charging power is equal in each interval. The total cost for each scheme is calculated. And the suggested scheme for optimal charging is Group Level optimal scheduling scheme. Although minimum cost is obtained in System Level scheduling scheme but that is impractical and the cost found in Group Level optimization scheme is quite closer to the System Level optimization scheme.

PRESENT WORK

In the present work the application of EVs as energy storage system for integrating large scale solar energy is demonstrated. The load curve is flattening and there cost is minimized. The actual load data of an Indian utility of a metro city is used for the study

Two optimal scheduling schemes have been proposed and then compared to reduce the net charging cost of the EVs. In the System Level scheduling optimization problem, the objective function is to minimize the cost and is subjected to constraints which are linear. In Group Level scheduling optimization problem, an algorithm has been developed. In equal allocation scheduling, the total charging and discharging power of an EV in an interval is calculated depending upon the price of electricity price on the previous day.

A. System Level Scheduling Optimization:

In this scheme, set of EVs are denoted by 'P' is considered which consist of two types of EVs. One is charging only set P^{CHG} which includes EVs which only charge their battery. Other types of EVs are V2G, P^{V2G} EVs which include EVs that perform charging as well as discharging. The total number of intervals is 'X' and the length of the interval is 'l'. Let w_{pi} is the total charging power of an EV m at interval i. For the charging power greater than zero, EV charges its battery. If the charging power is less than zero, EV discharges its battery. The charging only EVs set have charging power greater than or equal to zero while the V2G EVs set may have positive, zero or negative charging power in interval i as energy flows from grid to EVs as well as from EVs to grid. The charging period (T_p) should be in between the arrival time and departure time of the EVs.

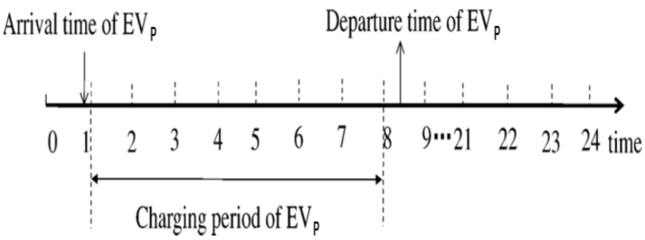

Figure 1: Charging time of EV p

Here, the capacity of battery of an EV p is denoted by E_p^{cap}. And EV p is charged at the station during its charging time till its departure time. And this final energy of EV p should be less than battery capacity. In the real pricing model, two assumptions have been made. The first assumption is that the losses during transmission are less and they can be neglected and the second assumption is that there is no congestion in transmission. By these assumptions variation of electricity price can be neglected and the electricity price is assumed to be constant at a particular time instant [4], [5]. So the electricity price can be taken as a linear function of the instant load [5], which is given as follows:

$$V(z_t) = g_0 + g_1 z \quad (1)$$

Where g_0 is intercept and g_1 is slope and z_t is the total load at time t. The total load can be divided into two parts; base load and charging load. Base load consists of total energy consumption excluding charging loads of EV. The charging load is due to the charging of an EV. Base load is assumed to be constant in an interval. If the load is less as compared to the generation on the grid, EV will be charged at that interval. During that interval charging load is positive otherwise, it is negative. The total load in any interval is equal to the sum of base load and charging load. And both base load as well as charging load in any interval is assumed to be constant so total load will be constant. Based on linear pricing model, the charging cost in interval i is given by:

$$C_i = \int_{R_i^b}^{z_i} (g_0 + g_1 z_t) = (g_0 z_i + g_1/2\, z_i^2) - (k_0 R_i^b + k_1/2\, (R_i^b)^2) \quad (2)$$

The charging cost depends on the charging load. If the charging load is positive i.e. if EV is taking energy from the grid the charging cost will be positive and if charging load is negative i.e. EV is providing energy to the grid then charging cost is also negative in that particular interval. In System Level optimization scheme, all the EVs are considered and the arrival time and the departure time of each EV in the system are assumed to be known during which EVs perform charging and discharging. Further, the initial energy and the final energy of the batteries of EVs are known. A single central controller is present at the utility which collects all the information about loads and EVs and then performs calculation and gives optimized values of charging power. The total cost is the sum of the charging and discharging costs of all the EVs over the interval set X. The total cost is then given by

$$C_{tot} = \sum_{i \epsilon X}((g_0 z_i + g_1/2\, z_i^2) - (k_0 R_i^b + k_1/2\, (R_i^b)^2) \quad (3)$$

The major objective of the scheme is to minimize the total cost. This objective function is subjected to many constraints which are following:

Objective: Minimize

$$\sum_{i \epsilon X} ((k_0 z_i + k_1/2 z_i^2) - (k_0 L_i^b + k_1/2\, (L_i^b)^2) \quad (4a)$$

Subjected to:-

$$z_i = R_i^b + \sum_{p\epsilon P} W_{pi} f_{pi}, \forall i \epsilon X \quad (4b)$$

$$0 \le E_p^{ini} + \sum_{k\epsilon O^{(i)}} W_{pk} f_{pk}\, l \le E_p^{cap}, \forall p \epsilon P, \forall i \epsilon X \quad (4c)$$

$$E_p^{ini} + \sum_{i\epsilon X} W_{pi} f_{pi}\, l \ge \mu_p E_p^{cap}, \forall p \epsilon P \quad (4d)$$

$$0 \le W_{pi} \le U_{max}, \forall i \epsilon X, \forall p \epsilon P^{CHG} \quad (4e)$$

$$-U_{max} \le W_{pi} \le U_{max}, \forall i \epsilon X, \forall p \epsilon P^{V2G} \quad (4f)$$

B. Group Level Scheduling Optimization:

The System Level optimal scheduling scheme gives the minimum total cost of EV charging. But this scheme is not practical because it requires data related to the future load and arriving time of each EV is assumed to be known for the whole day in advance. Moreover, in this scheme there is only one central controller which may overrun if the number of EVs exceed beyond its limit. To overcome these limitations, a Group Level scheduling optimization problem is formulated. The result which is obtained from Group Level scheduling optimization scheme is quite close to that in the System Level optimal scheduling scheme. And this scheme is practical unlike the previous scheme. In this scheme, EVs are divided into different groups. EVs of an area can be considered in a group, in this way number of groups can be formed. There is a Local group controller (LGC) installed for each group. The LGC set up communication connections with the aggregator located in power system and with the charging stations of a group. The LGC receives the predicted loads from the central controller at the beginning and then collects the EV information of each group from the charging station and performs scheduling optimization and transfer data to charging station to charge or discharge the battery. The communications and controls between the local controller and aggregator in the Group Level optimization scheme are illustrated in Figure 2. Each local group controller performs scheduling and in this scheme future arrival of EVs is not known. Therefore, a sliding window has to be maintained at each interval to know the current set which is connected at the charging station and their respective charging power. Each EV has its charging period. Any EV will belong to the current sliding window if and only if that EV is charging or discharging during that period. Figure 3 shows the sliding window of an EV. The present set of EV charging is EVs {2,3,4} and sliding window is given by intervals {2,3,4,5,6}.

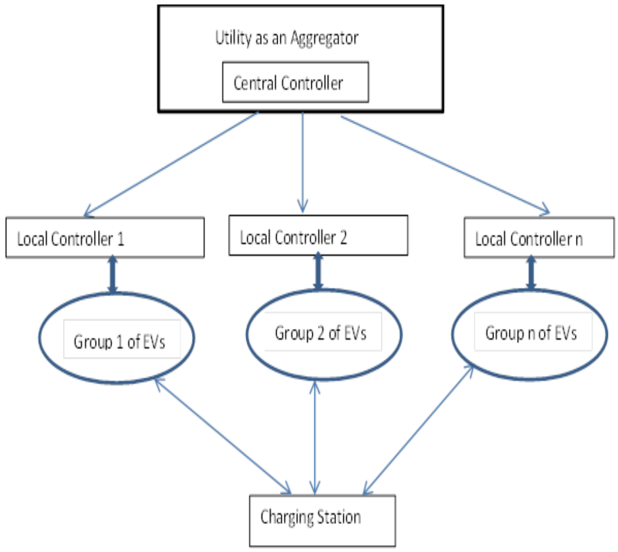

Figure 2: System Diagram for Group Level optimal scheduling scheme

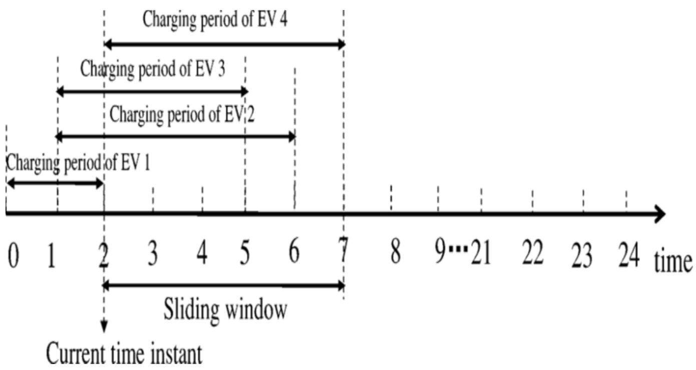

Figure 3: EV sliding window

EV1 has completed its charging before the current sliding window. Based on the all this current data, the Group Level scheduling optimization problem is formulated. And the objective and constraints are given as follows:

Objective Minimize:

$$\sum_{j\epsilon W_k^{(i)}} \left(\left(g_0 z_j + g_1/2\, z_j^2 \right) - \left(k_0 R_j^{bF} + k_1/2\, (R_j^{bF})^2 \right) \right) \quad (5a)$$

Subjected to:

$$z_j = R_i^{bF} + \sum_{p\epsilon Q_k^i} W_{pj} F_{pj}^{(i)}, j \epsilon M_k^{(i)} \quad (5b)$$

$$0 \le E_p^{(i)ini} + \sum_{d\epsilon o_k^{(j)}} W_{pk} F_{ps}^{(i)}\, l \le E_p^{cap}, \forall p \epsilon Q_k^{(i)}, \forall j \epsilon M_k^{(i)} \quad (5c)$$

$$E_p^{(i)ini} + \sum_{j\epsilon M_k^{(i)}} W_{pj} F_{pj}^{(i)}\, l \ge \mu_p E_p^{cap}, \forall p \epsilon Q_k^{(i)} \quad (5d)$$

$$0 \le W_{pj} \le U_{max}, \forall j \epsilon M_k^{(i)}, \forall p \epsilon Q_k^{(i)CHG} \quad (5e)$$

$$-U_{max} \le W_{pj} \le U_{max}, \forall i \epsilon X, \forall p \epsilon Q_k^{(i)V2G} \quad (5f)$$

In Group Level optimization scheme an algorithm is developed to implement the scheme. This algorithm is executed at the local load controller when central controller sends the predicted load to the Local controller. The local controller does the following steps:

1. Remain connected to each charging station present in a group to collect the current EV's information.
2. Find the present EV set and sliding window details.
3. Find the current charging interval matrix.
4. Solve the Group Level scheduling optimization problem to obtain the charging power.
5. Instruct EVs to perform charging or discharging with the obtained charging power.

PROCESS FLOW CHART

The Process flow chart for the given optimisation techniques is shown in Figure 4

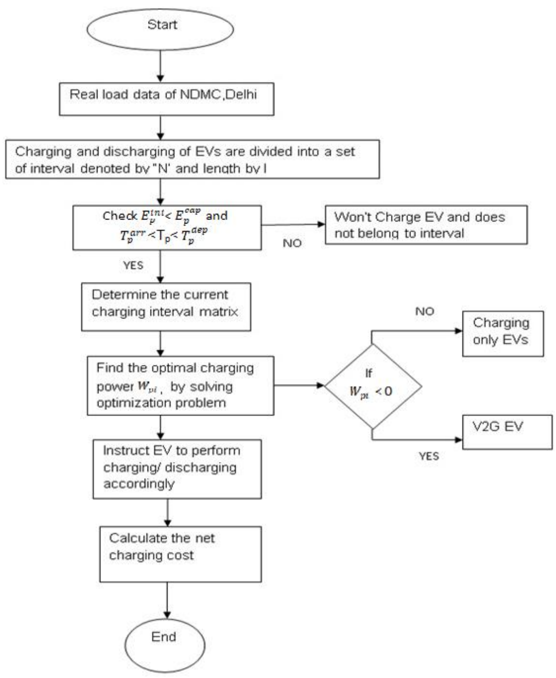

Figure 4: Process flow chart

RESULTS AND DISCUSSION

In System Level optimal scheduling scheme, real base load is used. However real base loads is not available in practical for the future. In Group Level optimal scheduling scheme, predicted base load is used, making scheme more practical. The actual time data of a power utility has been used to show it effectiveness.The base load, solar supply and net load are shown in Figure 5.

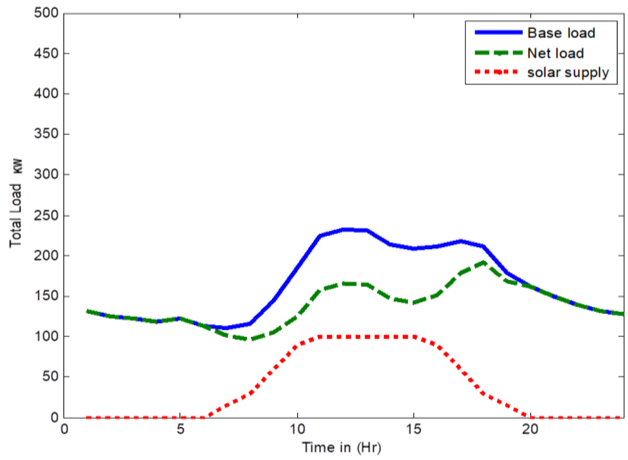

Figure 5: Base load and Net Load using Solar Supply

The variation of charging load with time is shown in Figure 6. It is shown that System Level optimization scheme and Group Level optimization scheme charge the EVs during off peak hours when demand is low(G2V), while discharge the EVs during peak hours(V2G) shown in Figure 6. The System Level optimization scheme flattens the load profile in interval 1-8, 10-17 and 20-22 to minimize the total cost as shown in Figure 7. The maximum power of EV is 10KW and energy is 80KWH. The System Level optimization scheme and Group Level optimization scheme calculate the charging power and discharging power by solving optimization problems. EV reaches to its final energy state at the end as shown in Figure 8. A set of 200 EVs is taken. All the EVs can perform charging(G2V) as well as discharging(V2G). It can be defined as ratio of EV which can perform charging to total no of EVs. Higher the charging only ratio means more number of charging only EVs which would result in higher cost in all the three schemes.

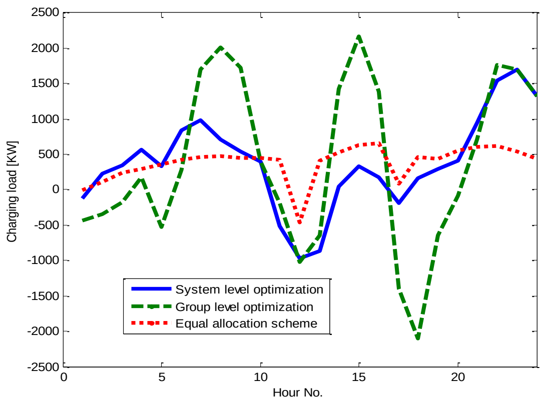

Figure 6: Variation of charging load with time

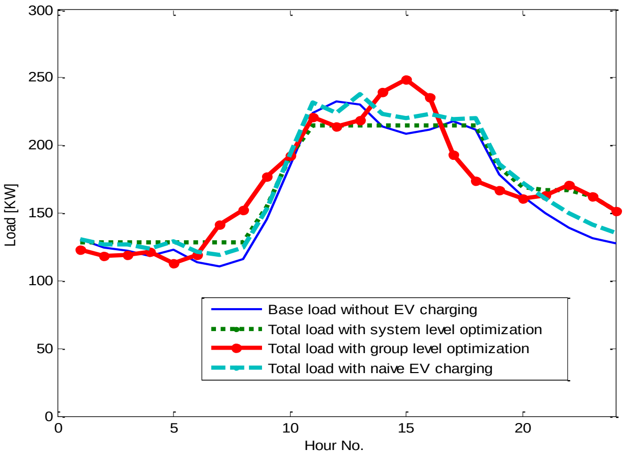

Figure 7: Load variation with time

Table 1: Charging Cost comparison of different schemes

Scheme Implemented	Total Cost (Rs.)
System Level optimization scheduling scheme	12634.4
Group Level optimization scheduling scheme	15537.8
Equal allocation scheme	16616.8

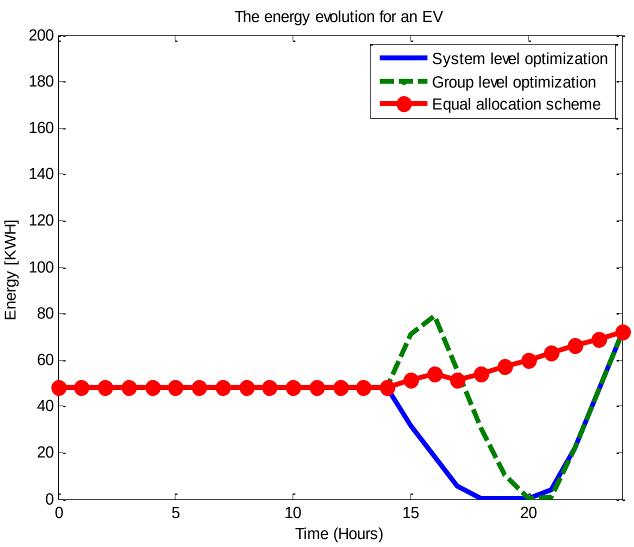

Figure 8: Energy variation of EV with time

In Group Level optimization scheduling scheme, local controllers are used to schedule the EVs in the groups consisting of random number of EVs. The performance of EVs with different group size is shown in Figure 9. In this paper, the total number of EVs are fixed i.e. 200. If we have large number of EVs in a group then number of groups will be less and vice versa. It is clear from the Figure 10 that larger group size is leading to lower total cost.

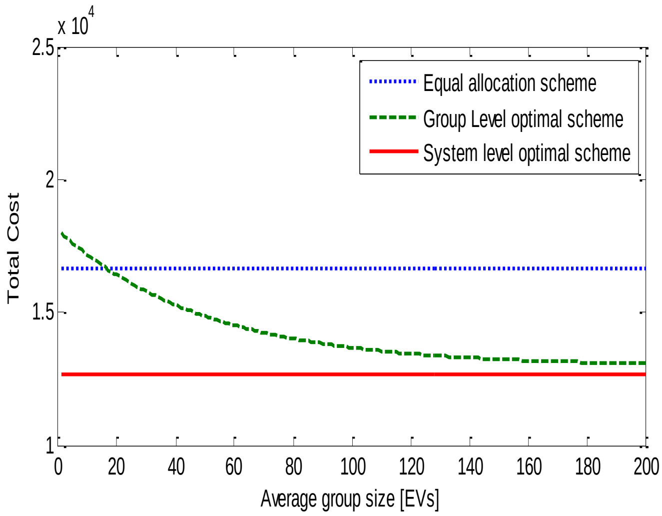

Figure 9: Effect on total cost under different group size

But in case of small number of groups, a load controller will have to communicate with more number of EVs which will include higher cost in data communication. In our work number of EVs is 200. We assume the number of EVs up to 400 and then integrated scheduled charging of EVs with the base load using System Level optimal scheduling scheme. Figure 10 shows that as we keep on increasing the number of EVs in a system it would results in flattening of load profile.

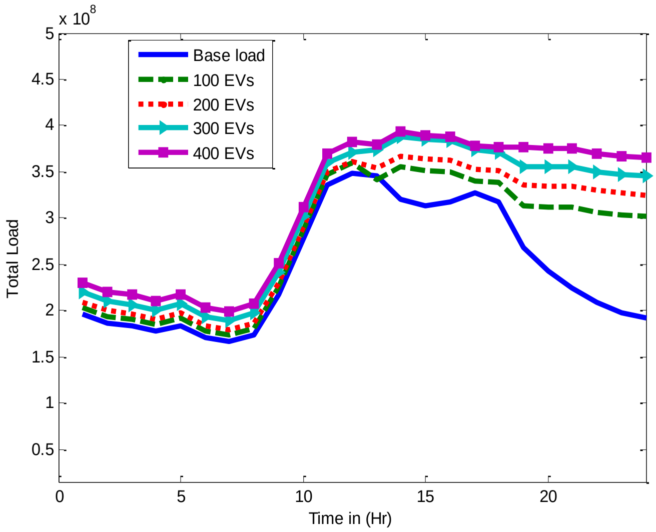

Figure 10: Total load with different number of EVs

CONCLUSION

The optimal charging (G2V) and discharging(V2G) power and minimum cost can be obtained by two schemes i.e. System Level scheduling and Group Level scheduling optimization schemes. The result of these two schemes are compared along with equal allocation scheme and it is seen that result of System Level optimal scheduling scheme provides the minimum charging cost but this scheme is not practical as it require future details such as base load and EVs charging load which cannot be determined earlier so Group Level scheduling scheme is preferred as the performance to this scheme is very close to System Level optimal scheduling scheme. Moreover, these schemes also flatten the load profile at some intervals and make best use of available solar energy.

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NOMENCLATURE

X	Set of interval
P	Electric Vehicles set
P^{CHG}	Set Charging-only EVs
P^{V2G}	Set Vehicle-to-Grid (V2G) EVs
W_{pi}	Charging power EV p in interval i
T_p	Charging period of EV p.
l	Length of an interval
E_p^{ini}	Initial energy of EV p.
E_p^{cap}	Battery capacity of EV p.
E_p^{fin}	Final energy of EV p.
U_{max}	Maximum charging power
μ_p	Final energy ratio of EV p.
z_i	Total load in interval i.
R_i^b	Real base load in interval i.
R_i^{bF}	Predicted base load in interval i.
y_i	Charging load in interval i.
g_o	Intercept in the cost model.
g_1	Slope in the cost model
C_i	Cost of EV charging in interval i
S	Group Set
M_k^i	Sliding window for interval i in group k
Q_k^i	Ongoing EV sets in interval i in group k.
$Q_k^{(i)CHG}$	Charging only EV set at starting of interval i in group k
$Q_k^{(i)V2G}$	V2G EV set at starting of interval i in group k.
t_p^{arr}	Arrival time of EV p.
t_p^{dop}	Departure time of EV p.
t_p^{c-s}	Starting time of the EV p for charging
t_p^{c-e}	Finished time of charging of EV p
F	Charging interval matrix
$O^{(i)}$	Previous interval set of interval i