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Allocation of appropriate charging station and intelligent charging scheduling for on-road electric vehicles

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Electrification of vehicles is an upgraded solution to deal with global warming. Although, anxiety related with Electric Vehicle (EV) usage is a great challenge to deal with. To avoid anxiety, selection of "appropriate" charging station at right time is necessary. Concomitantly, charging of EVs in uncoordinated manner can be stressful for the grid causing power loss, and instability issues. Hence, in this paper, a new intelligent "Strategy for Appropriate Charging Station Assignment and Intelligent Scheduling" (SACAIS) algorithm has been proposed. In the first layer of algorithm, the relevant charging station and the shortest path to reach the assigned Charging station for individual EVs has been done. After that, a combined scheduling of the vehicles has been done to minimize the total daily charging cost incurred by CSO considering grid to vehicle (G2V) and Vehicle to grid (V2G) mode simultaneously in the second layer of algorithm. Later to validate the robustness of the optimization techniques, Wilcoxon Signed Ranked Test and Quade test has been performed.

Keywords: Charging scheduling, Dijkstra's algorithm, grid to vehicles (G2V), linear programming, optimization techniques, vehicles to grid (V2G).

Introduction

In this Anthropocene period, Global warming, urbanization, and growing consumption of fossil fuels disrupting the ecological balance hastily. Bring back the balance between human made infrastructures and ecology required to be addressed as a significant component to renovate the energy entree. From the literature, it can be seen that, air pollution has the biggest impact on the environment[1a]. The fossil fuel driven vehicles are mostly responsible for the air pollution and to reduce it, deliberately, people are tending towards the electric vehicles (EV), because of its zero emission features[1b]. However, the main anxiety of EV drivers are "WHEN" and "WHERE" to charge the EV. Due to the poor charging infrastructure and planning, most of the charging stations (CS) are suffering from long queues and sudden breakdown at middle of the road. Besides these, they are suffering from long queues in CS, as they are unknown about the slot availability. In literature[1c], the authors were focused on the design of EVs. In[1d], the authors were focused on Electric vehicles Supply equipment (EVSE) to improve the charging infrastructure, but very few researchers dealt with the anxieties of EV owners. Therefore, more exploration is required to get rid of such anxieties as mentioned earlier. Smart strategies are needed to find out "appropriate" charging stations for charging EVs at apt time. In[1o], though relevant CS has been identified, but the shortest path to reach that CS has not been determined. In the other hand, charging of EVs in uncoordinated is another major concern, since it may create stresses on the utility, which may also cause increase of active power loss, instability, voltage sag and so many adverse effects[1e]. Many authors have taken various strategies to deal with this issue. In[1f], Vehicle to Grid (V2G) concept has been adopted as a remedy to deliver surplus power of the battery to the grid and can act as a spinning reserve[1g]. But here, the battery degradation has not been considered during V2G technique and simultaneous operation G2V and V2G mode of operation also missing. In the literatures[1h,1i], the authors have shown that, uncoordinated EV charging can cause more active power losses and therefore coordination of charging using dual mode of operation (G2V and V2G) can minimize the active power losses. Few of the authors introduced coordinated charging process, where, EV act as a load or sometimes as spinning reserve, for the grid[1j] (Lam *et al.* 2018), where EVs either working on G2V mode of operation or V2G mode of operation for a long duration. But the dual mode of operation at shorter time interval has not been found, which considered to be a major literature gap in charging scheduling process[1k-1l]. In literature[1m] simultaneous charging scheduling has been done in dual mode of operation (Jozi *et al*. 2017), but idle state of the vehicle (0 state) is missing. However, in[1n] (Tingting *et al.* 2018) idle state has been considered but in comprehensive manner, which needs to be elaborated more.

Therefore, from literature survey, it has been realized that, there are several major factors, which have not been well-thought-out in previous literatures. Consequently, in this paper, the major contributions are as follows:

(1) The selection of "appropriate" CS has been done by considering the availability of charging slots by using Integer Linear Programming (ILPP).

(2) The uncertainty of traffic congestions has been considered during charging scheduling.

(3) As per the status of loads in the grid and the dynamic tariff, coordination of G2V and V2G has been done in more frequent manner (at 30 min interval).

(4) A recent optimization technique named Henry Gas Solubility Optimization (HGSO) has been integrated with proposed SACAIS algorithm.

(5) Statistical non-parametric analysis has been performed to verify the consistency and robustness of SACAIS algorithm.

Problem layout

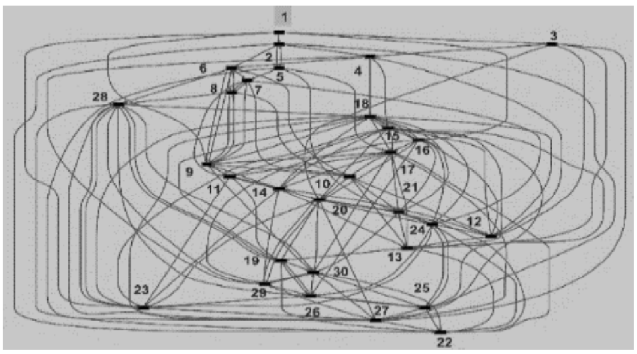


Fig. 1. Main network with directional path and 30 nodes.

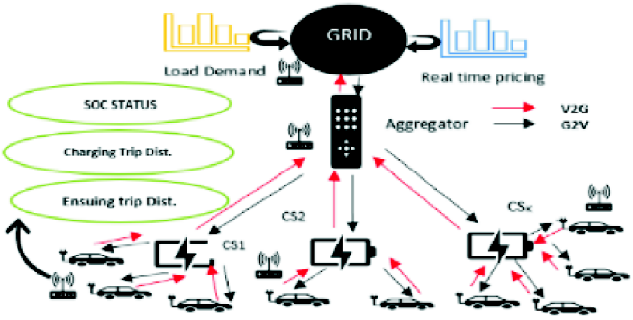


Fig. 2. Overall diagram of problem layout.

No circular path or self-loop path has been considered and all the paths are unidirectional. In Fig. 1, a road network with 30 numbers of nodes are shown, where these nodes are the road junction and the black lines implies the routes from one junction to another junction. In road junction 11, 17 and 22, three charging stations are there. Likewise, for higher node networks also the proposed algorithm could be applicable. The main anxiety works on EV drivers are regarding the actual timing and place of charge of the vehicles. It is always not necessary that, nearest charging station have to be the favorable one. It may happen that, the nearest charging station has a long queue or may be there are huge traffic congestion, which will cause the vehicles to breakdown at the middle of the road. This is a huge problem which needs to be taken care of.

But, due to the unavailability of the data regarding the traffic congestion, and to deal with these, from[1o], it has been observed that, generally traffic congestion follows Generalized extreme value (GEV) distribution. Therefore, this type of distribution has been considered to deal with traffic congestion.

After assigning appropriate charging station, the main challenge is to find out the apt path to reach the CS and afterwards its charging scheduling procedure needs to be done in such a manner, that the overall charging cost in minimum. Consequently, it is very important to know the driving pattern of the individual vehicles. To analyze the driving pattern of individual vehicles, the distribution pattern of daily arrival time, departure time, daily mileage and speed, needs to be known. In Fig. 2, the charging scheduling procedure has been shown, where multiple charging stations are there centrally controlled by the aggregator. This aggregator coordinate between the CS owner (CSO) and the grid. And as per the loading conditions and pricing set by the grid, CSO make the charging-discharging decision in such a way that, there will be win-win situation for both EV users and CSO.

Therefore, SACAIS can be alienated in two major level; in first level, the assignment of relevant charging station can be done and thereafter, in the second level of algorithm, the charging scheduling of those vehicles will occur with the objective to minimizing the daily charging cost.

Formulation of objective function

The main objective function is the diurnal total charging cost incurred by the CSO (C^{TOT}) as shown below.

$$\min\{C^{TOT}\} \tag{1}$$

which depends on total charging cost (C^{ch}) required for the dual mode of operation, which is the summation of G2V cost (C^{G2V}) and V2G cost (C^{V2G}).

$$C^{TOT} = f(C^{ch}, C^{bd}) \tag{2}$$

$$C^{ch} = f(C^{G2V}, C^{V2G}) \tag{3}$$

To calculate C^{G2V} and C^{V2G}, the corresponding equations are as follow, i.e.

$$C^{G2V} = \sum_{s=1}^{sl}\left(\sum_{pno}^{tp}(C_{Pno}^{s} - D_{Pno}^{s})\times c^{rate,Pno}\right)\times RTT(s) \tag{4}$$

$$C^{V2G} = \sum_{s=1}^{sl}\left(\sum_{pno=1}^{tp}(C_{Pno}^{s} - D_{Pno}^{s}).c^{rate,Pno}\right)\times RTT^{V2G}(S) \tag{5}$$

where, sl is the total number of slots, s is the slot number, tp is the total number of PHEVs, pno is the PHEV number, C_{Pno}^{s} is the charging strategy, D_{Pno}^{s} is the discharging strategy, $C^{rate,Pno}$ is the charging rate, which is considered to be 4 kWh (Charging an Electric Vehicle, [online]) and RTT is the real time tariff.

Again, due to discharge of battery during V2G, battery ageing occurred. Hence, battery degradation cost (C^{bg}) due to the has been considered, which depends on various factors which can be found in[1p]:

$$C^{bg} = \sum_{pno=1}^{tp}\left\{\frac{C^{batt,Pno}\times Batt^{cap,Pno} + Cost^{lab})\times|E^{V2G}|}{(LC^{batt}\times Batt^{cap,Pno}\times DD)}\right\} \tag{6}$$

Constraints in SACAIS

(1) Charging rates:

The charging rate ($C^{rate,Pno}$) should not exceed the rated power limit (PW^{rated}) as shown as below.

$$C^{rate,Pno} < PW^{rated} \tag{7}$$

(2) Energy requirements:

Required energy (E^{req}) must be fulfilled within the particular time interval for individual vehicles so that, with particular charging rates.

$$\sum_{s=s\_in}^{s\_out} ST_{Pno}^{s}.\, c^{rate,Pno} = E^{req} \tag{8}$$

(3) Battery SOC:

The SOC of the battery should not go below the 20% or the SOC must not exceed its maximum value.

$$SOC^{min} \le SOC_{Pno}^{s} \le SOC^{max} \tag{9}$$

(4) No. of charging stations:

The number of charging station (CS^{K}) should be less than the number of vehicles (Pno).

$CS^{K} < Pno$, where, $k \in$ no. of charging stations (10)

(5) Charging and discharging strategy:

To assess the charging (C_{Pno}^{s}) and discharging strategy (D_{Pno}) as shown as follows:

$$C_{Pno}^{s} = \left[C_{Pno}^{1}, \ldots\ldots, C_{Pno}^{S\_in}, \ldots C_{Pno}^{s} \ldots, C_{Pno}^{S\_out}, \ldots\ldots, C_{Pno}^{sl}\right] \tag{11}$$

$$C_{Pno}^{s} = \begin{cases} 1, \text{ if } ST_{Pno}^{s} = 1, \forall\ s \in P^{s,Pno}, \forall Pno \in \vec{Z} \\ 0, \text{ or else} \\ 0, \forall\ s \notin P^{s,Pno}, \forall Pno \in \vec{Z} \end{cases} \tag{12}$$

$$D_{Pno} = \left[D_{Pno}^{1}, \ldots, D_{Pno}^{S_{in}}, \ldots\ldots, D_{Pno}^{S_{out}}, \ldots\ldots, D_{Pno}^{sl}\right] \tag{13}$$

$$D_{Pno}^{s} = \begin{cases} 1, \text{ if } ST_{Pno}^{s} = 1, \forall\ s \in P^{s,Pno}, \forall Pno \in \vec{Z} \\ 0, \text{ or else} \\ 0, \forall\ s \notin P^{s,Pno}, \forall Pno \in \vec{Z} \end{cases} \tag{14}$$

To calculate the (11) and (13), (12) and (14) have been used.

The charging strategy for PEV_no^{th} vehicle can be defined by,

$$ST_{Pno} = \left[ST^1_{Pno}.., ST^{S_{in}}_{Pno}, ... ST^s_{Pno}.., ST^{sout}_{Pno}, .., ST^s_{Pno}\right] \quad (15)$$

$$ST^s_{Pno} = \begin{cases} 1, & charging \\ -1, & discharging, \ \forall Pno \in \vec{Z} \\ 0, & idle \end{cases} \quad (16)$$

where,

$$\sum_{slot=s\_in}^{s\_out} ST^s_{Pno}.\, c^{rate,Pno} = E^{req}, \forall \ Pno \in \vec{Z} \quad (17)$$

The energy discharged by all the vehicles can be formulated as,

$$E^{V2G} = \sum_{s=1}^{sl} D^s_{Pno} \times c^{rate,Pno} \ \forall \ Pno \in \vec{Z} \quad (18)$$

Again, the parking duration for PEV_no^{th} will be given by,

$$P^{s,Pno} = [t_{in,Pno}, .., t_{Pno}, ..., t_{out,Pno}] \quad (19)$$

The time horizon vector is given by $\vec{T}$, where the 24 h in a day has been divided into 48 equal slots and each slot is of 30 min.

$$\vec{T} = [1, .., s, ., s] \quad (20)$$

The number of cars arriving in a parking lot is denoted by the vector $\vec{Z} = [1, .., Pno, ... tp]$ (21)

Energy modelling

In order to satisfy the constraints, in (8), the equation for energy modelling eq. is given as follows.

$$E^{req} = SOC^r . Batt^{cap} / \eta^{ch} \quad (22)$$

$$eng_{dis}{}^{req} = SOC^r . Batt^{cap} . \eta^{dis} \quad (23)$$

where, $\eta^{ch} \in$ charging efficiency and $\eta^{dis} \in$ discharging efficiency.

Now, to calculate SOC^r, the corresponding eq. is be given by,

$$SOC^r = \begin{cases} 1 - SOC^{av}, & when, \ SOC^{dp} > 1 \\ (SOC^{dp} - SOC^{av}), & when, \ SOC^{av} < SOC^{dp} < 1 \\ 0, & when, \ SOC^{av} = SOC^{dp} \\ -(SOC^{av} - SOC^{dp}), & 0.2 < SOC^{dp} < SOC^{av} \end{cases} \quad (24)$$

where, SOC arrival (SOC^{av}) and SOC departure (SOC^{dp}) can be calculated by (25) and (26)[1q].

$$SOC^{av} = \left[1 - \left(d^{ch} / AER\right)\right] - E_{con} \quad (25)$$

$$SOC^{dp} = \left[\left(ETL / AER\right) + 0.2\%\right] - E_{con} \quad (26)$$

Solution strategy of SACAIS

First layer

In this layer, appropriate charging station for each and every vehicle needs to be determined. To deal with this issue, Integer Linear Programming Problem (ILPP), has been used. Here, p be total number of PHEVs and chs be the total number of Charging stations *(CSs)*, where $p, chs \in \{Z^+\}$. Now, matrix C, named assignment matrix, which can be expressed as $C\ (chs, p)$ where each PHEVs can be assigned to CS_{chs} and it is the combination of assignment problem[1r] and as well as transportation problem[1s].

Due to dynamic nature of EVs, instead of (C (chs, p)), it can be modified as (C (chs, p, t)), where, $t \in$ time.

The main objective is to keep the SOC^{av} at its maximum value, to find out the appropriate charging station.

$$max\ \{SOC^{av}(chs, p, t) - \sum_{chs=1}^{chs} \sum_{e=1}^{e} (E_{con}(chs, p, t) . x(chs, p, t)) \quad (27)$$

where, $E_{con} \in$ consumption of PHEV's energy to reach its appropriate charging station and x (chs, p, t) is the decision variable. Here,

$$(chs, p, t) =$$

$$x(chs, p, t) = \begin{cases} 1, & \text{if } EV_p \text{ is assigned to } CS_{ch} \text{ at time } t \\ 0, & \text{otherwise} \end{cases} \quad (28)$$

Subjects to,

$$\sum_{ch=1}^{CS_{chs}} x\ (chs, p, t) = 1, \forall \ EV_p \quad (29)$$

where, $1 \le p \le EV$ and each vehicle can be reach only one charging station at a time and $p \rightarrow Z+$

$$\sum_{p=1}^{EV_p} x\ (chs, p, t) \le CS_{chs}, \forall \ CS_f \ \rightarrow Z+ \quad (30)$$

where $1 \le chs \le CS_{chs}$ the capacity of each charging station should not exceed its maximum limit.

The first trip length d^{ch} should be the more than or equal to distance of EVs from charging stations dis^{p_chs}.

i.e. $dis^{p\_chs} \le d^{ch}$ (31)

Energy modelling for ILPP

The energy consumption at ideal condition and the practical condition are given by[1t].

$$E_{con} = \frac{Batt^{cap,p}.d^{ch}}{AER^{p}} \tag{32}$$

$$E_{con} = \frac{Batt^{cap,p}.d^{ch}}{AER^{p}} \times ECM \tag{33}$$

The empirical formula for urban type road has been shown below, where ECM is the Energy Consumption Multiplier[1u].

$$ECM = 0.21 + \left(\frac{1.531}{V^{m}}\right) - 0.001\,V^{m} \tag{34}$$

Here, V^m is the modified speed, which has been derived from the Greenshields's traffic congestion model[1v].

Using linear regression model using (35), the relation between the change of velocity and jam density has been shown[1w].

$$V^{m} = \nu^{f}\left[1 - \left(\frac{k^{d}}{j^{coff}}\right)\right] \tag{35}$$

where, ν^f is the free flow velocity, k^d is the jam density and j^{coff} is the jam coefficient.

Since jam density is uncertain in nature. Therefore, statistical distribution has been considered which follows GEV distribution[1x]. This is the combination of Fréchet, Gumbel, and Weibull distributions.

$$(k^{d}\,|k, \sigma, \mu) = \left(\frac{1}{\sigma}\right) \times \exp\left(-\left(1 + k.\frac{k^{d} - \mu}{\sigma}\right)^{-\frac{1}{k}}\right) \times \left(1 + k.\frac{k^{d} - \mu}{\sigma}\right)^{-1-\frac{1}{k}} \tag{36}$$

Dijkstra's algorithm

After allotment of EV to their appropriate CS by ILPP, it is important to reach the corresponding CS using the shortest path from the current location of the EV, considering battery capacity constraints. Here, the shortest route has been identified using Dijkstra's algorithm. This can be called a greedy algorithm also (Grbac *et al.* 2017).

Algorithm for Dijkstra's shortest path

Initialisation

$S = \phi$ where, $s \in set$ 1, which contains vertices for which shortest path has been finalised.

$q = V[G]$; $Q \in$ set of vertices for which the shortest path is yet to be finalised.

while $Q\,! = \phi$

{

U = extract Min (Q) using heap sort;

$S = S \cup \{U\}$;

for each $\nu \in Adj\,[U]$ and not in Q

{

If $(d\,[\nu] > d\,[U] + \omega)$

{

$d\,[\nu] = d\,[\nu] + \omega$;

$\pi\,[\nu] = U\pi \in$ set of parent nodes or predecessors

}

}

}

End

Second layer

After reaching of EVs to its corresponding charging station, using telemetric system of EVs, arrival SOC, and charging status can be fetched. But here, for experimental purposes, these values have been determined. Thereafter, the Charging Station Operator (CSO) set its charging process using dual mode of operation.

Henry's gas solubility optimization

For minimization of diurnal charging cost, Henry's gas solubility optimization (HGSO) can been used[1y].

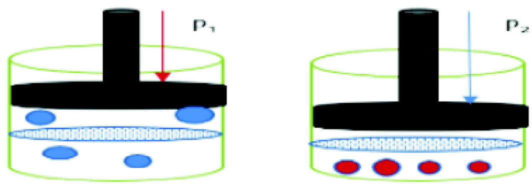


Fig. 3. The concept of HGSO, where, pressure ($P_2 > P_1$) and this will continue until all the gas molecule dissolves until it reaches to its equilibrium.

Flowchart of HGSO

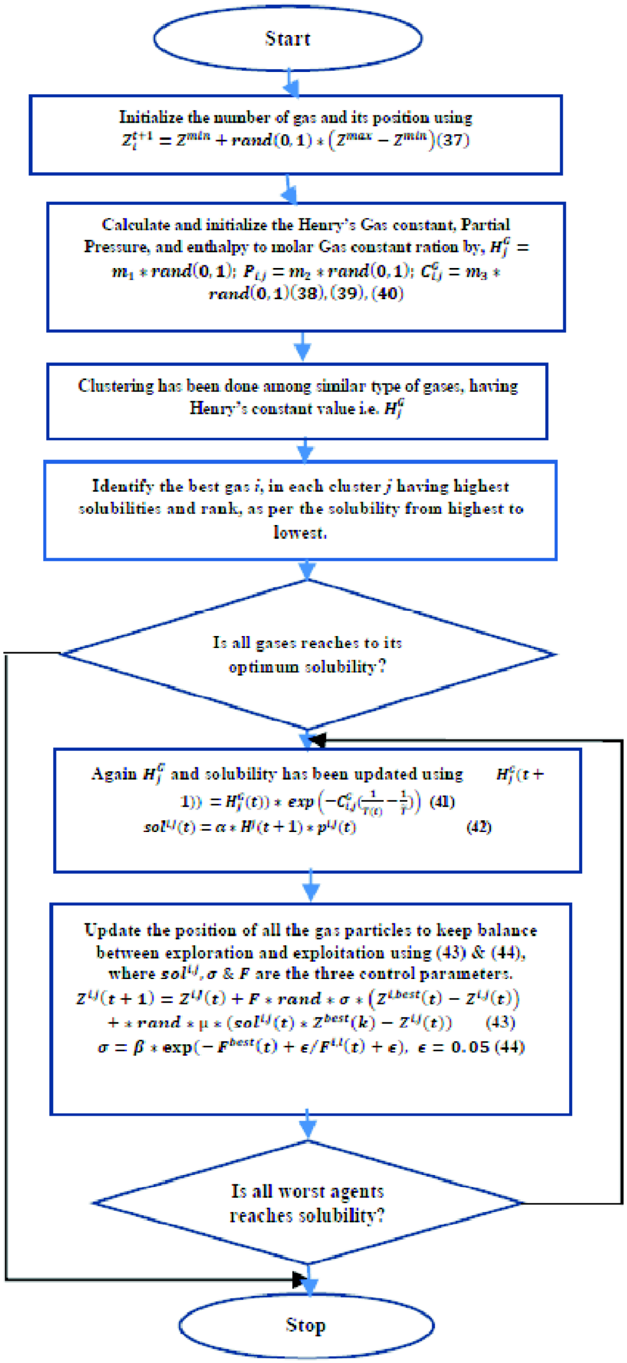


Fig. 4. Flowchart for HGSO.

HGSO in SACAIS algorithm

Execution procedure, Results and discussion

The solution strategy for both first and second layer of optimization has been described using the following flowchart as shown in Fig. 5.

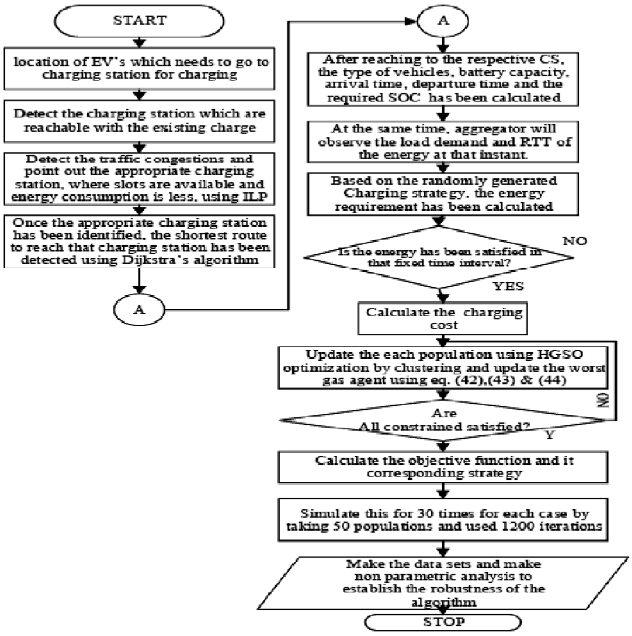


Fig. 5. Flowchart of the work process.

Input data for test case 1

In test case 1, 30 vehicles are taken, which contains PHEV30, PHEV40 and BEV (Battery Electric Vehicle) and their specifications has been shown in[1z]. The vehicles have been chosen in such a manner that, most of them are of lower battery capacity. Only few vehicles are having higher battery capacity.

Basically, in urban areas during early morning and afternoon, the road congestions and electrical loading can differ. The traffic congestion during early morning and evening is different. Due to the difference in electrical loadings real time tariff set by the grid is also different. Therefore, in very obvious reason, the scheduling strategies for EVs during these two scenarios should be different, which needs to be observed.

Therefore, this test case, has been divided into two major scenarios with respect to the timing. Each scenario is of 12 h. Test case 1, scenario 1 (C1S1), is starting from 00:00

hrs and it will continue up to 11:59 hrs and for test case 1, scenario 2, (C1S2), the timing is starting from 12:00 hrs and will continue till 23:59 hrs.

Input data for test case 2

In the test case 2, total 50 vehicles have been considered, which contains Hyundai ionic, BMW i3[2a] and Nissan leaf[2b], whose specifications are given in[2a]. This test case contains vehicles with higher battery capacity. The case 2, scenario 1 (C2S1) and case 2, scenario 2 (C2S2), have been chosen considering the precious concept as test case 1.

Network

To begin the simulation, at first a network has been created, which contains 30 nodes and 151 edges as shown in Fig. 6. The network has been made critical to replicate some practical scenario. Three charging station are there at node number 11, 17 and 22 with slot availability in 12, 8 and 10 respectively. This network has been used to simulate for test case 1.

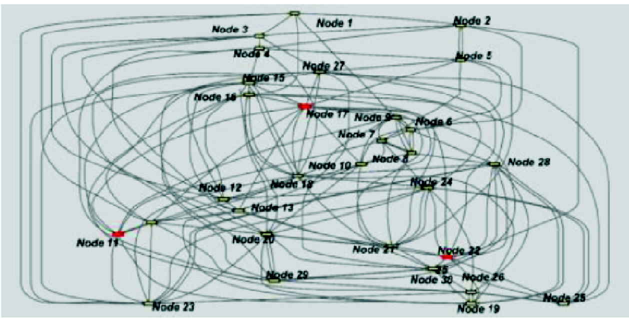


Fig. 6. The network with 30 nodes and 151 edges.

Again, for simulation of test case 2, a bigger network has been created, which contains 51 nodes and 352 edges. The path length is of higher and no circular paths are there. Node number 11, 17 and 22 has been considered as CS, where 15, 18 and 17 slots are available respectively. All paths are unidirectional as shown in Fig. 7.

Arrival and departure time of vehicles in charging station

In C1S1, the average time for arrival and departure time of cars in CS are 4:00 hrs and 10:00 hrs respectively[2c]. Again, for C1S2[2c], it has been observed that arrival and departure time of vehicles are 14:00 hrs and 22:00 hrs respectively. For both the scenarios, standard deviation is of 1.2 h. These two attributes follow normal distribution[2c] and the values are shown in graphically in Fig. 8 and Fig. 9.

Speed of the vehicles

From[2d], it has observed that, the velocity of the vehicles follows GEV distribution, as discussed previous section. The mean speed is of 60 km/h[2e], where, the shape factor is of 6.8 and the scale factor is negative, for both C1S1 and C2S1. Again, for the C1S2 and C2S2, the free flow average velocity is 55 km/h[2e]. Using Fig. 10, the input data for free flow velocity has been shown.

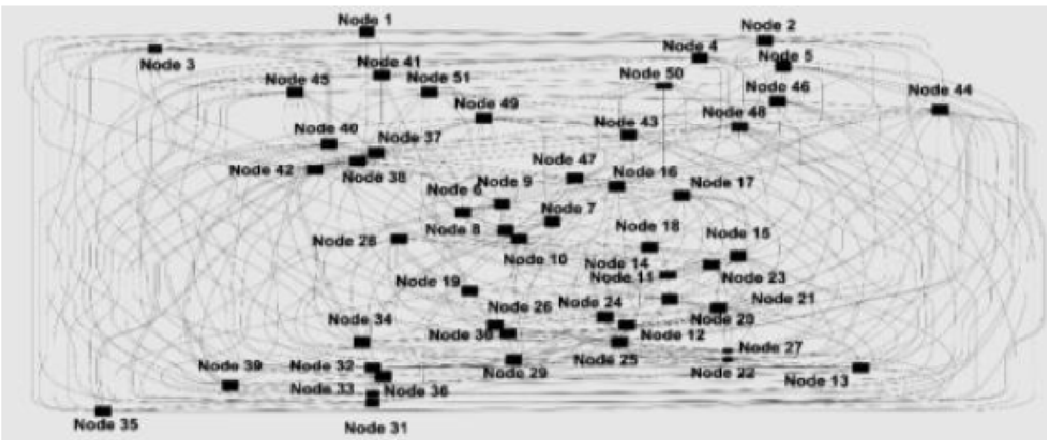


Fig. 7. The network with 50 nodes and 352 edges.

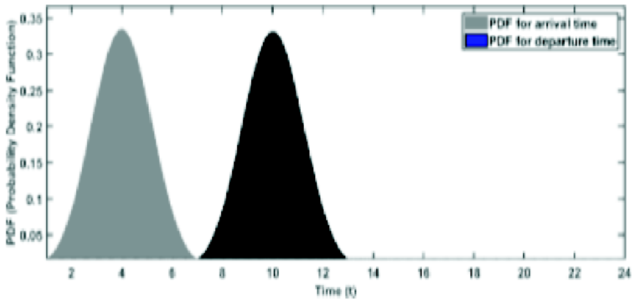


Fig. 8

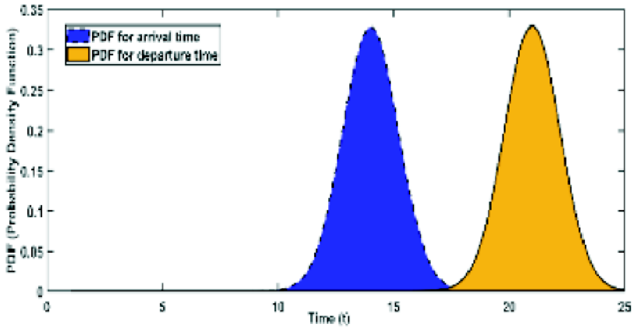


Fig. 9

Fig. 8, 9. Arrival time and departure time for test case 1 and 2.

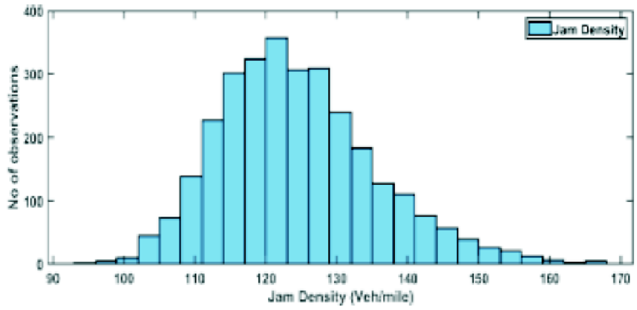


Fig. 11

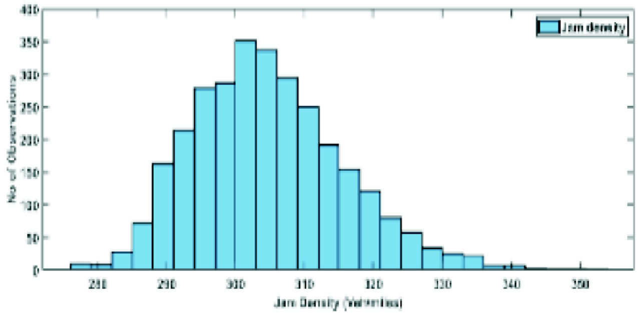


Fig. 12

Fig. 11, 12. Jam density for C1S1 and C2S1 and Jam density for C1S2 and C2S2.

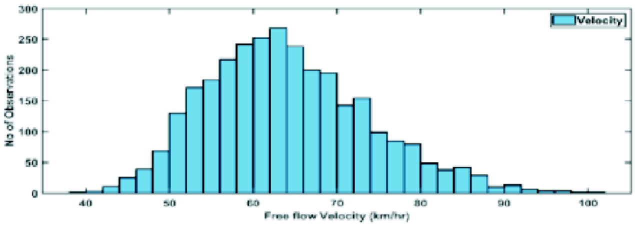


Fig. 10. Distribution of free flow velocity.

Vehicle congestions and jam coefficient

The most challenging aspect of the proper charging station allotment is vehicle congestions. From[2d], it has been observed that, urban congestion follows GEV distribution with the shape factor of 10 and the scale factor is of negative. For every case, jam coefficient 800[1t]. The input data has been shown graphically in Fig. 11 and Fig. 12. Again using Fig. 13 and Fig. 14, the jam density of roads from vehicles to the probable CS have been shown.

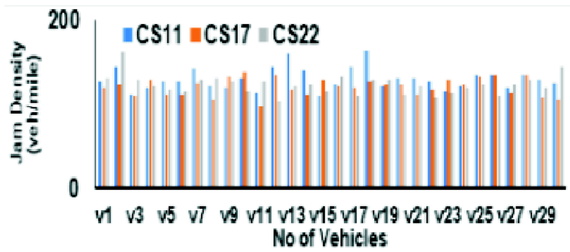


Fig. 13. Jam density for C1S1.

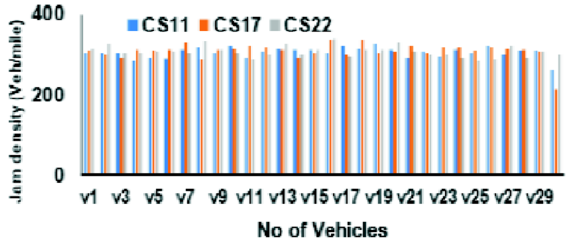


Fig. 14. Jam density for C1S2.

Daily trip distance (DTD) and charging trip distance (CTD)

From literature[2c], it has been observed that the average daily mileage of the vehicles is generally of 55 km with the standard deviation of 10 km. Again, for bigger cities (Test case 2) the average mileage is of 125 miles, with the stan-

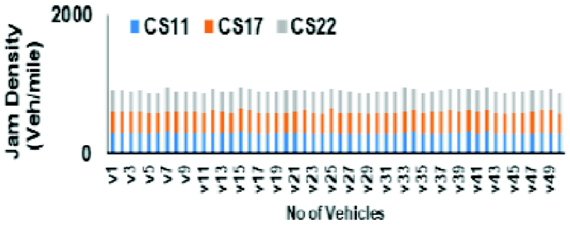


Fig. 15. Jam density for C2S1.

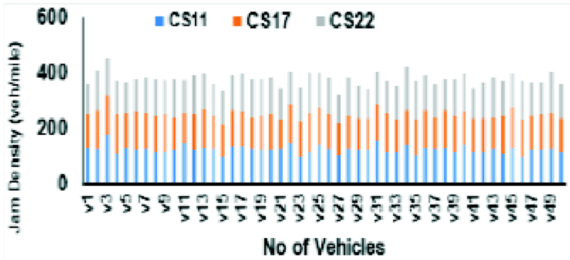


Fig. 16. Jam density for C2S2.

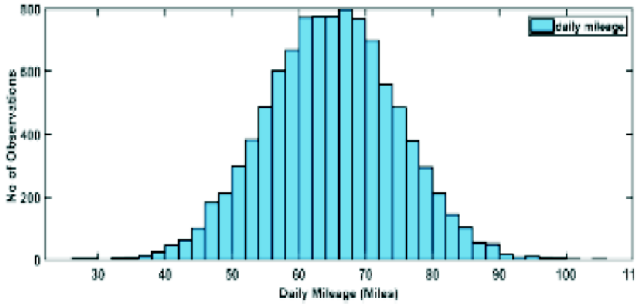


Fig. 17

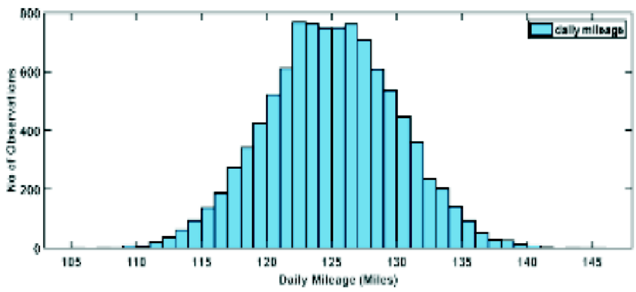


Fig. 18

Fig. 17, 18. Daily mileage for C1S1 and C2S1 and daily mileage for C1S2 and C2S2.

dard deviation of 10 miles[2e]. These two parameters follow normal distribution[2c], as shown Figs. 17 and 18.

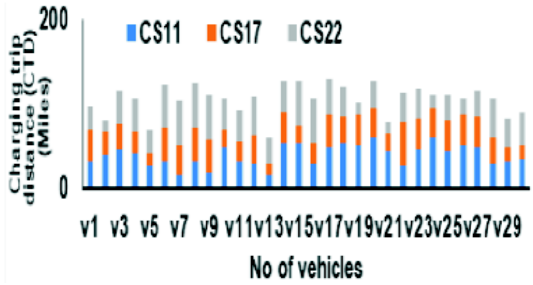


Fig. 19. CTD in C1S1.

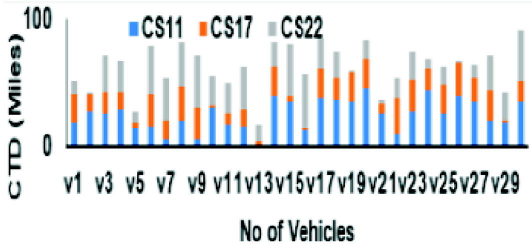


Fig. 20. CTD in C1S2.

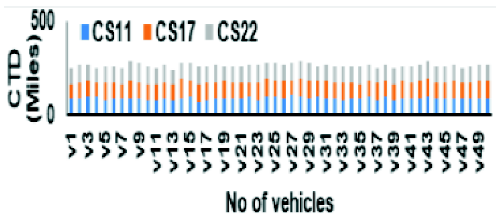


Fig. 21. CTD in C2S1.

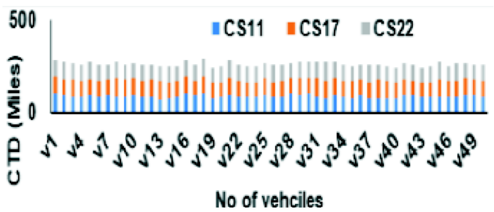


Fig. 22. CTD in C2S2.

Appropriate charging station allotment and finding shortest path to reach CS

As per the solution strategy, using ILPP, the appropriate charging station for individual vehicles has been determined for both the scenarios of Test Case 1 and 2. Firstly, an ideal scenario has been considered where, traffic congestions have not been considered. Only the CTD and availability of slots have been considered to identify the appropriate charging stations for corresponding vehicles as shown in Figs. 23, 25, 27 and 29.

Again, ILPP applied for same number of vehicles considering traffic congestions and its effects on energy consumptions of vehicles has been observed which have been shown in Figs. 24, 26, 28 and 30. More elaborately, it can be said that, in Fig. 23, the allotment of vehicles in appropriate CSs are shown. Due to traffic congestion some vehicles have been changed their respective charging stations, which can be observed from Table 1. Likewise, for C1S2, C2S1 and C2S2 also, EVs have changed their respective CS due to the traffic congestions, as shown in Table 1 and can be validated using Figs. 25–30.

After successful allotment of appropriate charging station, next thing is to decide the shortest route to reach its corresponding CS. For which, Dijkstra's shortest path algorithm has been applied. Using Fig. 35, the route for vehicle number 1 has been shown. Likewise, for C1S1, C1S2, C2S1 and C2S2, the path of vehicles to reach their corresponding CS has been tabulated form in Tables 2 and 3 respectively.

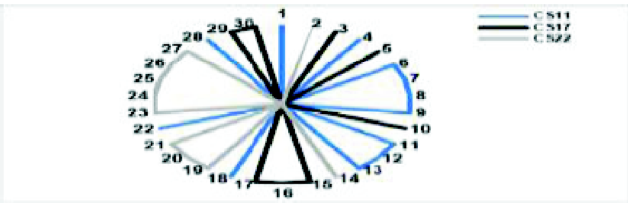


Fig. 23

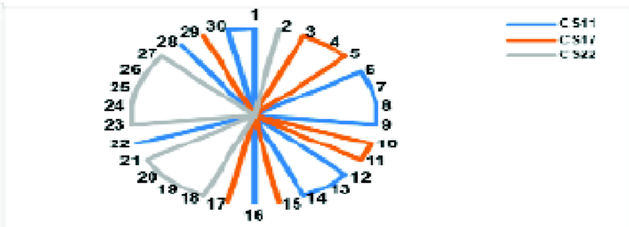


Fig. 24

Fig. 23, 24. Allotment of charging station for C1S1 in ideal condition and in practical condition.

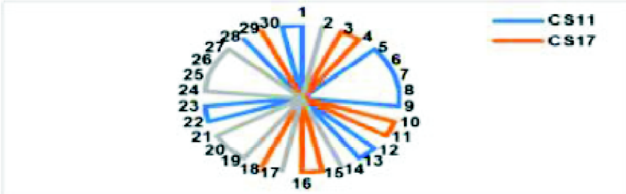


Fig. 25

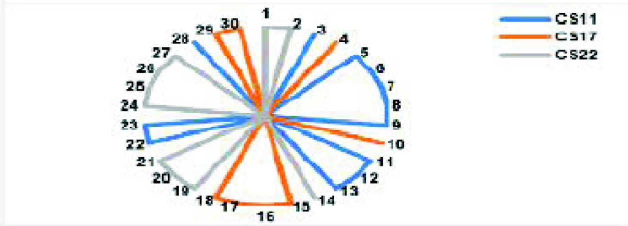


Fig. 26

Fig. 25, 26. Allotment of charging station for C1S2 in ideal condition and in practical condition.

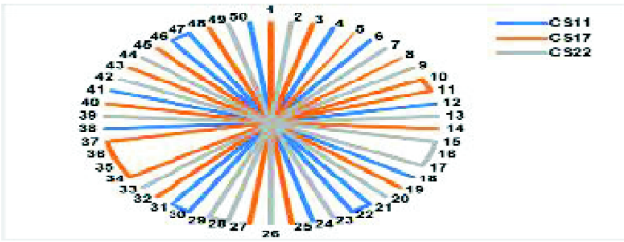


Fig. 27

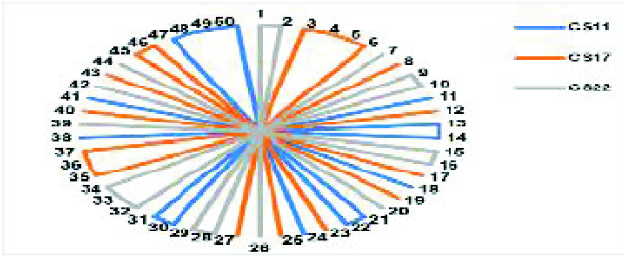


Fig. 28

Fig. 27, 28. Allotment of charging station for C2S1 ideal condition and in practical condition.

Real time tariff (RTT) for charging scheduling

A real time data from National Electricity Market of Singapore[2e] (EMCSG-*online, 2020*) has been considered for the combined charging scheduling.

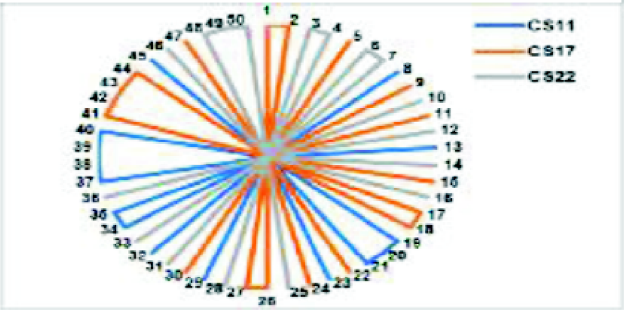


Fig. 29

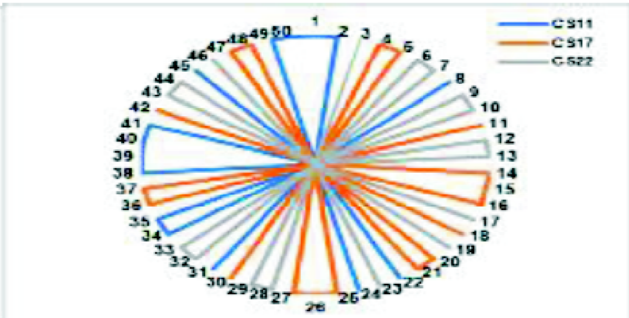


Fig. 30

Fig. 29, 30. Allotment of charging station for C2S2 in ideal condition and in practical condition.

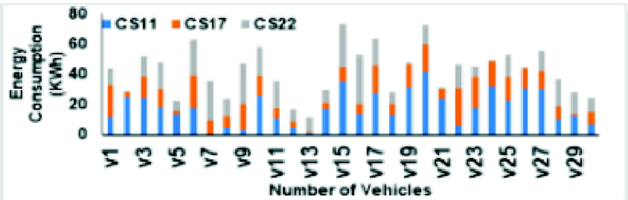


Fig. 31

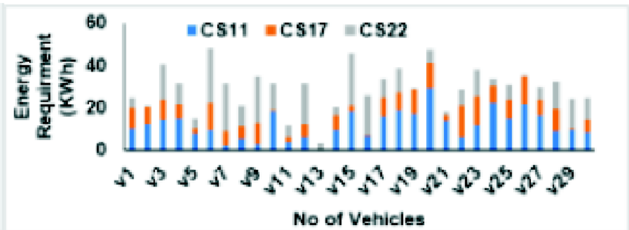


Fig. 32

Fig. 31, 32. Energy consumption for C1S1 and C1S2 in practical condition.

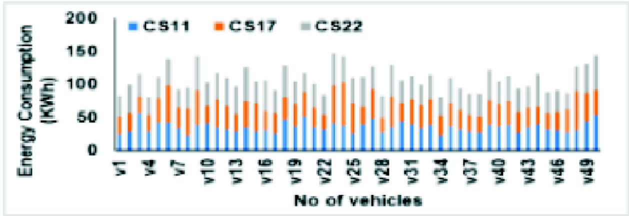


Fig. 33

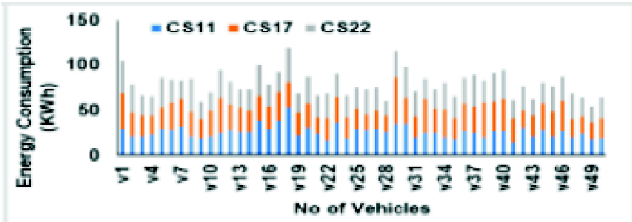


Fig. 34

Fig. 33, 34. Energy consumption for C2S1 and C2S2 in practical condition.

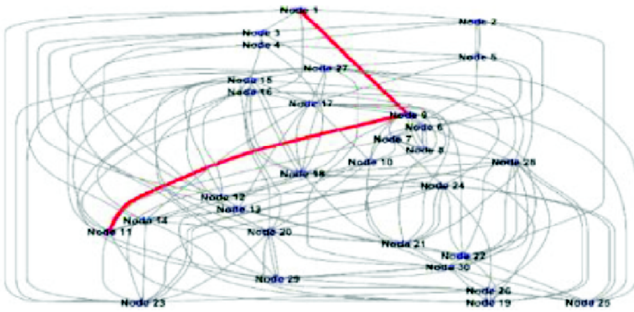


Fig. 35. Vehicle route one of the vehicles in test case 1.

Table 1. Vehicles changed their respective charging stations while practical aspects have been considered

Scenarios	Vehicles ID, changed its CS in practical scenario
C1S1	4, 11, 14, 17, 25, 27
C1S2	1, 3, 17, 30
C2S1	1, 6, 7, 10, 11, 13, 14, 15, 16, 24, 25, 27, 28, 29, 30, 31, 33, 35, 36, 37, 39, 41, 45, 48, 49, 50
C2S2	1, 2, 4, 9, 11, 13, 14, 16, 17, 19, 20, 21, 22, 23, 24, 25, 29, 31, 32, 36, 37, 41, 43, 44, 48, 49, 50

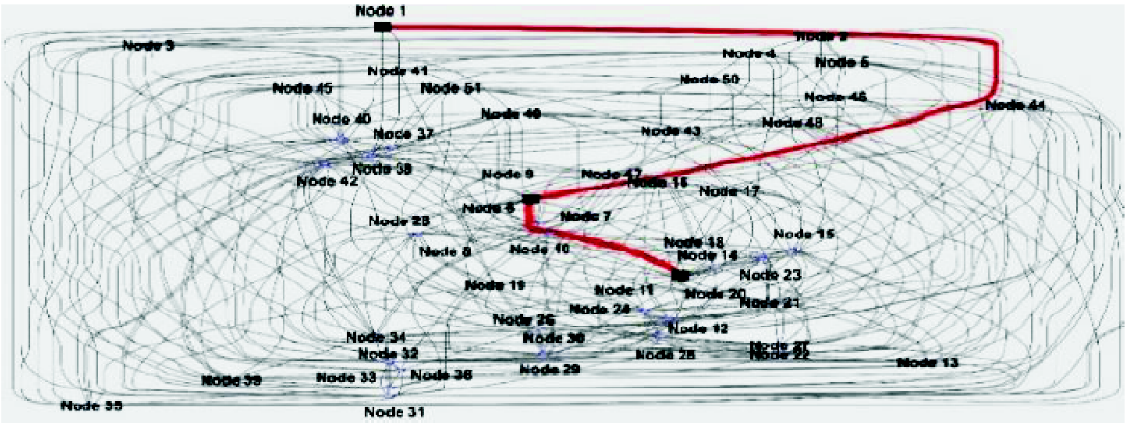


Fig. 36. Vehicle route one of the vehicles in test case 2.

Table 2. Path for 30 vehicles in smaller network

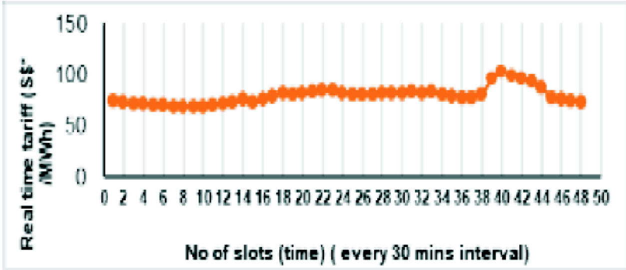
CS	Vehicles route to reach CS	
	First scenario	Second scenario
11	1-9-11	1-9-5-11
	4-5-7-11	5-7-11
	6-7-11	8-7-11
	7-11	7-11
	8-7-11	6-7-11
	9-11	9-11
	12-14-11	12-14-11
	13-14-11	13-14-11
	18-23-14-11	22-13-14-11
	22-13-14-11	23-14-11
	28-23-14-11	28-23-14-11
17	5-17	3-13-17
	10-17	4-5-17
	14-15-17	10-17
	15-17	11-17
	16-17	15-17
	27-15-17	16-17
	29-30-17	18-15-17
	11-17	29-30-17
22	11-30-17	
	2-22	2-22
	3-27-22	14-1-2-22
	17-21-22	17-21-22
	19-22	19-22
	20-21-22	20-21-22
	21-22	24-21-22
	23-27-22	25-22
	24-21-22	26-19-22
	25-22	27-22

Table 3. Path for 50 vehicles in larger network

CS	Vehicles route to reach CS	
	First scenario	Second scenario
11	1-9-11	1-9-11
	8-7-11	2-5-7-11
	9-11	8-7-11
	12-14-11	22-13-14-11
	14-11	24-12-14-11
	15-17-9-11	31-35-48-11
	17-9-11	34-7-11
	23-14-11	35-48-11
	24-12-14-11	38-48-11
	25-48-11	39-33-48-11
	29-14-11	40-6-7-11
	34-7-11	41-33-48-11
	42-1-9-11	45-14-11
	48-11	49-7-11
	50-14-11	50-14-11
17	2-5-17	4-5-17
	3-13-17	5-17
	10-17	14-15-17
	13-17	15-17
	16-17	16-17
	18-15-17	18-15-17
	21-22-17	20-30-17
	22-17	21-22-17
	26-30-17	25-22-17
	28-30-17	26-30-17
	30-17	27-15-17
	37-4-5-17	30-17
	38-1-2-5-17	36-5-17
	39-2-5-17	37-4-5-17

Table-3 (contd.)

	44-30-17	42-3-13-17
	45-3-13-17	47-5-17
	46-5-17	48-5-17
	11-17	11-17
22	4-5-21-22	3-13-19-22
	5-21-22	6-46-22
	6-46-22	7-10-21-22
	7-10-21-22	9-18-19-22
	19-22	10-21-22
	20-21-22	12-13-19-22
	27-22	13-19-22
	31-3-13-19-22	17-21-22
	32-33-13-19-22	19-22
	33-46-22	23-27-22
	35-37-46-22	28-19-22
	36-5-21-22	29-28-19-22
	40-37-46-22	32-33-46-22
	41-33-46-22	33-46-22
	43-37-46-22	43-37-46-22
	47-5-21-22	44-30-21-22
	49-19-22	46-22



*S$: Singapore Dollar

Fig. 37. Real time tariff from month of February 2020.

Combined scheduling through aggregator

After successful allotment of EVs to their respective CS, combined scheduling with dual mode of operation has been done to minimize the daily charging cost of the EVs, by satisfying required energy, using G2V, V2G and idle mode (0 state) in simultaneous manner as per the RTT.

This has been performed for C1S1, C1S2, C2S1 and C2S2 and its corresponding scheduling have been shown by Figs. 38–41, where, yellow square is representing G2V mode and blue spot is showing V2G mode. By using Figs. 38 to 41, Figs. 42 to 45 have been developed, where, the

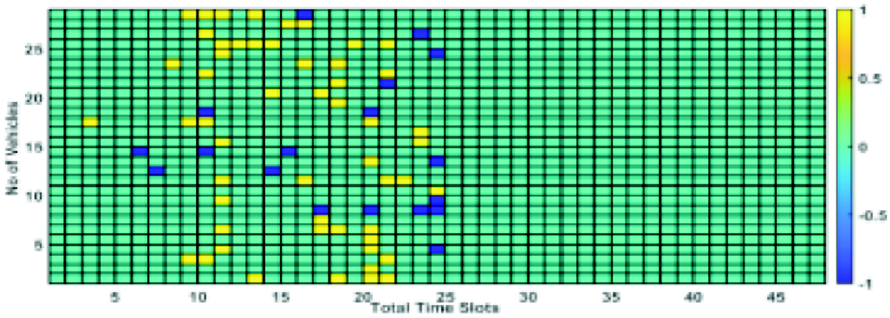


Fig. 38. Charging scheduling for C1S1.

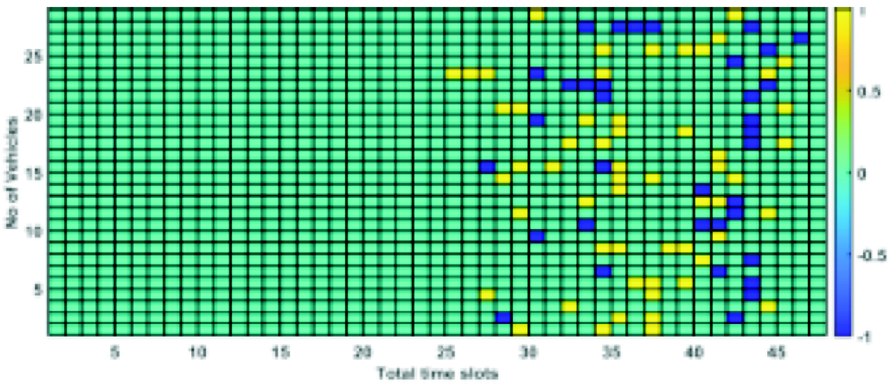


Fig. 39. Charging scheduling for C1S2.

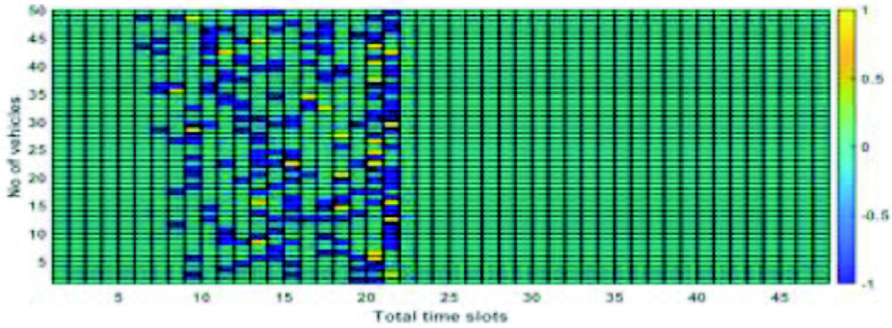


Fig. 40. Charging scheduling for C2S1.

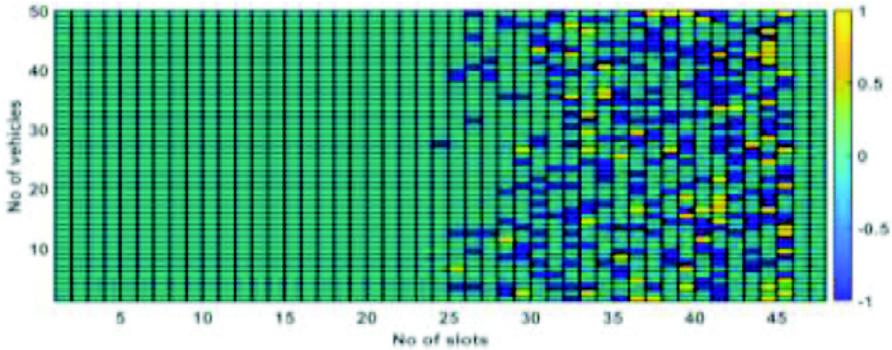


Fig. 41. Charging scheduling for C2S2.

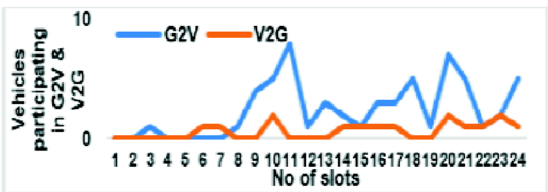


Fig. 42

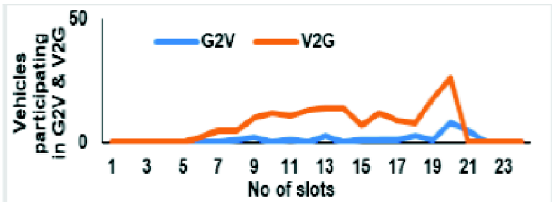


Fig. 44

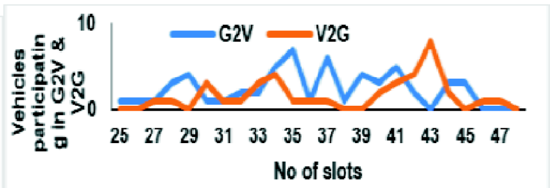


Fig. 43

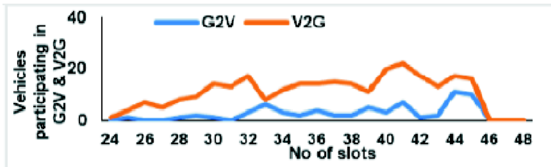


Fig. 45

Fig. 42, 43. Participation of vehicles in G2V and V2G in C1S1 and participation of vehicles in G2V and V2G in C1S2.

Fig. 44, 45. Participation of vehicles in G2V and V2G in C2S1 and participation of vehicles in G2V and V2G in C2S2.

number of EVs participating in G2V and V2G mode in every half an hour of operation has been plotted. It is desirable that, when the RTT is lower, the EVs should participate in G2V mode and when the RTT is higher, the vehicles should participate in V2G mode.

From, Fig. 42, it has been observed that, since RTT is lower most of the vehicles are participating in G2V mode and very few vehicles are participating in V2G mode. Again, in C1S2, where RTT is higher, EVs should participate more in V2G mode. But from Fig. 43, it has been observed that, instead of V2G, EVs are participating in G2V mode. But, in Test case 2, where number of EVs are more and the battery capacity of the EVs are higher, in that scenario, by observing the charging strategy, it can be realized that, in both C2S1 and C2S2, the vehicles are behaving exactly which is desired as shown in Figs. 44 and 45 respectively. Therefore, from the above observations, it has been analyzed that, for better coordination of G2V and V2G mode of operation, it is desirable to have higher number of EVs of higher battery capacity. Lower number of vehicles with less battery capacity is not a great idea for it. Moreover, from the above analysis, and observing the Figs. 42, 43, 44 and 45, it can be said that, for charging of EVs, the ideal session is from 00:00 hrs to 11:59 hrs. EV owners, having higher battery capacity, can participate more in V2G mode during the session i.e. 12:00 hrs to 23:59 hrs and can earn incentives by delivering the surplus power of battery to the grid. Moreover, using HGSO the daily charging cost for charging scheduling has been minimized and to validate the superiority of this optimization, it has been compared with a benchmark optimization, and from convergence criteria as shown in Figs. 46, 47, 48 and 49, it has been observed that, HGSO is giving better result. Each scenario for individual test cases has been simulated for thirty times and from Table 4, it has been observed that, the standard deviation for all the test cases are very low which signifies that, for both HGSO and DE in SACAIS algorithm can give consistent output. But for more authenticity of the robustness of SACAIS algorithm two non-parametric statistical analysis has been performed.

Wilcoxon signed rank test (WSRT)

From, Table 5, it can be assessed that, for all test cases, the test statistic value is larger than the absolute value. This signifies that the null hypothesis can be accepted[2f]. Therefore, there is no significant change in the outcome of the simulation results for both HGSO and DE in SACAIS algorithm.

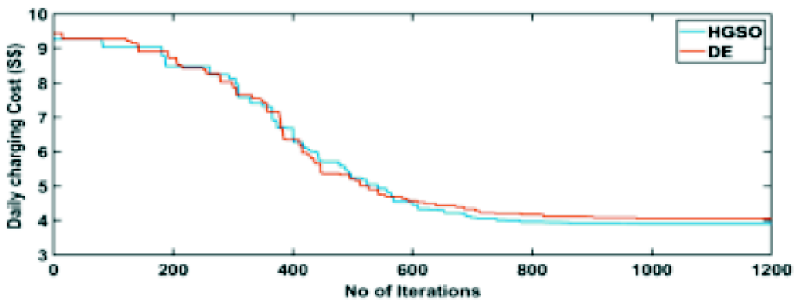


Fig. 46

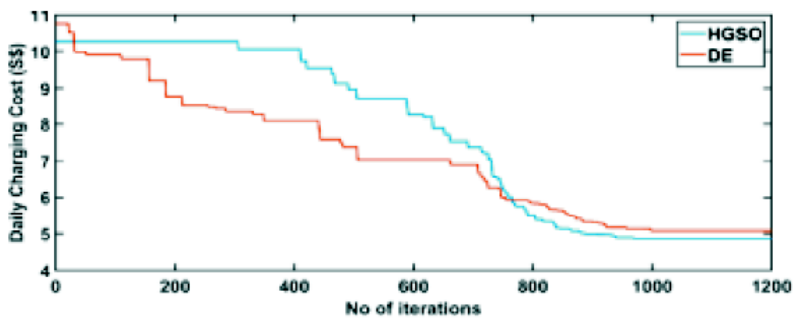


Fig. 47

Fig. 46, 47. Convergence characteristics of C1S1 and convergence characteristics of C1S2.

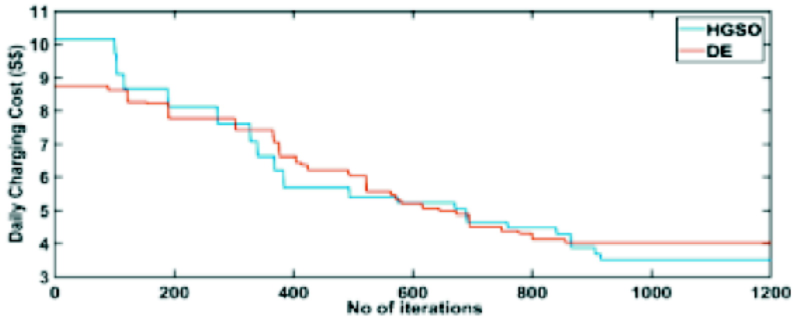


Fig. 48

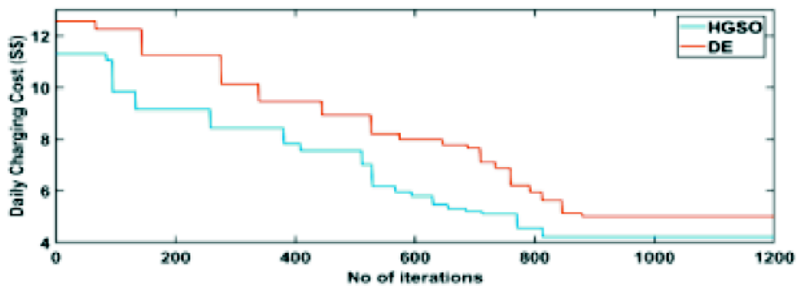


Fig. 49

Fig. 48, 49. Convergence characteristics of C2S1 and convergence characteristics of C2S2.

Table 4. Best cost, mean cost and the standard deviation for all the test cases

Optimization techniques	Min. cost (S$*)	Max. cost (S$)	Avg. cost (μ)	Standard dev. (σ)	Best cost (S$)
		C1S1			
HGSO	3.9033	4.01378	3.9616	0.0353	3.9033
DE	4.0517	5.54986	4.8064	0.4312	4.0517
		C1S2			
HGSO	4.689	5.58994	5.1564	0.2761	4.689
DE	5.0768	6.63917	5.8172	0.4463	5.0768
		C2S1			
HGSO	3.5092	4.83120	4.1047	0.4463	3.5092
DE	4.0122	5.1751	4.6023	0.3436	4.0122
		C2S2			
HGSO	4.2132	5.36723	4.8742	0.3777	4.2132
DE	5.0012	6.30260	5.6089	0.4526	5.0012

Quade test (QT)

Using Quade test[29], from Table 6, it has been observed that, for all the scenarios in both the test cases, the absolute value from f-distribution table (Sheikh *et al.* 2006) is less than

Table 5. Wilcoxon signed rank test for both the scenarios for test case 1 and 2

Optimization	Confidence interval	Test statistic value C1S1	C1S2	C2S1	C2S2	Abs. value
HGSO	(95%)	213	144	226	231	137
DE	(95%)	195.5	232	205.5	214.5	137

Table 6. Quade test for both the scenarios for test case 1 and 2

No. of sample	Confidence interval	Test statistic value T1	T2	T3	T4	Abs. value
30	(95%)	93	56.54	29.12	61.64	4.18

the test statistic value. Hence, it can be said that, for all the test cases, outcomes of HGSO is more superior and better than DE in SACAIS algorithm.

Conclusions

This paper proposed a new "Strategy for Appropriate Charging Station Assignment and Intelligent Scheduling" (SACAIS) algorithm with the integration of optimization techniques. Proper allotment of CS for EVs has been performed by finding shortest path to reach there, followed by minimization of daily charging cost of charging. From the results, it can be that, if higher number of vehicles are connected to the grid with battery capacity, then dual mode of operation for charging scheduling is more apt. Again, due to the consideration of jam density, it has been observed that, due to the higher consumption of battery, daily charging cost is increasing. Moreover, using HGSO and DE, the efficacy and robustness of the SACAIS algorithm are ensured, which may help to develop a smart phone application in near future using SACAIS algorithm.

References

1. (a) Z. Lu *et al.*, *IEEE Int. Conf. on Big Data*, 2018, 4469; (b) A. Tintelecan, A. Dobra and A. C. Martis, *C. Electr. Veh. Int. Conf.*, 2019, 1; (c) S. R. Meher, S. Banerjee, B. Vankayalapati and R. K. Singh, *IEEE Trans. on Veh.*, 2020; (d) S. Hui and X. Yonghai, *Int. Conf. on Electr. Distrib.*, 2016, 1; (e) E. Akhavan-Rezai, M. F. Shaaban, E. F. El-Saadany and A. Zidan, *IEEE Power and Energy Soc. Gen. Meet.*, 2012, 1; (f) C. Liu, K. T. Chau, D. Wu and S. Gao, *Proceedings of the IEEE*, 2013, 2409; (g) M. Yilmaz, and P. T. Krein, *IEEE Trans. on Power Electro.*, 2012, 5673; (h) V. Monteiro, J. G. Pinto and J. L. Afonso, *IEEE Trans. on Veh. Technol.*, 2015, 1007; (i) M. Ansari, A. T. Al-Awami, E. Sortomme and M. A. Abido, *IEEE Transactions on Smart Grid*, 2014, **6**, 261; (j) M. Ansari, A. T. Al-Awami, E. Sortomme and M. A. Abido, *IEEE Trans. on Smart Grid.*, 2014, 261; (k) B. Khorramdel, H. Khorramdel, J. Aghaei, A. Heidari and V. G. Agelidis, *IEEE Trans. on Smart Grid*, 2015, **6**, 1575; (l) S. M. Abuelenin and A. Y. Abul-Magd, *ICCVE*, 2014, 391; (m) F. Jozi, K. Mazlumi and H. Hosseini, *IEEE 4th Int. Conf. on Knowledge-Based Eng. and Innovation*, 2017, 941; (n) T. He, J. Zhu, J. Zhang and L. Zheng, *J. of Elect. Eng.*, 2018, 28; (o) R. Mkahl, A. N. S. Moh, J. Gaber and M. Wack, *EEVC*, 2015; (p) W. Kempton, *et al., J. of Power Sources*, 2005, **144**, 268; (q) [online] https://batteryuniversity.com/learn/article/bu_1004_charging_ an_electric_vehicle, Accessed February 2020; (r) D. Ding, J. Li, P. Tu, H. Wang and T. Cao, *IEEE Access*, 2020, 8543; (s) H. Rakha and B. Crowther, *Transp. Research Record*, 2020, 248; (t) N. G. Omran and S. Filizadeh, *IEEE Trans. on Smart Grid*, 2013, 632; (u) K. N. Kumar, B. Sivaneasan, P. H. Cheah, P. L. So and D. Z. Wang, *IEEE Trans. on Smart Grid*, 2013, 1051; (v) M. Huber, A. Trippe, P. Kuhn and T. Hamacher, *IEEE PES Innov. Smart Grid Techno.*, 2012, 1; (w) Z. Li and R. Laurence, *J. of Mod. Transp.*, 2015, 107; (x) [online] http://www.emcsg.com//MarketData/Price Information, Accessed February 2020; (y) S. Mishra, C. Hota, L. Kumar and A. Nayak, *IEEE Access*, 2019, 100512; (z) Tutz, Gerhard, *et al., Adv. in Data Anal. and Classification*, 2018, 281.
2. (a) H. R. Sheikh, M. F. Sabir and A. C. Bovik, *IEEE Trans. on Image Process*, 2009, 3440; (b) R. Mehta, *et al.*, *IEEE Trans. on Smart Grid*, 2016, 299; (c) B. Zhang, J. Peng, S. Li and L.Chen, *Computers and Indus. Eng.*, 2016, **102**, 186; (d) P. Prakash, *et al.. Transp. Research*, 2020, 409; (e) T. G. Grbac and N. Domazet, *Int. Symp. on Intelligent and Distributed Computing*, 2017, 39; (f) F. Hashim, *et al., Future Gen. Comp. Syst.*, 2019, **101**, 646; (g) A. Aminuddin, *et al., J. of Phys. Conf. Series.*, 2019, **1366**, 012076.