PV assisted Fuzzy based EV charge scheduling for demand side energy management: a case study

Soumya Ghorai
Department of Electrical Engineering
Jadavpur University
Kolkata, India
soumyaghoraijuee2013@gmail.com

Deepanjan Majumdar,Tushar Jash
School of Energy Studies
Jadavpur University
Kolkata, India
deepanjanmajumdar07@gmail.com
tusharjash@yahoo.co.uk

Susanta Ray
Department of Electrical Engineering
Jadavpur University
Kolkata, India
raysusant@gmail.com

***Abstract*—Targeting a solution for mitigating fossil fuel crisis along with diminishing environmental pollution, rapid adoption of electric vehicles (EV) is taking place. Consequently charging strategy of those vehicles is coming up with great concern. As stochastic charging activities of EVs can greatly stress the distribution system causing grid overloading, peak load increasing, a scheduling of EV charging is needed. On the other side, power system load curve smoothing is needed always for load following, frequency regulation and Voltage regulation. After going through a detailed case study of the city Kolkata, India, a multi aggregator based online fuzzy coordination algorithm (OL-FCA) for charging plug-in electric vehicles (PEVs) in smart grid networks with maximum efficient usage of rooftop PV generation is presented here . It is showed that this kind of harmonization of power industry and transport industry can significantly improve the load factor by 87 percent ensuring proper utilization of clean energy and load ripple reduction.**

***Index Terms*—charge scheduling; EV ; fuzzy based scheduling; peak load shaving**

I. INTRODUCTION

Keeping pace with climate crisis and continuous depletion of fossil fuel integrating a large-scaled intermittent source to the utility grid may yield an adverse effect on voltage/frequency control which lead to severe power quality problems. The problem is same for in case of stochastic charging pattern of EVs.If charging of an EV completely depends on its owner(stochastic charging), the load during peak hours increase as these times coincide with the time at which the owner either arrives at workplace/home. The larger is the number of EVs accumulated for charging at a time, the greater is the increase in the peak load of the grid. Enabling the transition to plug-in hybrid electric vehicles (PHEVs) and plug-in electrical vehicles (PEVs) is one of the anticipated benefits of the smart grid environment as by taking help of information and communication technologies these vehicles provide many incentives for not only the transportation industry but also the power industries(increasing the load factor). At the recieving end of the EV charge scheduling(EVCS),stakeholders include include the grid operator, the service provider (aggregator), and the consumer (EV owner).Each one's benefit is the goal of EVCS. Load curve smoothing is an important concern for power quality improvement. There are technologies like Pump storage power plant(60 percent efficiency) [1] battery energy storage system(BESS)(80-85 percent efficiency for Li-ion cells) [2] [3].Till date, enough research has not been performed on EV's potential for load curve smoothing and maximum efficient usage of renewables.

Electric vehicle charging schedule(EVCS) is a trade-off between aggregator and a customer for optimizing benefits from each one's perspective. A heuristic search algorithm is presented in [4] to allocate suitable charging rate sensing EV user‘s demand taking real time(PV) generation Power.To cater practical situations a pricing strategy is presented [5] where the aggregator purchases energy based on average scheduling requests per day and customers are penalized for not arriving at the scheduled slot. By using Starklberg game model, a pricing strategy and charging strategy for PVCS is presented keeping aim of minimizing the operating cost & maximum utilization of PV generation [6]. A mixed-linear integer is presented [7] targeting minimizing Operating cost for one day operation in terms of net power used from grid, solar surplus sold to grid, the price for purchasing and profit earning. Whereas,improving the maximum sensitivity (MSS) optimization, an online fuzzy coordination algorithm is cited [8] targeting minimizing the cost of charging Plug-in Electric Vehicles, keeping constraints of maximum voltage deviation, maximum demand level, total system loss. But they didn't explored PV potential for peak shaving in their paper. Whereas on the real ground of Ankara city, USA EV charging model has been developed after a detailed case study. [9]

In this article, a multi aggregator based online fuzzy coordination algorithm (OL-FCA) has been presented for charging plug-in electric vehicles (PEVs) in smart grid networks with maximum efficient usage of rooftop PV generation . Real time scheduling has been omitted because in that case the aggregator should be enabled with Artificial neural network (ANN) pattern recognition technique to forecast the load pattern [10] and to forecast the PV generation output based on weather conditions (not only weather conditions, dust precipitation is a major factor for diminishing solar panel efficiency), which is very costly and complex.

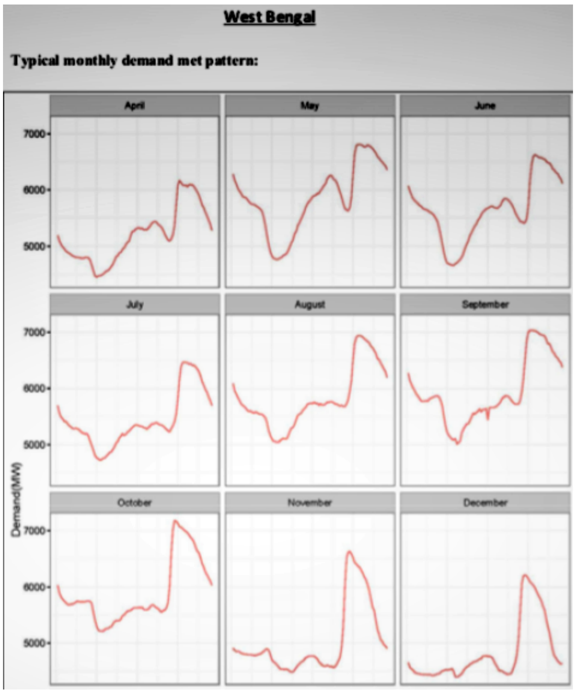


Fig. 1. Load curve patterns monthly in West Bengal given by POSOCO

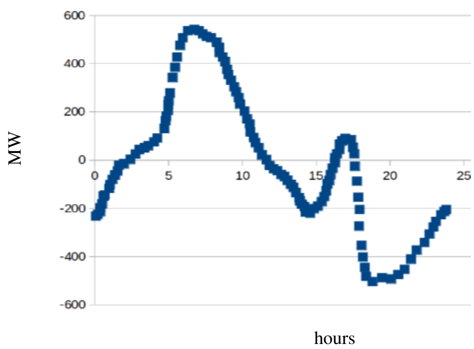


Fig. 2. Daily load fluctuation pattern w.r.t the average demand throughout a day of month May

Moreover, in case of purpose of service is commercial, having a rigid schedule already, the EVCS strategy proposed in [8] would be hazardous for service vehicles.The presented miniature model is distributed, offline, mobility aware electric vehicle charging scheduling(EVCS) solved by efficient utilization of idle bus in stands, obviously considering a rooftop photovoltaic mounted charging station(PVCS). The feasibility has been shown by taking support of one standard bus route and incorporating the model in it. All scheduled services(public transport) have been proposed to be fully electrified and one fourth of vehicles with ownership has been assumed to be fully electrified. Load curve valley filling is done by EV mounting which is not daylight dependent. Whereas generally the peak hours of load curve happens nearly 7:00-8:00 pm in night, BESS systems has to be introduced into the grid. Night peak shaving byn solar photovoltaic, would be impossible nearly without battery pack. It is also possible if V2G(Vehicle to grid) technology is enabled but this wouldn't be a considerable amount. In our work, we have not considered V2G and Plug-in heavy electric vehicles(PHEV) in our studies. In this model, all the charging stations should be rooftop PV installed.

II. CASE STUDY OF EXISTING INFRASTRUCTURE AND FORECASTING

A. Load curve pattern

Typical monthly demand met pattern of West Bengal, a state of East India for 12 months has been collected from electricity demand pattern analysis Power System Operation Corporation (POSOCO) 2016 release. (fig.1) Taking any daily load distribution profile of one month, averaging the total demand over 24 hours, a average load line is superimposed onto the actual load profile. Subtracting the actual load from the average load line a load fluctuation curve has been derived spanning 24 hours. (fig.2.) In this fluctuation curve positive outcome represents valleys which are to be filled by controlled output of renewables and negative outcome means peaks of load curve which are to be shaved by charging of EVs mounted to the grid. As West Bengal's capital Kolkata's average electrical energy consumption is nearly one-fifth of total demand West Bengal, in this model the load fluctuation curve of Kolkata has been assumed for simplicity by dividing the POSOCO load profile by five over the 24 hours. Month May has been taken for model designing because over 24 hours load curve valley making interval is the largest for May among 12 months. In that case, the highest constraint for the sizing of BESS is being considered.

As in case of day long PV generation data, the load fluctuation curve, under loading and overloading depth in terms of electrical power(MW) has been listed by every 15 minutes interval of the day consecutively.

B. Transport Industry of the Metropolitan

All case studies and model developing has been carried out in the real ground of Kolkata, India.

1) There are total 102 routes combining AC , non-AC, 60 bus stands , 11 bus depots for public transport. In case of new routes are introduced ,110 routes has been taken for computation. 8B bus stand, Jadavpur, Kolkata, is near 1285 m^2. A standard Bus Depot area is near 3600 m^2 . One standard Petrol Pump in the city has area of 640 m^2.
2) Total no of service cars (Ola + Uber+ Yellow Taxi) in the city is 45,160 currently(Times of India ,March, 2016). Each 4-wheeler per day runs 150 km in an average.In case of E-car electricity consumption rate is 10 kwh/100 km.
3) Total no of Private car in the city is 2,22,069 (Times of India, same date). Each private car per day runs 50 km in an average. There are 259 routes running daily supported by Private Buses in the city.
4) A standard route in the city has been picked up which makes 65 trips per day, from both sides. (starting from 5 am to 9 pm, per 15 minutes service). Trip distance 32 km.

C. Rooftop solar photovoltaic genaration data

1) Net meter reading of a rooftop solar panel installation,an array comprising of 4 poly-crystaline silicon solar panel at Department of Energy Studies, Jadavpur University, Kolkata(22.5726° N, 88.3639° E), showed total generation of 3235.5 kwh when checked on 2nd February, 2019 which was installed in last of November,2014. Total area of this installation is 6.47 m^2 and tilt angle 22 degree south faced.
2) Seventy percent area of bus stands and bus depots, petrol pumps and commercial buildings in the city has been proposed to be installed with rooftop solar panels. In this process total area available for rooftop installation comes out to be 10,13,000 m^2 .(60 bus stands, 11 bus depots, 70 petrol pumps, 200 commercial buildings rooftop each having 4500 m^2 convertable to PV installation)
3) Taking solar insolation average from NASA ,it can be stated that equator facing Poly-crystalline silicon solar panels are 6.8 percent efficient in the city's weather and dust condition.Most importantly ,by taking the live data over years, all the parameters to effect solar panel efficiency has been averaged out and a relevant forecasting can be done easily. For example, average radiation of May is 5.39 kwh /m^2 /day. So, in case of May forecasted average solar generation from rooftop installation all over the proposed cites, per day will be (0.068*5.39*10,13,000=) 371.2 MWh.
4) If the panels are south faced with tilt angle equal to latitude, from "JRC European Commission Photovoltaic Geographical Information System - Interactive Maps" putting latitude, longitude, tilt angle as inputs and solar panel efficiency 6.8 percent solar generation potential in terms of electrical power(in MW) has been listed by every 15 minutes of the day.

D. EV consumption and charging infrastructure

1) Case study pointed that one standard bus in the city's current traffic condition consumes 1.45 kwh/km. From here, It's been calculated that to cater one route 3.05 Mwh electric energy is needed daily.
2) Considering all the routes from case study 336.34 Mwh is needed daily to cater the public transport.Similarly, to cater 25 percent all other forms of road transports if fully run by electrical energy, the energy required is 930 Mwh. Total valley or hill area of May load fluctuation curve is 2574 MWh. So percentage share of energy to suffice scheduled(govt sponsored) & unscheduled transports with respect to the area, is 13.05 percent and 36 percent respectively.
3) Controlling charging rate strategy for EVCS by a heuristic search algorithm [4] will be very complex control circuit and cost very high. In case of large scale implementation we have alleviated any kind of complex infrastructure for charging purpose and carried or plan based on existing infrastructure available in the city. There are two types of charger, one is fast charger of 120 kw charging rate, current rating 0-160 amp and another is slow charger of charging rate 60 kw , current rating 0-80 amp.

III. System Algorithm

In our system every CS(charging station) is comprised with EV charging infrastructure and roof mounted grid connected PV cells. Load fluctuation curve is the input here. A day contains 96 consecutive intervals each of 15 minutes. For, i^{th} interval A_i is the total area of valleys and B_i is the total area of hills from the load fluctuation curve. As private cabs and buses can not be scheduled, it has been assumed that throughout the 96 intervals of a day, there will be a constant demand(x_i) of private electric vehicles and it is per battery station 0.028 Mwh/interval which is 36 percent of total area of the valley and public transport demand(y_i) is 13.05 percent of the valley area. (section C.2.). W_i is per interval PV generation data which is forecasted to shave the hilly area of load curve by 16.16 percent. $output_i$ is the no of buses that is to be charged at the interval. According to the highest $output_i$ among the 96 $output_i$ of consecutive interval, the no of idle buses has to be decided. Idle bus means the bus in the route which is not required to suffice the schedule in case of first in first out rule.

During Valley filling

1) Private transport demand (x_i) and public bus demand (y_i) will be taken from grid as 13.05 percent and 36 percent of the interval area.
2) PV generation output W_i will be stored in the battery bank which is 16.16 percent of the total valley area or hilly area. (section B.3.)
3) If 36 percent area of the interval is greater than 0.028 Mwh, the rest energy will be stored in battery bank.(Unscheduled means private road transports are to be supplied by each charging station is 0.028 Mwh per interval constantly). Otherwise, battery bank & grid will jointly fulfill the 0.028 mwh demand for unscheduled transports per interval.

During hill shaving

1) Only from the battery bank but not from grid, private EVs will get charged.
2) The stored solar energy will be released to grid corresponding to 16.16 percent of the area of the interval.
3) No public transport bus will be charged in this time.
4) If loading demand for the CS in the interval is greater than solar generation of the interval, then battery bank and PV generation will jointly fill the demand of grid and vice-versa.

IV. Traffic Algorithm

A. Proposed OL-FCA for score determining of WBTC buses after arriving destination

As an alternative to random charging of PEV batteries, we have taken advantage of the sophisticated smart grid communication backbone and implements an Online Fuzzy Communication Algorithm (OL-FCA) that will improve grid performance and automatically will co-ordinate PEVs.The Fuzzy inference system has two parameters as input to determine the score of each bus as depicted

Algorithm 1 System Algorithm

$j = i + 1$
$A_i = 1/8(a_i + a_j) \leftarrow (+)$area of the interval
$B_i = 1/8(b_i + b_j) \leftarrow (-)$area of the interval
$W_i = 1/8(w_i + w_j) \leftarrow$ PV generation of the interval
$\sum x_i = 36$ percent of $\sum A_i = (0.028 * 96)$
$y_i = 13.05$ percent of A_i
$\sum A_i = \sum B_i = Area$
$\sum W_i = 16.16$ percent of Area
$S_i = 16.16$ percent of B_i
$\sum S_i = \sum W_i$
for starting from one 96 consecutive intervals **do**
  $m = i - 1$
  $output_i = y_i/0.015 \leftarrow$ scheduled charging unit(no of bus) of govt transport as charger has 60 kw rating
  $s2g_i = S_i$
  $g2s_i = x_i + y_i$
  $battery_i = battery_m - 0.028 + x_i + w_i - y_i$
end for

below.One is SOC input and another is defined by the time required for the bus to get charged enough so that it can complete at least the next half trip without getting plugged for charging whereas the time is to be calculated from it's launching into it's destination stand. SOC input has been give a triangular membership function,rest are crisp input , defuzzification method is centroid method.

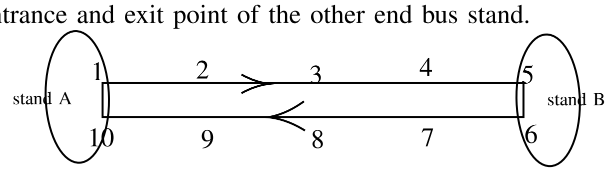
1) Fuzzification of SOC: To fuzzify the SOC content of Bus battery, the triangular membership function has been used. There is six domains of SOC level - very high(above 80 percent), high(70 to 80 percent), moderate(60 to 70 percent), low(50 to 60 percent), very low(40 to 50 percent), emergency(less than 40 percent).For good health of the Li-ion battery SOC level should not be allowed to go above 90 percent and fall below 30 percent anytime. The membership design is such that a bus battery will get full membership of the domain if amount of SOC defines the domain properly.The membership function is

$$\mu_{soc} = \begin{cases} 4 - \frac{x}{10} & \text{if } 30 \leq soc \leq 40 \\ 5 - \frac{x}{10} & \text{if } 40 \leq soc \leq 50 \\ 6 - \frac{x}{10} & \text{if } 50 \leq soc \leq 60 \\ \frac{x}{5} - 12 & \text{if } 60 \leq soc \leq 65 \\ 14 - \frac{x}{5} & \text{if } 65 \leq soc \leq 70 \\ \frac{x}{10} - 7 & \text{if } 70 \leq soc \leq 80 \\ \frac{x}{10} - 8 & \text{if } 80 \leq soc \leq 90 \end{cases} \}$$

2) FIS rules for score determination: Fuzzy score will also depends on the need of time to charge the particular vehicle so that it can at least complete the next half trip which is a function of the trip distance. The charging stations is presumed as such no vehicle will be charged during trip because it will break the transport schedule which is not desirable in the case. So, how many time is needed to charge the vehicle enabling it for completion at least half the trip means the trip distance is the second prior factor after SOC condition to determine its fuzzy score. The fuzzy inference system is designed such that after reaching the stand ,the bus with lowest SOC and highest trip distance will get the highest score.If for the given moment the bus possess any one of the two condition it will get comparatively lower score but SOC demand will get priority.The bus not possessing any one of the condition will get the lowest score. If the SOC level is above 50 percent, irrespective of the second condition the vehicle will not get score above 2.5. Similarly if the SOC is above 70 percent , the vehicle will not get score above 0.5 anyway.

B. Traffic algorithm for a particular moment at any given i^{th} interval

A miniature model of a standard scheduled route has been simulated which show that the taken EVCS can run successfully. Algorithm.2. stated the steps for traffic simulation. Route distance is 16 km and average speed is 16 km/hour and bus is available every 15 minutes from each end. We have taken average speed everywhere for simplicity. As per $output_i$ from algorithm 1, no of idle buses will be 6 in the route to enable maximum valley filling possible by EV mounting. Minimum no of Bus is 10 makes sum total of 16 buses in the route. The route is modelled as a [2*5] matrix in which every route of the matrix naming alphabetically '1-10' , denotes the current position of one bus. Matrix element (1,1) that is point 1 is the exit point of one end stand A and point 10 is the entrance of A stand, similarly point 5 & 6 elements are entrance and exit point of the other end bus stand.



The rule of traffic simulation done was:

1) Based on SOC and time needed to prepare for the next half trip, every bus will get a fuzzy score entering the bus stop.
2) Two types of charger are there, fast & slow. P Q is assumed to be the total no of buses to be charged at one interval. Depending on the score and $output_i$ of system algorithm, higher score P no of buses will get charged by fast charger and second higher Q no of buses will get charged by slow charger. Such that $2P + Q = output_i$.
3) Rest of the buses in bus stop will gt an idle time upto next interval.
4) If the Bus score throw it under higher P but the score is less than 2.5, the fast charger will charge the stationary battery pack. Similarly, if the Bus score throw it under less higher Q but the score is less than 0.5, the fast charger will charge the stationary battery pack.
5) For a trip to be started now, the bus getting the highest score at the moment will start the journey.
6) When a bus requires charging, if the grid is in under loading condition means in the valley portion of the load curve, it will get the energy from direct grid but if the grid is in overloading condition it will get the energy from battery pack. In that case the

Algorithm 2 Traffic Algorithm

This program runs at the advent of each interval
input $pos_i[16] \leftarrow$ initial positions of 16 public buses in the interval i
input $soc_i[16] \leftarrow$ initial SOC percentage of those 16 public buses in the interval i
if interval $i < 96$ **then**
  $j = i + 1$
  if position of the bus is point 1 or 2 or 3 or 4 or 6 or 7 or 8 or 9 **then**
    $pos_j = pos_i + 1 \leftarrow$ the bus will run to the next point in the next interval
    $soc_j = soc_i - 5.8 \leftarrow$ for travelling 15 minutes soc will decrease
  else
    if position of the bus is point 5 or 10 **then**
      Fuzzy score determination of the buses based on soc and trip distance by the stand based aggregator
      sorting of the scores
      if the bus score falls into highest P no of scores **then**
        if fuzzy score greater then 2.5 **then**
          $soc_j = soc_i + 30 \leftarrow$ 15 minutes charge by fast charger
          if grid is in overloading condition by taking input from load fluctuation curve **then**
            battery bank of the stand will charge the bus
          else
            grid will charge the bus
          end if
        else
          instead of the bus battery pack of the stand will get charged by fast charger from the grid
        end if
      end if
    else
      if the bus score falls into higher Q no of scores **then**
        if fuzzy score greater then 0.5 **then**
          $soc_j = soc_i + 15 \leftarrow$ 15 minutes charge by slow charger
          if grid is in overloading condition by taking input from load fluctuation curve **then**
            battery bank of the stand will charge the bus
          else
            grid will charge the bus
          end if
        else
          instead of the bus battery pack of the stand will get charged by slow charger from the grid
        end if
      end if
        if pos_i was point 5 **then**
          fuzzy score check again based on $soc_j \leftarrow$ upgraded soc and trip distance
          if the bus with the highest score **then**
            $pos_j = pos_i + 1 \leftarrow$ this bus is selected for next half trip
          else
            $pos_j = pos_i \leftarrow$ the bus will become idle at the stand upto the next interval
          end if
        end if
        if pos_i was point 10 **then**
          fuzzy score check again based on $soc_j \leftarrow$ upgraded soc and trip distance
          if the bus with the highest score **then**
            $pos_j = pos_i + 1 \leftarrow$ this bus is selected for next half trip
          else
            $pos_j = pos_i \leftarrow$ the bus will become idle at the other end stand upto the next interval
          end if
        end if
      end if
    end if
else
  terminate the program
end if

battery pack will be higher for the bus stops than other charging station among 341 charging stations all over the city.

7) There will be no charging facility during the journey. Only charging can occur at the starting or ending point of the journey.
8) As public transport services in the city end up before 11 pm on the day and grid overloading stops after 1 AM in an average the buses will start getting charged until trip starts next day. The charged distribution should be such that before the scheduled time of first trip all the bus get equal SOC.

V. Results

The actual load fluctuation curve and the curve after proposed treatment is like Fig.2.a. Approximately the city's peak load was 124 MW, whereas after the proposed EVCS treatment it has become 67 MW. As the average load demand is same, load factor is improved by more than 87 percent here.

The battery pack capacity for the bus stands would be 2.67 MWh due to extra energy storage for supporting public transport during valley forming of load curve(Fig.2.e.) & other charging station is 2.4 MWh.(Fig.2.f.) So totally in Kolkata city by our proposed strategy total battery capacity would be 834 MWh. That is still lesser than 960 MWh which is the capacity if the same improvement was done only by BESS without the harmonization of ev demand and power industry proposed here.

Results from traffic algorithm shows us the statuses of each of the 16 buses on the standard route whether it is

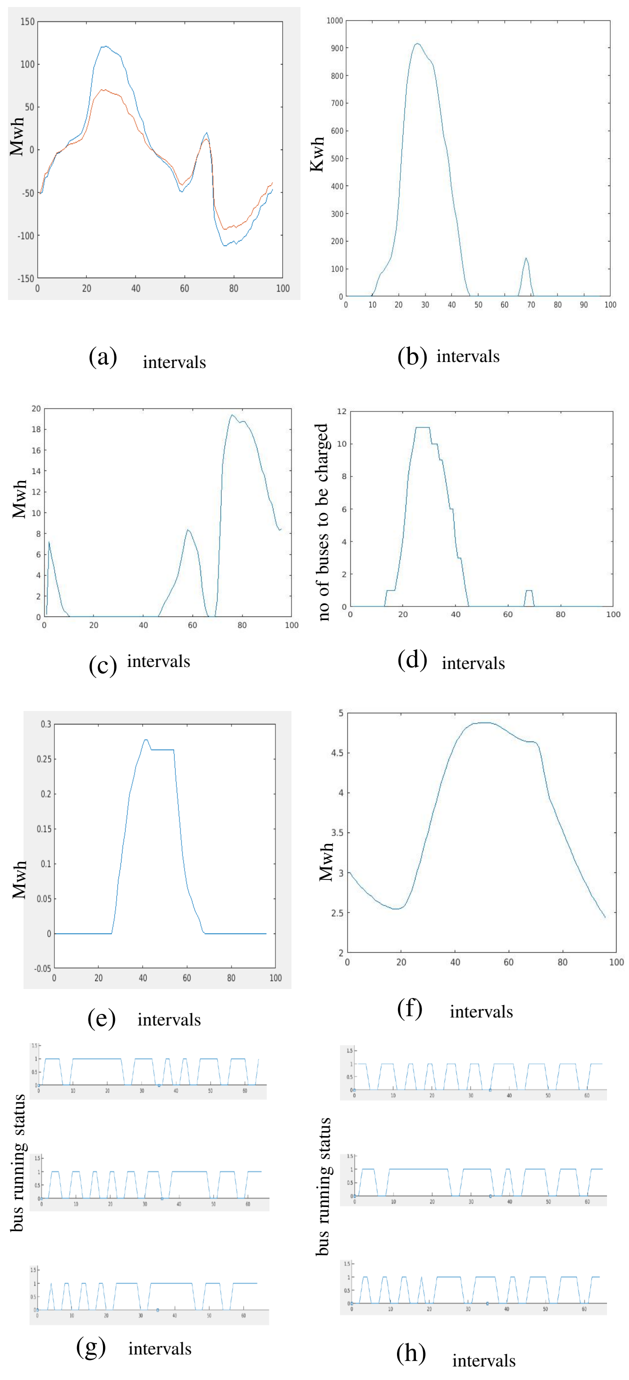


Fig. 3. Interval 0 means 12:00am - 12:15 am and interval 96 means 11:45 pm - 12:00 am.[for images a ,b, c, d, e & f] For image g & h interval 0 means 5:00 am- 5:15 am and interval 64 means 8:45pm-9:00 pm (a) Blue- actual load fluctuation curve, red- after treatment ; (b) energy given to grid Mwh per interval; (c) energy given to grid Mwh per interval; (d) Number of govt buses charging schedule per bus stand per interval; (e) Energy needed o support public transport during valley forming of load curve ; (f) battery energy storage over 96 intervals in a battery bank station in Mwh; (g) Online tracking of bus no 2,3,4 among the 16 buses over 96 intervals of a day; (h) Online tracking of bus no 6,7,8 [random pick among the 16 statuses]

on route (state 0) or in rest standing in the bus stand(state 1).As the service starts at interval 1 which is 5 am and ends at 64 which is 9 pm, the graph is provided only upto 64 intervals. It can be seen that at the end of the day every bus has been entered in their stands timely by our algorithm of automated traffic manager.Therefore, the online aggregator is running successfully. (Fig. 2.g. & Fig.2.f.)

The problem of load profile smoothing with this simple fuzzy based approach is considering maximum possible PV penetration. Whereas, to implement this algorithm private transport has got a tight schedule as a whole over the day. In that case based on emergency and other priorities like how many time before the owner has booked for this charging slot etc. can be considered to determine which particular vehicle the grid will consider for charging at that particular slot for the particular charging station. OL-FCA will run efficiently for that case.

VI. Conclusion

As from as the survey of the city was concerned, the unscheduled electric bus in the city mainly kept on charging during 12:00 to 2:00 pm and 12:00 am to 2:00 am. From here it can be concluded that the unscheduled vehicles charging time mostly coincides with peak over-loading hours of grid which is very uncomfortable for grid. Moreover, as an energy balancing solution [**?**] showed that battery storage is now competitive with other large scale solutions for energy balancing,i) Gas peaking plants 218 dollars per MWh,ii)Solar thermal 137 dollars per MWh, iii)Pumped hydro 161 dollars per MWh,(the cost of pumped hydro would be significantly variable depending on the scale and size of the project and other factors such as proximity to power lines) iv) Lithium Ion batteries 216 dollars per MWh.There is a sharp declining of battery pack cost over the years. So , it can be considered that as time passes by, in near future BESS technology would be the most economical solution for energy balancing. Instead of the proposed strategy, if energy balancing of grid and electric vehicle charging schedule were taken care of separately, BESS capacity for the city would be 980 Mwh. In our case, proposed capacity for current scenario came out as 834 Mwh along with a charging schedule for EVs in the city.

References

[1] M. Baun, M. A. Awadallah, and B. Venkatesh, “Implementation of load-curve smoothing algorithm based on battery energy storage system,” in *2016 IEEE Canadian Conference on Electrical and Computer Engineering (CCECE)*. IEEE, pp. 1–5, 2016.

[2] H. Mehdipoor and S. Jadid, “Charging/discharging scheduling of electrical vehicles considering uncertainty of pv generations in smart homes,” in *2014 19th Conference on Electrical Power Distribution Networks (EPDC)*. IEEE, pp. 110–115, 2014.

[3] Mingshen, M. Yunfei, T. Jiang, J. Hongjie, L. Xue, H. Kai, and W. Tong, “Load curve smoothing strategy based on unified state model of different demand side resources,” *Journal of Modern Power Systems and Clean Energy*, vol. 6, no. 3, pp. 540–554, 2018.

[4] Q. Chen, N. Liu, X. Lu, and J. Zhang, “A heuristic charging strategy for real-time operation of pv-based charging station for electric vehicles,” in *2014 IEEE Innovative Smart Grid Technologies-Asia (ISGT ASIA)*. IEEE, pp. 465–469, 2014.

[5] V. Gupta, S. R. Konda, R. Kumar, and B. K. Panigrahi, “Multiaggregator collaborative electric vehicle charge scheduling under variable energy purchase and ev cancelation events,” *IEEE Transactions on Industrial Informatics*, vol. 14, no. 7, pp. 2894–2902, 2017.

[6] J. Tao, D. Huang, D. Li, X. Yang, and C. Ling, “Pricing strategy and charging management for pv-assisted electric vehicle charging station,” in *2018 13th IEEE Conference on Industrial Electronics and Applications (ICIEA)*. IEEE, pp. 577–581, 2018.

[7] A. Ivanova, J. A. Fernandez, C. Crawford, and N. Djilali, “Coordinated charging of electric vehicles connected to a net-metered pv parking lot,” in *2017 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe)*. IEEE, pp. 1–6, 2017.

[8] A. S. Masoum, S. Deilami, A. Abu-Siada, and M. A. Masoum, “Fuzzy approach for online coordination of plug-in electric vehicle charging in smart grid,” *IEEE Transactions on Sustainable Energy*, vol. 6, no. 3, pp. 1112–1121, 2014.

[9] I. Colak, R. Bayindir, A. Aksoz, E. Hossain, and S. Sayilgan, “Designing a competitive electric vehicle charging station with solar pv and storage,” in *2015 IEEE International Telecommunications Energy Conference (INTELEC)*. IEEE, pp. 1–6,2015.

[10] S. Chapaloglou, A. Nesiadis, P. Iliadis, K. Atsonios, N. Nikolopoulos, P. Grammelis, C. Yiakopoulos, I. Antoniadis, and E. Kakaras, “Smart energy management algorithm for load smoothing and peak shaving based on load forecasting of an island’s power system,” *Applied Energy*, vol. 238, pp. 627–642, 2019.