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An Optimal Battery Charging And Schedule Control Strategy For Electric Bus Rapid Transit

Semaria Ruiz
Nicolás Arroyo, Andrés Acosta, Christian Portilla and Jairo Espinosa

Departamento de Energía Eléctrica y Automática
Universidad Nacional de Colombia - Sede Medellín
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Contents

Problem statement

Private car usage generate negative externalities [1]:

- Parking-space shortage
- Traffic congestion

Fig. 1. Parking-space shortage example.

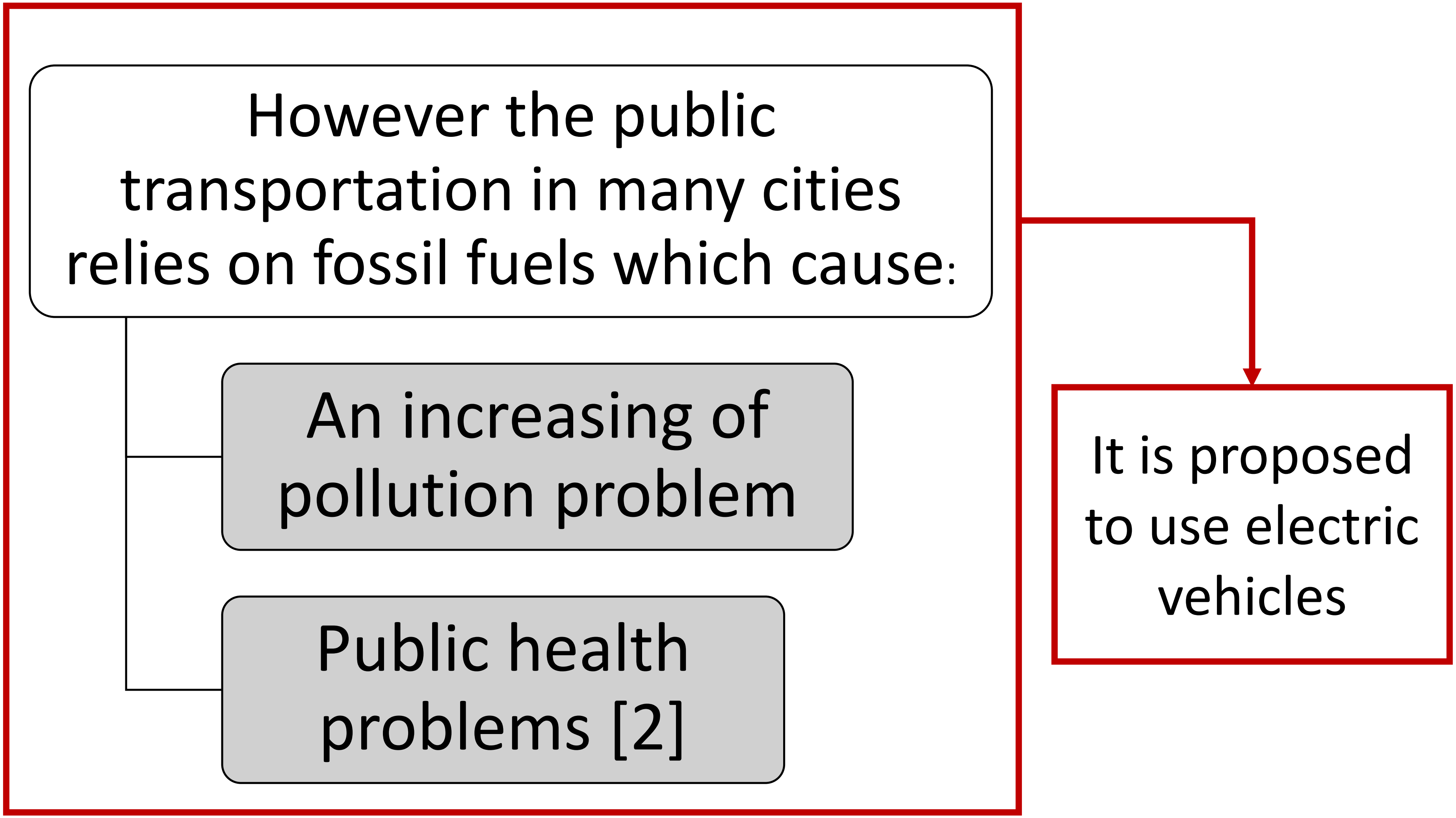
Fig. 2. Traffic congestion example.

Problem statement

Fig. 3. Bus rapid transit (BRT) example.

Using massive transportation modes like buses, BRT instead of cars and motorcycles

Problem statement



However the public transportation in many cities relies on fossil fuels which cause:

- An increasing of pollution problem
- Public health problems [2]

It is proposed to use electric vehicles

State of the art

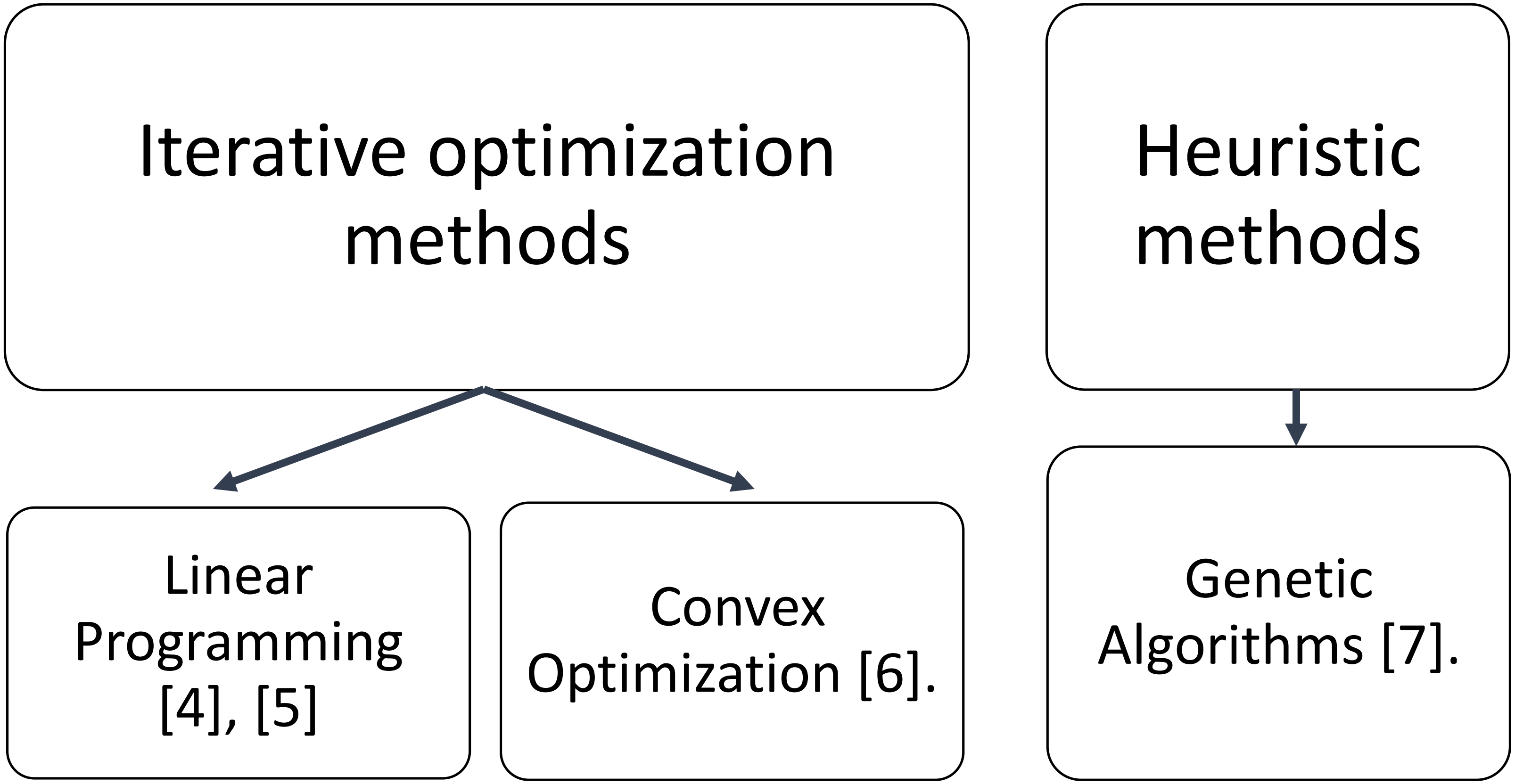
Control techniques for optimal integration of electric vehicles (EVs) with the power grid [3].

Two types of interaction between EVs and power grid

- Unidirectional power interaction: the vehicles cannot provide active power to the grid, hence they are always seen as loads
- Bidirectional power interaction: vehicles can provide power to the grid in order to help actively with the generation-load balance.

State of the art

In both approaches deterministic and heuristic optimization methods are used.



- Iterative optimization methods
  - Linear Programming [4], [5]
  - Convex Optimization [6].
- Heuristic methods
  - Genetic Algorithms [7].

Proposed issue

A novel scheduling strategy for charging and dispatching electric heterogeneous Bus Rapid Transit (BRT) fleets equipped with batteries

Using the Simulation of Urban MObility (SUMO) package, we determine the required BRTs departures to supply a transport demand

- We consider two vehicle classes with different dimensions and capacities.

This information is sent to the optimization algorithm to find the optimal departure schedule and charging power of each BRT.

- Our optimization reduces the energy cost, and search that the BRTs fill the daily transportation requirements.
- We used the Branch and Cut optimization algorithm.

Proposed issue

Charging station

Fig. 5. Charging station.

$P_{c1}(t)$

$P_{c2}(t)$

Fig. 4. Electric BRT with different capacities.

Power exchanged with the grid, and vehicles that will covers a defined route

Proposed issue

- **Decision variables**

$$\boxed{\epsilon_k}, \boxed{P_{ck}}, \boxed{A_{sk}}$$

Where:
$N \in R$: is the number of simulation time steps
$N_{ev,k} \in R$: is the number of type *k* BRTs
$n_{v,k} \in R$: is the number of departures of type *k* BRTs

$\boldsymbol{\epsilon_k} \in \boldsymbol{R}^{(\boldsymbol{N} \times \boldsymbol{N_{ev,k}})}$: is a binary matrix of slack variables for charging/discharging constraints of type *k* BRTs

$\boldsymbol{P_{ck}} \in \boldsymbol{R}^{(\boldsymbol{N} \times \boldsymbol{N_{ev,k}})}$*:* is the charging power of the type *k* BRTs. *j* is the number of type *k* BRTs

$\boldsymbol{A_{sk}} \in \boldsymbol{R}^{(\boldsymbol{n_{v,k}} \times \boldsymbol{N_{ev,k}})}$: is a selection matrix containing 1’s in the position of the vehicle that departs to perform a travel, and 0 otherwise

Proposed issue

$$A_{sk}$$

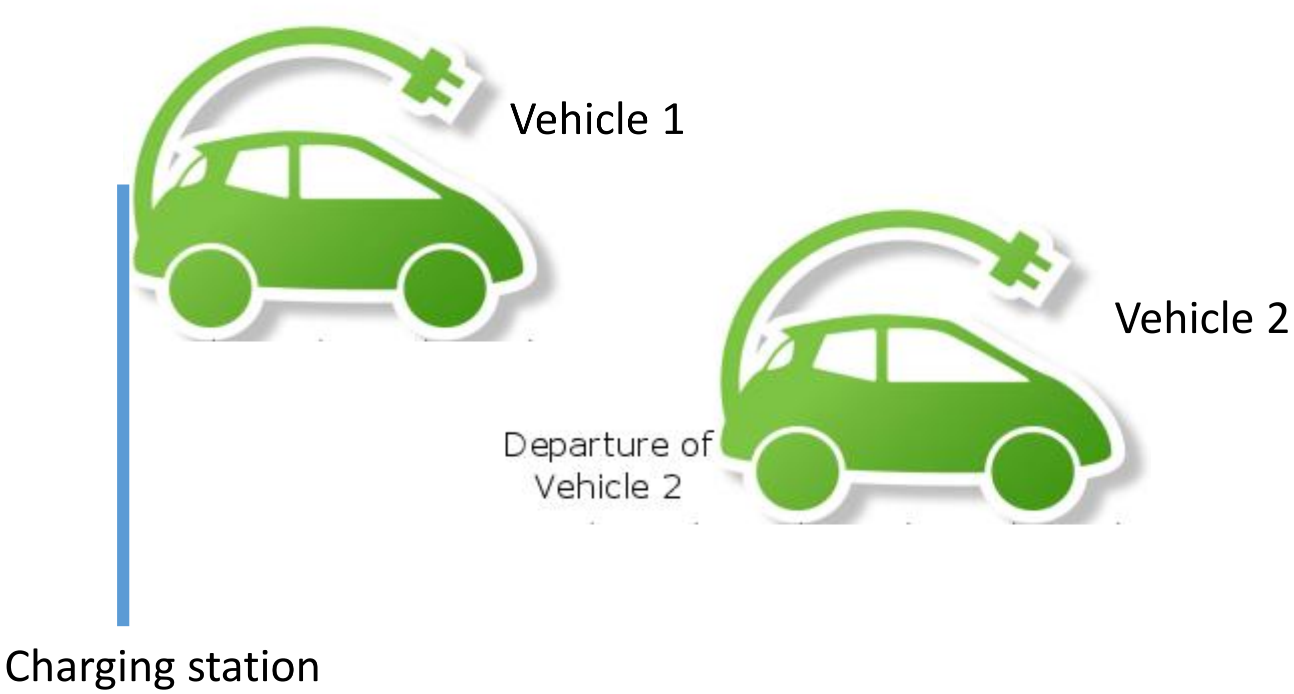


Fig. 6. Example of a vehicle depart.

$$A_{sk} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

Proposed issue

- **Cost function:**

$$f = \boxed{E_p} \cdot \sum_{k=1,2} \sum_{j=1}^{N_{ev,k}} P_{ck}(i,j) + \sum_{k=1,2} w_{\epsilon k} \left\| \sum_{j=1}^{N_{ev,k}} \epsilon_k(i,j) \right\|$$

Daily average electricity price

- **Constraints:**

Battery model:

$$E_{bk}(t+1) = E_{bk}(t)(1-\sigma_{bk}) + P_{ck}(t) - P_{dk}(t)$$

Energy and power limits:

$$\boldsymbol{E_k^m} \leq E_{bk} \leq \boldsymbol{E_k^M}$$

$$0 \leq P_{ck} \leq \boldsymbol{P_k^M}$$

$$\sum_{i=1,2} \sum_{j=1}^{N_{ev\,i}} P_{ck}(i,j) \leq \boldsymbol{P_{lim}}$$

Where:

$E_{bk} \in R^{(N \times N_{ev,k})}$ is the energy in batteries of type *i* BRTs

$\sigma_{bk} \in R$ is the self-discharging factor of a battery of type *i* BRTs

$P_{dk} \in R^{(N \times N_{ev,k})}$ is the discharging power of the type *i* BRTs

E_k^m is the minimum energy capacity of a battery of type *i* BRTs

E_k^M is the maximum energy capacity of a battery of type *i* BRTs

P_k^M is the maximum power capacity of a battery of type *i* BRTs

P_{lim} is the maximum power capacity of the feeder

Proposed issue

Energy consumption in travels:

$$\boxed{P_{dk} = C_{tk} A_{sk}}$$

Assigns the electric consumption of a travel to the vehicle indicated in A_{sk}

$$\boxed{\sum_{j=1}^{N_{ev,k}} A_{sk}(i,j) = 1}$$

A travel is performed just by one vehicle

$$\boxed{\left(A_{sk}^{T} A_{Rk}\right)^{T} \leq \mathbf{1}}$$

A vehicle just can perform one travel at time

Where:

$C_{tk} \in R^{(N \times n_{v,k})}$: is a matrix that contains the energy consumption of the vehicle per step time (Data from SUMO)

$A_{Rk} \in R^{(n_{v,k} \times N)}$: is a matrix that contains 1's in position where a travel is being executed

Proposed issue

$\left(A_{sk}^{T}A_{Rk}\right)^{T}$

Binary matrix, which have 1’s at step times positions when a vehicle is performing a route

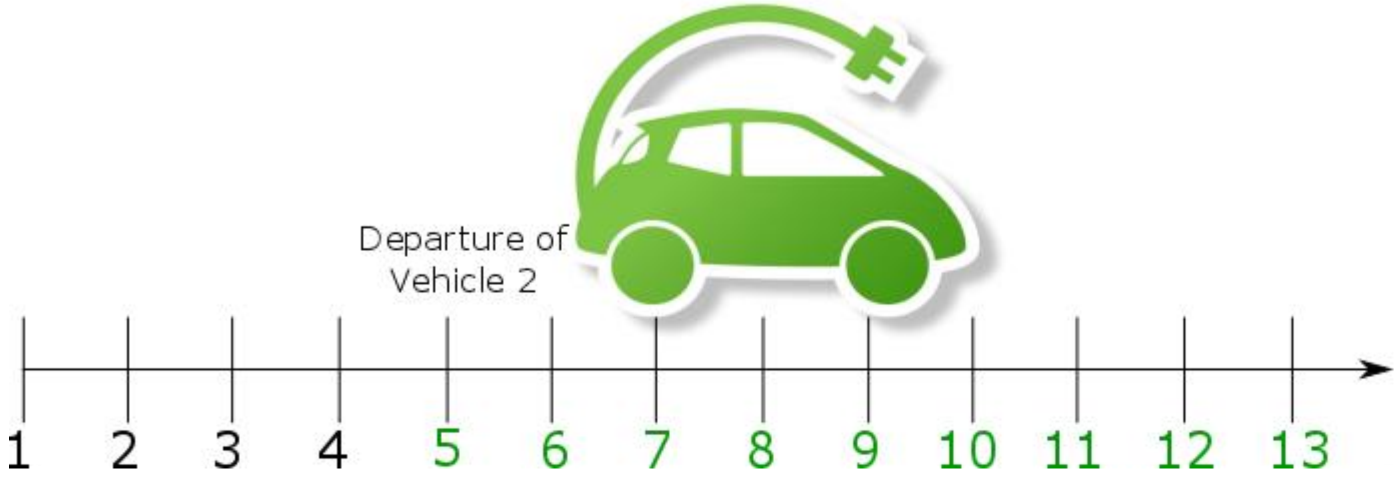


Fig. 7. Example of operating schedule of a vehicle.

$$A_{sk}^{T}A_{Rk} = \begin{array}{c}\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}\end{array}\begin{array}{l}\text{Vehicle 1}\\ \text{Vehicle 2}\end{array}$$

Case of study

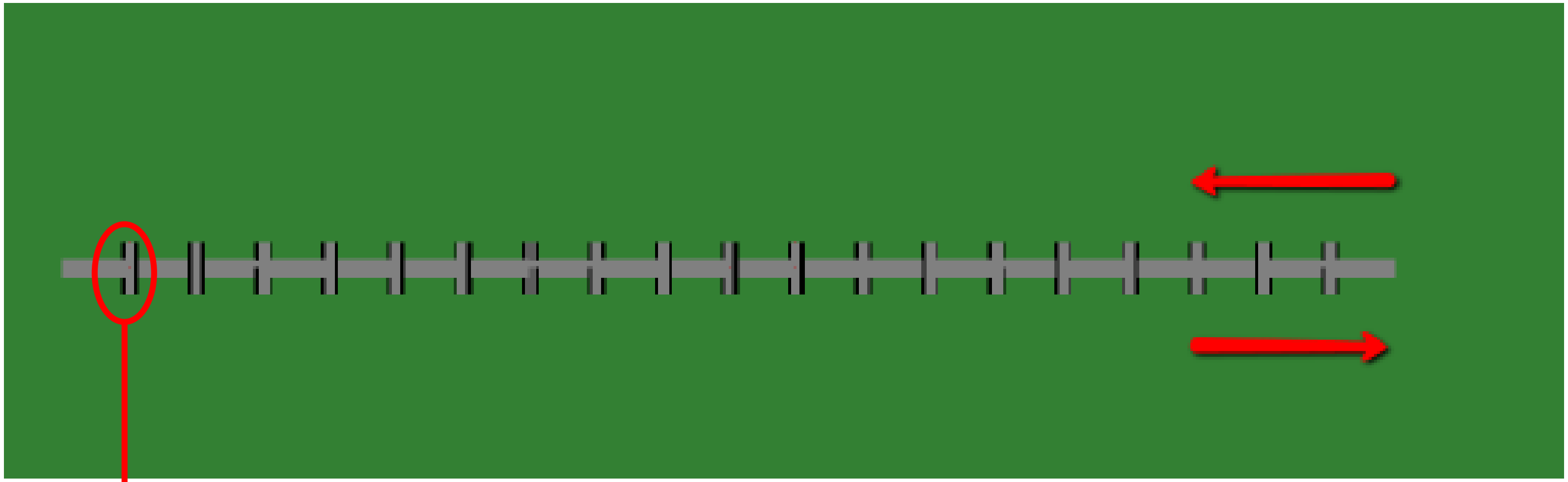


Fig. 8. Simulation scenario in SUMO.

The flow of passengers in a BRT station is proportional to the number of stations that are ahead

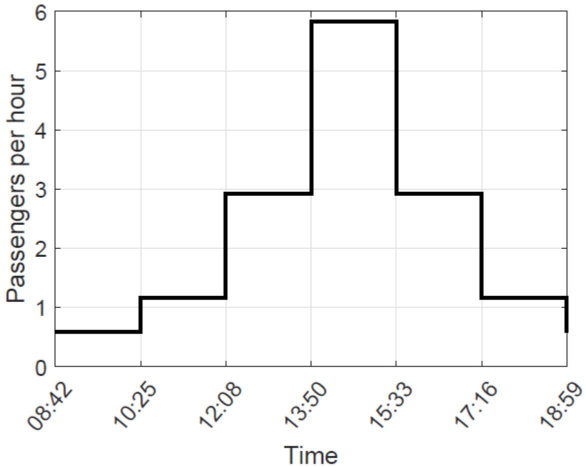
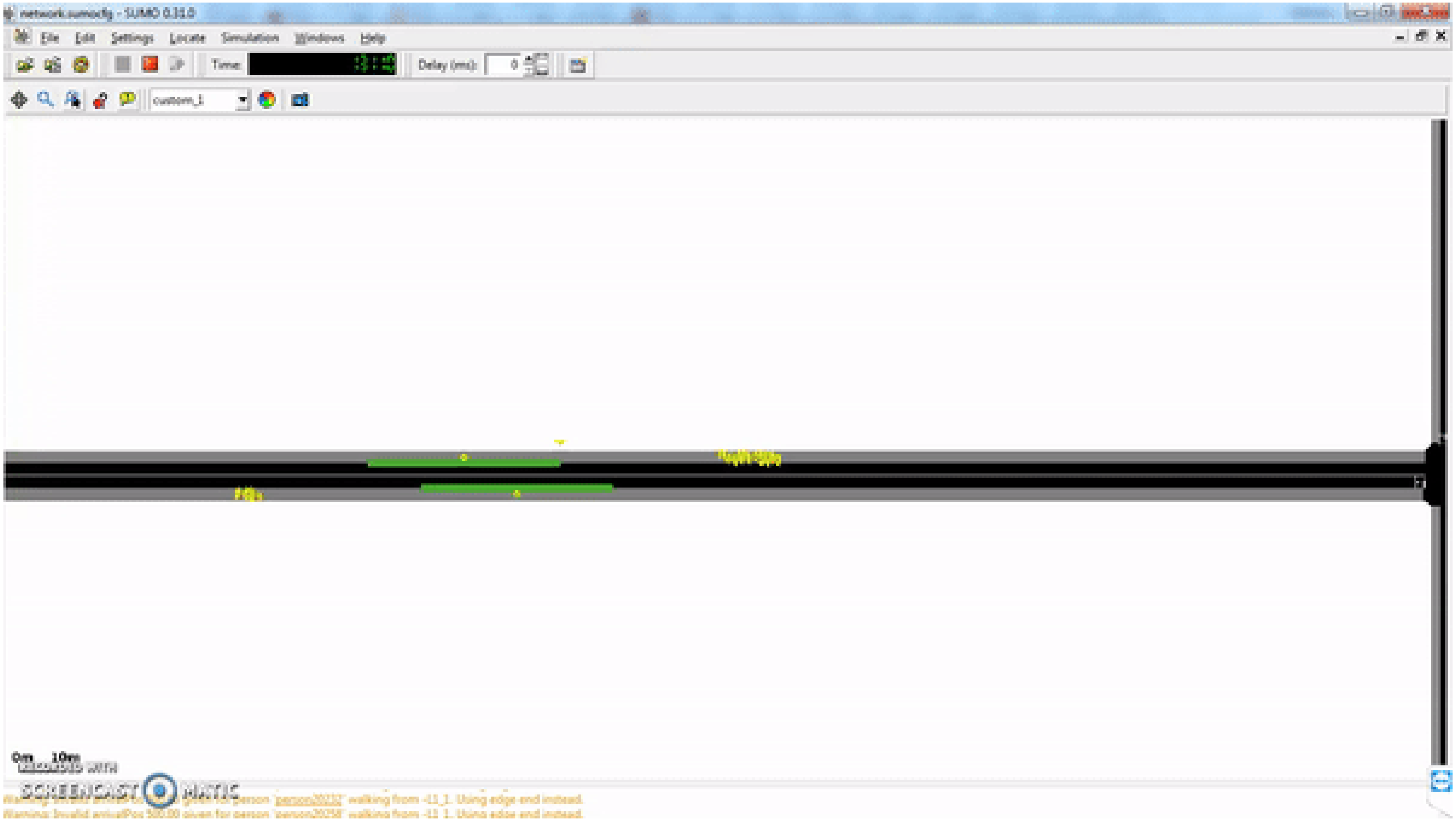


Fig. 9. Passengers flow in BRT stations.

20 BRT stations.

The Length of the edges comprising the BRT route is 500 m.

Case of study



```
Warning: [illegible] given for person 'person20232' walking from -11_1. Using edge end instead.
Warning: Invalid arrivalPos 500.00 given for person 'person20258' walking from -11_1. Using edge end instead.
```

Case of study

Table I. Batteries parameters.

Parameters	Electric BRTs of type 1	Electric BRTs of type 2
Rated energy capacity	E_1^M= 324 kWh	E_2^M= 547 kWh
Maximum charging/discharging power	P_1^M=60 kW	P_2^M=108 kW
Number of BRTs	N_{ev1}=5	N_{ev2}=10

Dispatch of type 1 or type 2 BRTs:

If the maximum occupancy of BRTs is lower than 80 %, BRTs of type 2 are departed, otherwise, a type 1 BRT is departed.

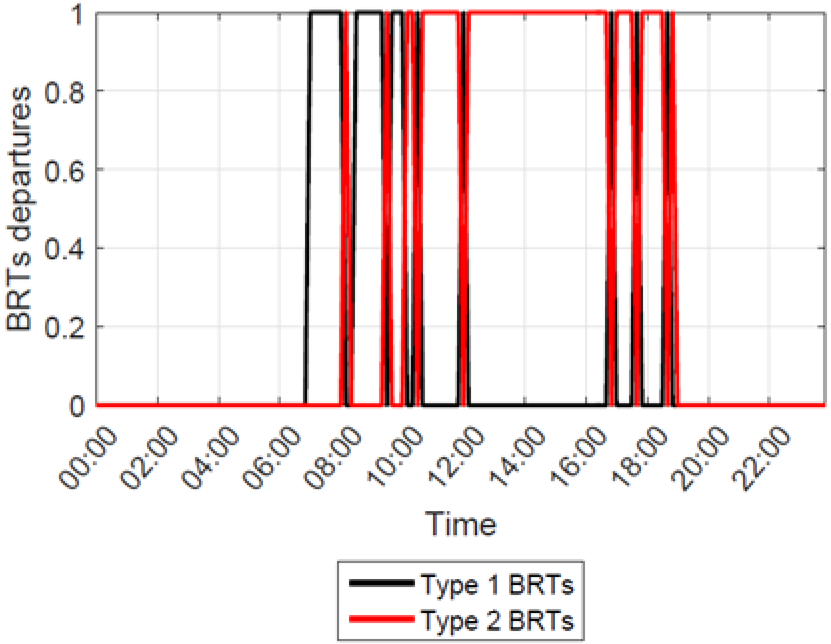


Fig. 10. Programmed BRTs departures from the charging station.

Simulation horizon: One day, with time steps of 10 minutes.

Results and analysis

Electricity price variation

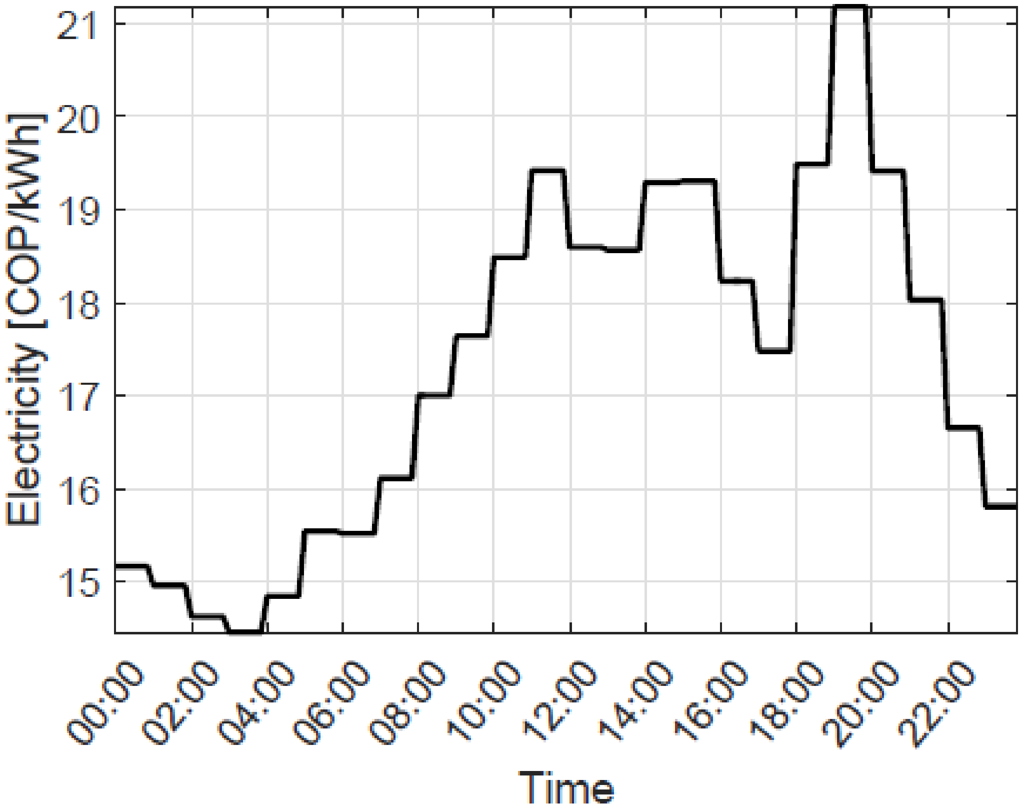


Fig. 11. Daily average national energy spot price for Colombia in 2017 [8].

Results and analysis

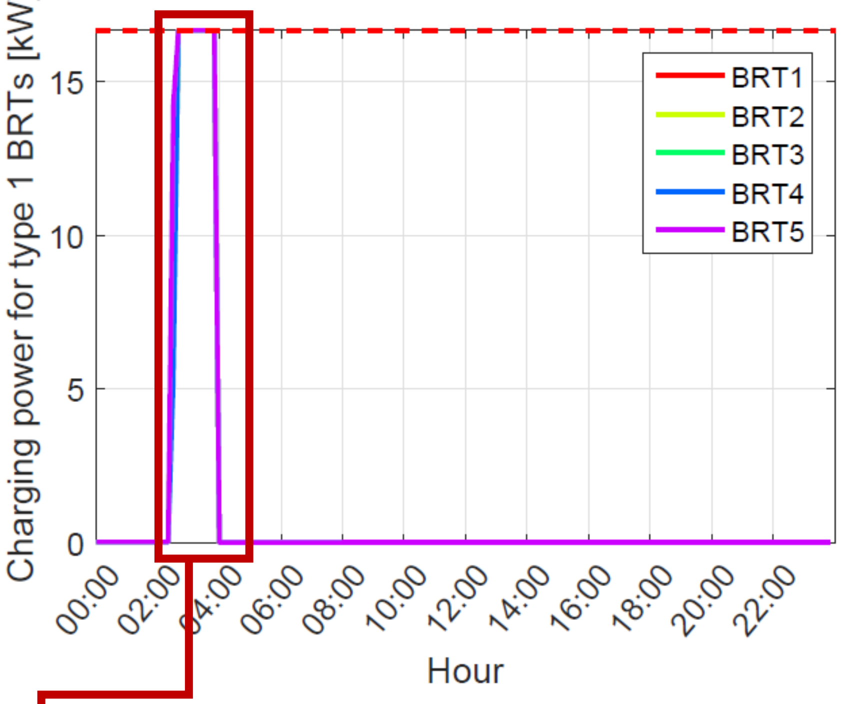


Fig. 12. Charging power of type 1 BRTs.

Lowest energy price hours

21 trips

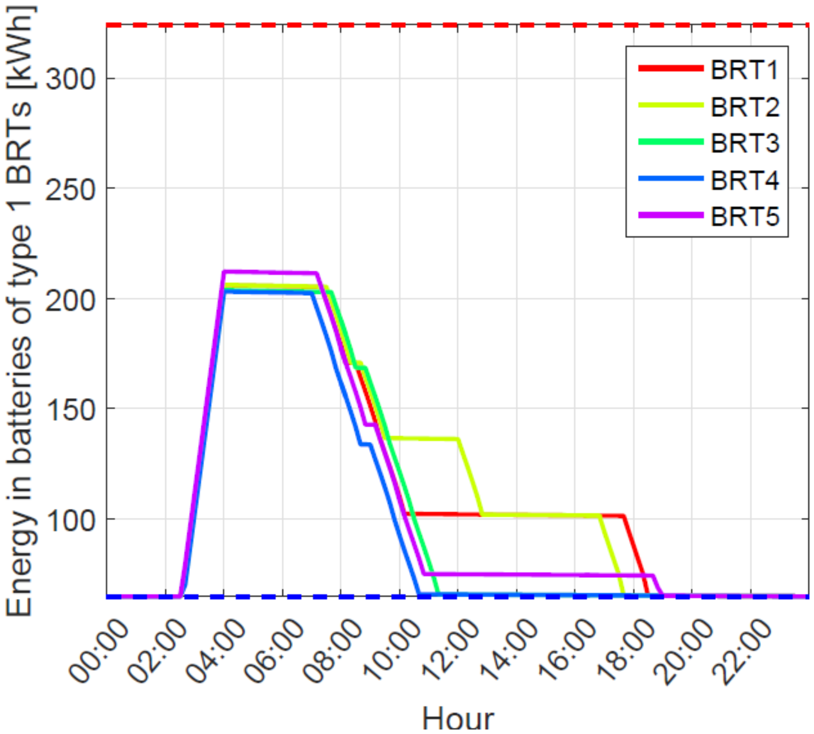


Fig. 13. Energy in batteries of type 1 BRTs.

Results and analysis

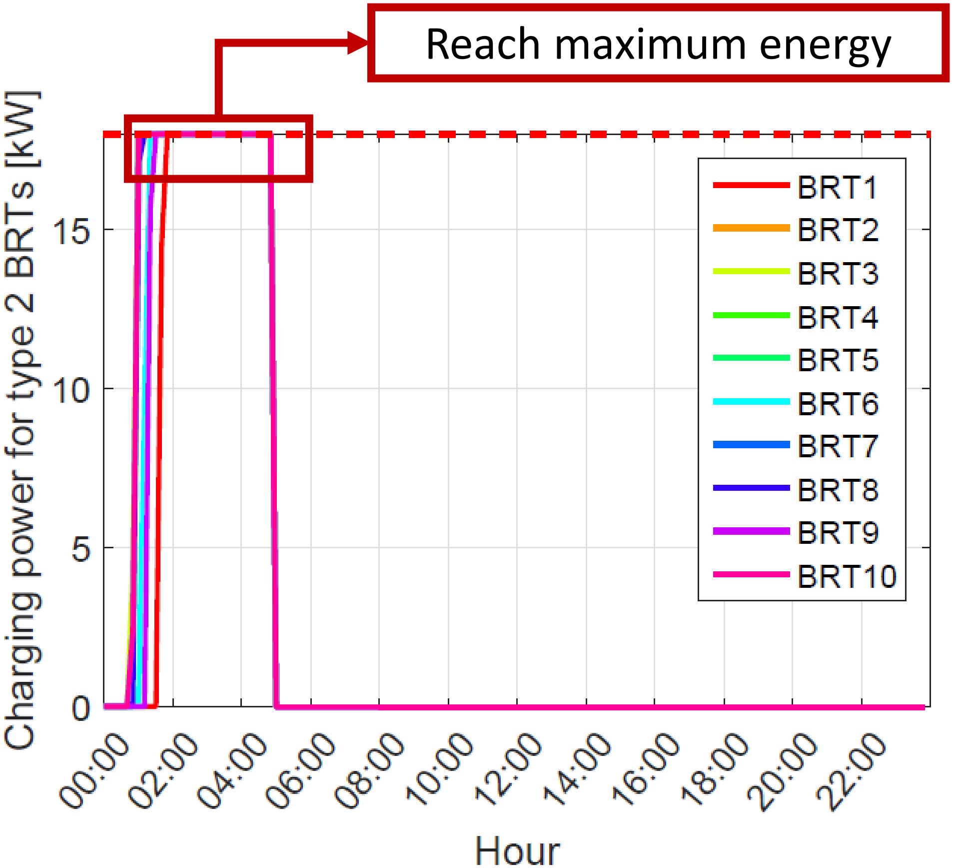


Fig. 14. Charging power of type 2 BRTs.

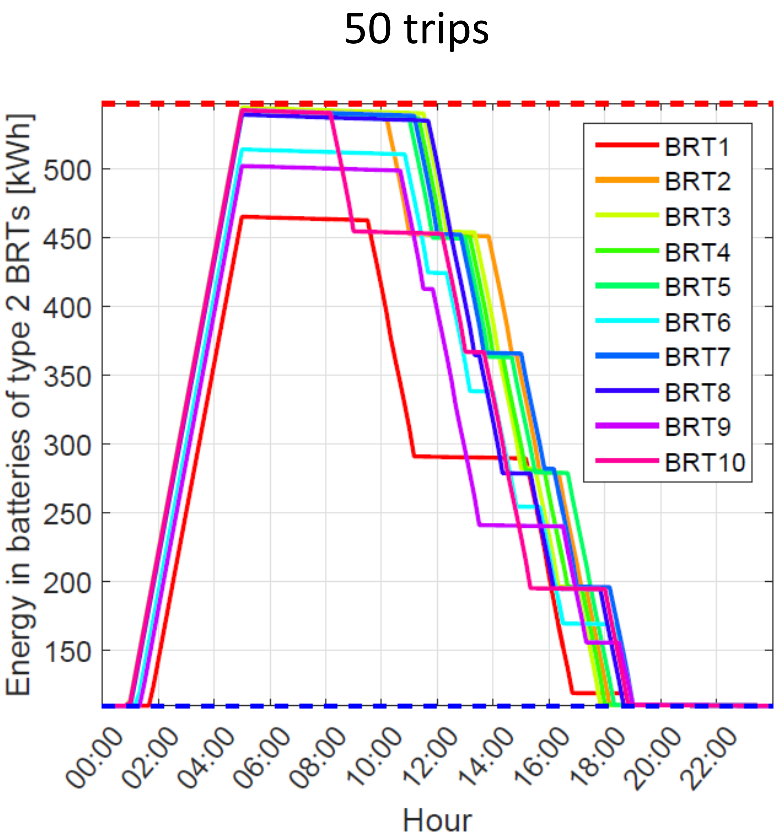


Fig. 15. Energy in batteries of type 2 BRTs.

We reach savings of 27.5% per day, compared to an equal charging strategy.

Conclusions

Contributions of this work:

- Linearization of the product between charging and discharging power that must be zero in all time steps: inclusion of slack variables
- The proposed strategy was able to reduce the operation cost compared with a conventional equal charging strategy
  - It allows a sensitivity of the charging power of the BRTs to the price of energy
  - BRTs only charge the energy that they need to complete the programmed trips

Future works:

- Improving the estimation the daily demand
- Include the active participation of BRTs with the power grid

THANKS

QUESTIONS, SUGGESTIONS, COMMENTS

References

- [1] P. David *et al.*, “Medellin y su calidad del aire,” *Esc. Int. Desarro. Sosten.*, 2016.
- [2] C. J. Chou, C. W. Chen, and C. Conley, “A systematic approach to generate service model for sustainability,” *J. Clean. Prod.*, vol. 29–30, pp. 173–187, 2012
- [3] K. M. Tan, V. K. Ramachandaramurthy, and J. Y. Yong, “Integration of electric vehicles in smart grid: A review on vehicle to grid technologies and optimization techniques,” Renewable and Sustainable Energy Reviews, vol. 53, pp. 720–732, 2016. [Online]. Available: http://dx.doi.org/10.1016/j.rser.2015.09.012
- [4] E. Sortomme and M. A. El-Sharkawi, “Optimal charging strategies for unidirectional vehicle-to-grid,” IEEE Transactions on Smart Grid, vol. 2, no. 1, pp. 119–126, 2011.
- [5] C. Ahn, C. T. Li, and H. Peng, “Optimal decentralized charging control algorithm for electrified vehicles connected to smart grid,” Journal of Power Sources, vol. 196, no. 23, pp. 10 369–10 379, 2011. [Online]. Available: http://dx.doi.org/10.1016/j.jpowsour.2011.06.093
- [6] Y. He, B. Venkatesh, and L. Guan, “Optimal scheduling for charging and discharging of electric vehicles,” IEEE Transactions on Smart Grid, vol. 3, no. 3, pp. 1095–1105, 2012.
- [7] A. Y. Saber and G. K. Venayagamoorthy, “Intelligent unit commitment with vehicle-to-grid -A cost-emission optimization,” Journal of Power Sources, vol. 195, no. 3, pp. 898–911, 2010.
- [8] XM Compañía Expertos en Mercados S.A. E.S.P., «Histórico Transacciones y Precio», *Plataforma de información inteligente XM*, 2017. [En línea]. Disponible en: http://informacioninteligente10.xm.com.co/transacciones/Paginas/HistoricoTransacciones.aspx . [Accedido: 20-nov-2017].

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Grupo de Automática de la Universidad Nacional - GAUNAL
Facultad de Minas

Carrera 80 #65-223
Medellín, Colombia
(+57 4) 425 52 95
jespinov@unal.edu.co

gaunal.medellin.unal.edu.co **www.minas.medellin.unal.edu.co**