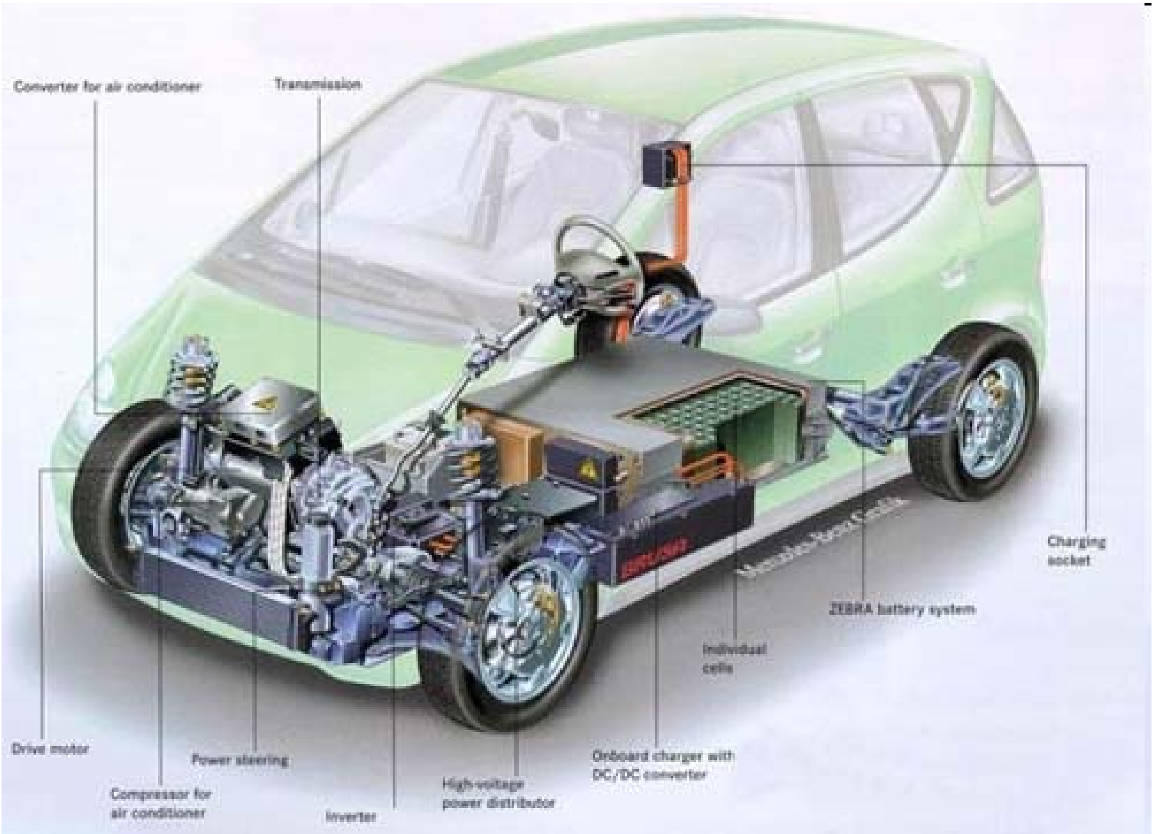
Direct Load Control Decision Model

applied to

Electric Vehicle Charging Points

Armero Huertas, Ismael
Barcenilla Torres, María
Dmitrieva, Ekaterina
Donner, Christian
Naya, Jorge
Peñamil Alcázar, Marcos

INTRODUCTION



Electric vehicles are becoming an **alternative** to internal combustion engine vehicles due to their **low emissions**, **high energy efficiency** and **competitive autonomy range**.

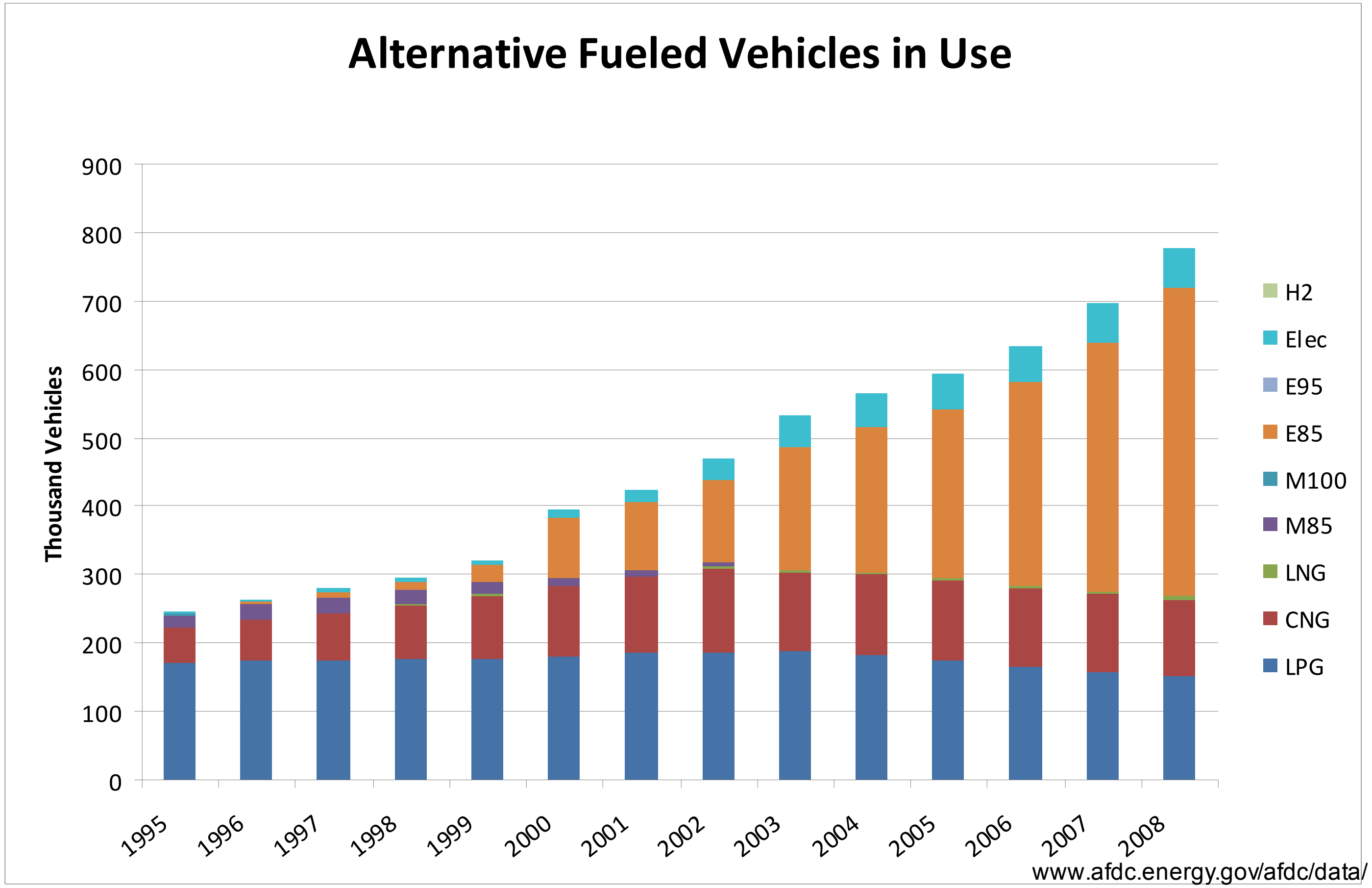
Electric vehicles (EV) and Plug-in Hybrid Electric Vehicle (PHEV) are the two main current available technologies.

INTRODUCTION

In 2009, the Council of Ministers gave its approval to the signing of three Collaboration Agreements in order to implement an operational start-up of a pilot network of public electric vehicle recharging stations, within the framework of a pilot project called **MOVELE**.

One of project MOVELE´s aim is to activate stimulus measures among the local authorities concerned to **enable the creation of a network of supply points** located on streets and in public car parks, as a step towards a total of 2000 electric vehicles being driven on the roads within two years.

INTRODUCTION



www.afdc.energy.gov/afdc/data/

INTRODUCTION

Electric vehicles are propelled by an electric motor (or motors) powered by rechargable battery packs. Electric motors have several **advantages** over internal combustion engines (ICEs):

- Energy efficient
- Environmentally friendly
- Performance benefits
- Reduce energy dependance

Electric vehicles face also significant battery-related **challenges**:

- Driving range
- Recharge time
- Battery cost
- Bulk and weight

INTRODUCTION

Current available electric vehicles have a shorter range per charge than most conventional vehicles have per tank of gas. EV manufacturers typically target a minimum range of 100 milles (**160 km aprox**.). For instance, according to the U.S. department of Transportation Federal Highway Administration, 100 milles is sufficient for more than **90% of all household vehicle trips** in the United States. For longer trips, it is necessary to charge the vehicle or swap the battery en route.

INTRODUCTION

The public charging infrastructure should consist of charging locations where vehicle owners are highly concentrated:

- shopping centers
- city parking lots and garages
- airports
- hotels
- government offices
- other businesses

Widespread public charging infrastructure will help facilitate the penetration of all-electric vehicles and plug-in hybrid electric vehicles and help address consumer "**range anxiety**" for those vehicles with limited range.

INTRODUCTION

What to really expect based on different personal driving habits?

Nissan has published an overview of the range of variations we can expect:

- Cruising at 60km/h with ambient temp of 20ºC: 222 km.
- Averaging 38 km/h in city traffic drops range to 170 km, assuming no A/C.
- At 88km/h on a highway in 35ºC temp and A/C: 112 km.
- Winter temps of -10ºC with the heater on, will drop range to be 24 km.

EXAMPLES OF ELECTRIC VEHICLES

Charging demo of an electric car: Tesla Roadster

ASSUMPTIONS AND COMMENTS

- Three EV models with different capacities and charging rates.
- Electricity prices real (14th-15th April).
- Initial level and capacity integer.
- Time unit is one hour.
- Arriving and leaving times are thus integer.
- Vehicles allways want to leave the garage at full energy capacity.
- To avoid battery damage a minimum level of energy storage should be achieved without discharging (70% capacity).

FIRST MODEL

SETS

- $i = 1, \ldots, n \ (\text{number of cars})$
- $j = 0, \ldots, 48 \ (\text{hours})$

PARAMETERS

- $arrive_i$ $\rightarrow$ Arrival time of EV i
- $leave_i$ $\rightarrow$ Leaving time of EV i
- $level_i$ $\rightarrow$ Initial power level of EV i
- $demand_i$ $\rightarrow$ Power demand of EV i
- $capacity_i$ $\rightarrow$ Maximum capacity the battery has in car i
- $price_j$ $\rightarrow$ Price of electricity at time j

- L $\rightarrow$ Power limit of the garage (KW)
- m $\rightarrow$ Minimum level of recharge rate (KW)
- GR $\rightarrow$ Maximum recharging rate of the garage (KWh)
- CR_i $\rightarrow$ Maximum recharging rate of EV i (KWh)
- CR^*_i $\rightarrow$ Min $\{CR_i, GR\}$ (KWh)

VARIABLES

- $DNS1_i$ = Demand not satisfied counting from 70% of capacity i
- $DNS2_i$ = Demand not satisfied until 70% of capacity i
- P_{ij} = Power supplied to i in hour j
- $\delta_{ij} = \begin{cases} 1, & \text{if car i charges during hour j,} \\ 0, & \text{otherwise} \end{cases}$
- $\alpha_{ij} = \begin{cases} 1, & \text{if car i starts charge at hour j+1,} \\ 0, & \text{otherwise} \end{cases}$

CONSTRAINTS

- Not to exceed the limit of power provided by the garage

$$\sum_{i=1}^{n} P_{ij} \leq L \ \forall j$$

- Not to charge before the car arrives

$$\sum_{j=0}^{arrive_i} \delta_{ij} = 0 \ \forall i$$

- Not to charge once the car has left

$$\sum_{j=leave_i}^{48} \delta_{ij} = 0 \ \forall i$$

i	*cars*
j	*hours*

- The power provided has to meet both garage and car specifications

$$P_{ij} \leq CR_i^* \cdot \delta_{ij} \;\; \forall i, j \text{ where } CR_i^* = \min\{CR_i, GR\}$$

- Minimum power supplied (min offer)

$$P_{ij} \geq \delta_{ij} \cdot m \;\; \forall i, j$$

- Demand should be equal to the supplied plus not satisfied demand

$$demand_i = DNS1_i + DNS2_i + \sum_{j=1}^{48} P_{ij} \;\; \forall i$$

- Number of times i starts charging

$$\delta_{ij+1} - \delta_{ij} \leq \alpha_{ij} \;\; \forall i, j$$

i	*cars*
j	*hours*

- At most each car is started once

$$\sum_{j=1}^{48} \alpha_{ij} \leq 1 \ \forall i$$

- Demand (below 70%) not satisfied

$$DNS2_i = 0.7 \cdot capacity_i - \min\left\{0.7 \cdot capacity_i,\ \sum_{j=0}^{48} P_{ij} + initial\_level_i\right\}$$

- We divide the total amount of demand not satisfied into two parts

$$DNS1_i \leq 0.3 \cdot capacity_i \ \forall i$$

- Demand not satisfied below 70%

$$DNS2_i \leq 0.7 \cdot capacity_i \ \forall i$$

i	*cars*
j	*hours*

- $\delta_{ij},\ \alpha_{ij} \in \{0,1\}$
- $\text{supplied}_i,\ DNS1_i,\ DNS2_i,\ P_{ij} \in$ ¡

i *cars*

j *hours*

OBJECTIVE FUNCTION

We want to minimize the cost for the garage penalizing the demand not satisfied

$$\min\left(\sum_{i=1}^{n}\sum_{j=1}^{48} P_{ij}\cdot price_j + p_1\cdot\sum_{i=1}^{n} DNS1_i + p_2\cdot\sum_{i=1}^{n} DNS2_i\right)$$

i	*cars*
j	*hours*

SECOND MODEL
(Selling energy)

VEHICLE TO GRID

Vehicle to grid (V2G): **sell demand** by delivering electricity into the grid.

- Most vehicles are parked an average of 95 percent of the time, their batteries could be used to let electricity flow from their car to the power lines and back, with a great revenue value to the utilities.

Peak load leveling:

- Balance loads by “valley filling” (charging at night when demand is low) and “peak shaving” (sending power back to te grid when demand is high).
- New ways to keep voltage and frequency stable and provide reserves to meet sudden demands for power.

SETS

- $i = 1,\ldots,n \ (\text{number of cars})$
- $j = 0,\ldots,48 \ (\text{hours})$

i	*cars*
j	*hours*

PARAMETERS

- L $\rightarrow$ Power limit of the garage (KW)
- m $\rightarrow$ Minimum level of recharge rate (KW)
- GR $\rightarrow$ Maximum recharging rate of the garage (KWh)
- CR_i $\rightarrow$ Maximum recharging rate of EV i (KWh)
- CR^*_i $\rightarrow$ Min $\{CR_i, GR\}$ (KWh)

i	*cars*
j	*hours*

VARIABLES

- $DNS1_i$ = Demand not satisfied counting from 70% of capacity i
- $DNS2_i$ = Demand not satisfied until 70% of capacity i
- P_{ij} = Power supplied to i in hour j
- Q_{ij} = Power discharged from i in hour j
- $\delta_{ij} = \begin{cases} 1, & \text{if car i charges during hour j,} \\ 0, & \text{otherwise} \end{cases}$
- $\eta_{ij} = \begin{cases} 1, & \text{if car i is discharges during hour j,} \\ 0, & \text{otherwise} \end{cases}$

i	*cars*
j	*hours*

CONSTRAINTS

- Not to exceed the limit of power provided by the garage

$$-L \leq \sum_{i=1}^{n} (P_{ij} - Q_{ij}) \leq L \ \forall j$$

- Not to charge/discharge before the car arrives

$$\sum_{j=0}^{arrive_i} \delta_{ij} = 0 \ \forall i \qquad \sum_{j=0}^{arrive_i} \eta_{ij} = 0 \ \forall i$$

- Not to charge/discharge once the car has left

$$\sum_{j=leave_i}^{48} \delta_{ij} = 0 \ \forall i \qquad \sum_{j=leave_i}^{48} \eta_{ij} = 0 \ \forall i$$

i	$cars$
j	$hours$

- The power provided has to meet both garage and car specifications

$$P_{ij} \leq CR_i^* \cdot \delta_{ij} \;;\; Q_{ij} \leq CR_i^* \cdot \eta_{ij} \quad \forall i, j \quad \text{where } CR_i^* = \min\{CR_i, GR\}$$

- Minimum power the garage offers or sells

$$P_{ij} \geq \delta_{ij} \mathrm{m} \;\forall i, j \quad Q_{ij} \geq \eta_{ij} \cdot m \;\forall i, j$$

- Demand should be equal to the supplied plus the not satisfied demand

$$demand_i = DNS1_i + DNS2_i + \sum_{j=1}^{48} P_{ij} - \sum_{j=1}^{48} Q_{ij} \quad \forall i$$

- DNS1 is the demand over 70% not satisfied, so

$$DNS1_1 \leq 0.3 * capacity_i \quad \forall \mathrm{i}$$

i	*cars*
j	*hours*

- You can´t charge or discharge at the same time

$$\delta_{ij} + \eta_{ij} \leq 1 \ \forall i, j$$

- State of charge car i at hour j

$$SOC_{ij} = initial\_level_i + \sum_{k=0}^{j} P_{ij} - \sum_{k=0}^{j} Q_{ij}$$

- The state of charge can be never below 0%

$$SOC_{ij} \geq 0$$

- Variable FLAG defines either you are over or below 70%

$$SOC_{ij} \geq 0.7 * capacity_i * FLAG_{ij} \ \forall i, j$$

$$SOC_{ij} \leq 0.7 * capacity_i * (1 - FLAG_{ij}) + capacity_i * FLAG_{ij}$$

i	$cars$
j	$hours$

- Not allow the battery to go below 70% once it reached that level

$$FLAG_{ij+1} - FLAG_{ij} \geq 0 \ \forall i, \ \forall j \neq 48$$

- Battery can´t be discharged when level is below 70%

$$\eta_{ij} \leq FLAG_{ij} \quad \forall i, j$$

- Battery can´t stop charging before it reaches the 70% level

$$\delta_{ij+1} - \delta_{ij} \leq \alpha_{ij} + FLAG_{ij} \quad \forall i \quad \forall j \neq 48$$

- Below 70%, battery can only start charging once

$$\sum_{j=0}^{48} \alpha_{ij} \leq 1 \quad \forall i$$

i	*cars*
j	*hours*

- $\delta_{ij},\ \eta_{ij}, FLAG_{ij} \in \{0,1\}$
- $DNS1_i,\ DNS2_i,\ P_{ij}, Q_{ij}, SOC_{ij} \in$ ¡

i *cars*

j *hours*

OBJECTIVE FUNCTION

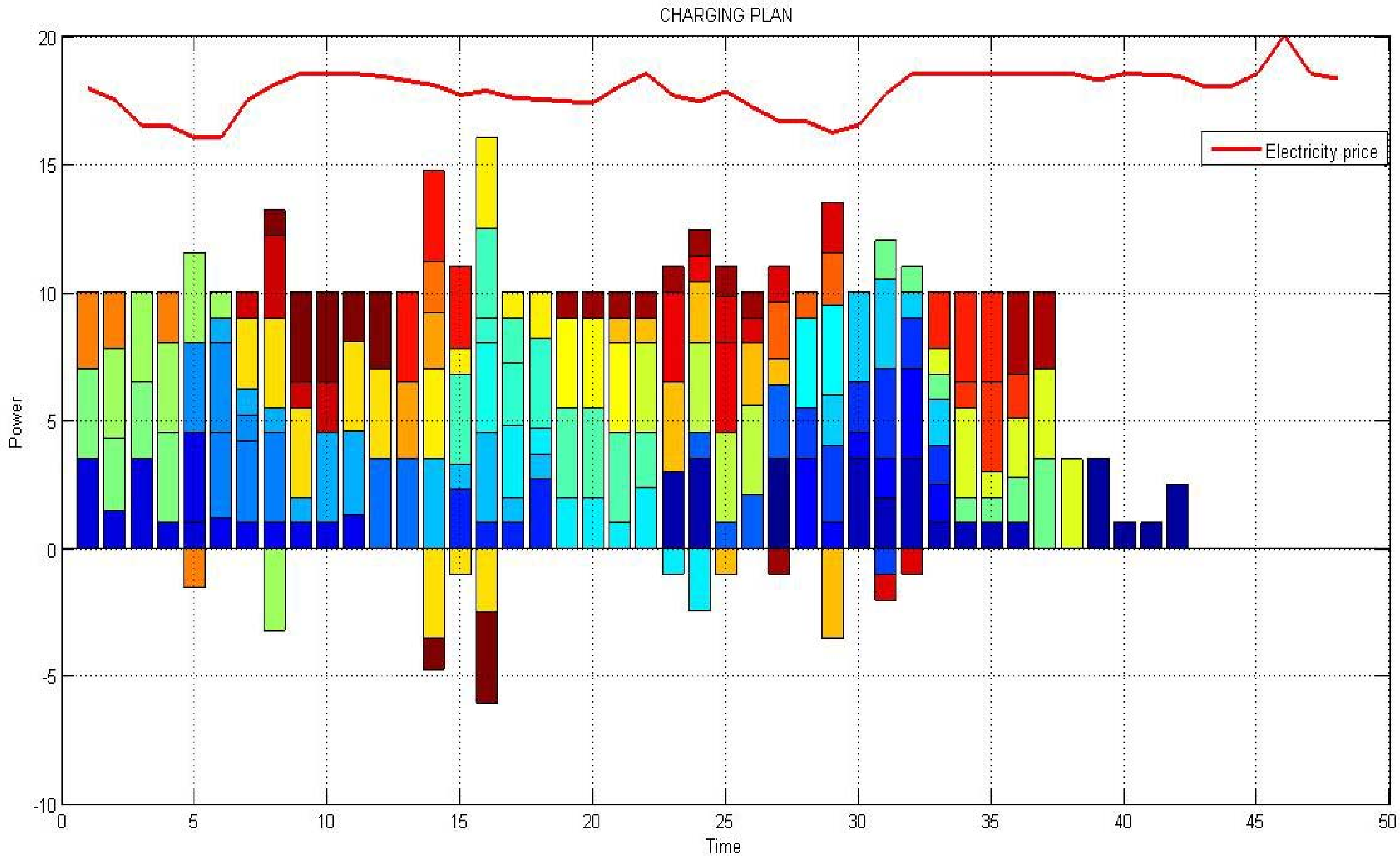
Minimize the cost counting the energy we sell and penalizing the demand not satisfied

$$\min\left(\sum_{i=1}^{n}\sum_{j=1}^{48}(P_{ij}-Q_{ij})\cdot price_j + p_1\cdot\sum_{i=1}^{n}DNS1_i + p_2\cdot\sum_{i=1}^{n}DNS2_i\right)$$

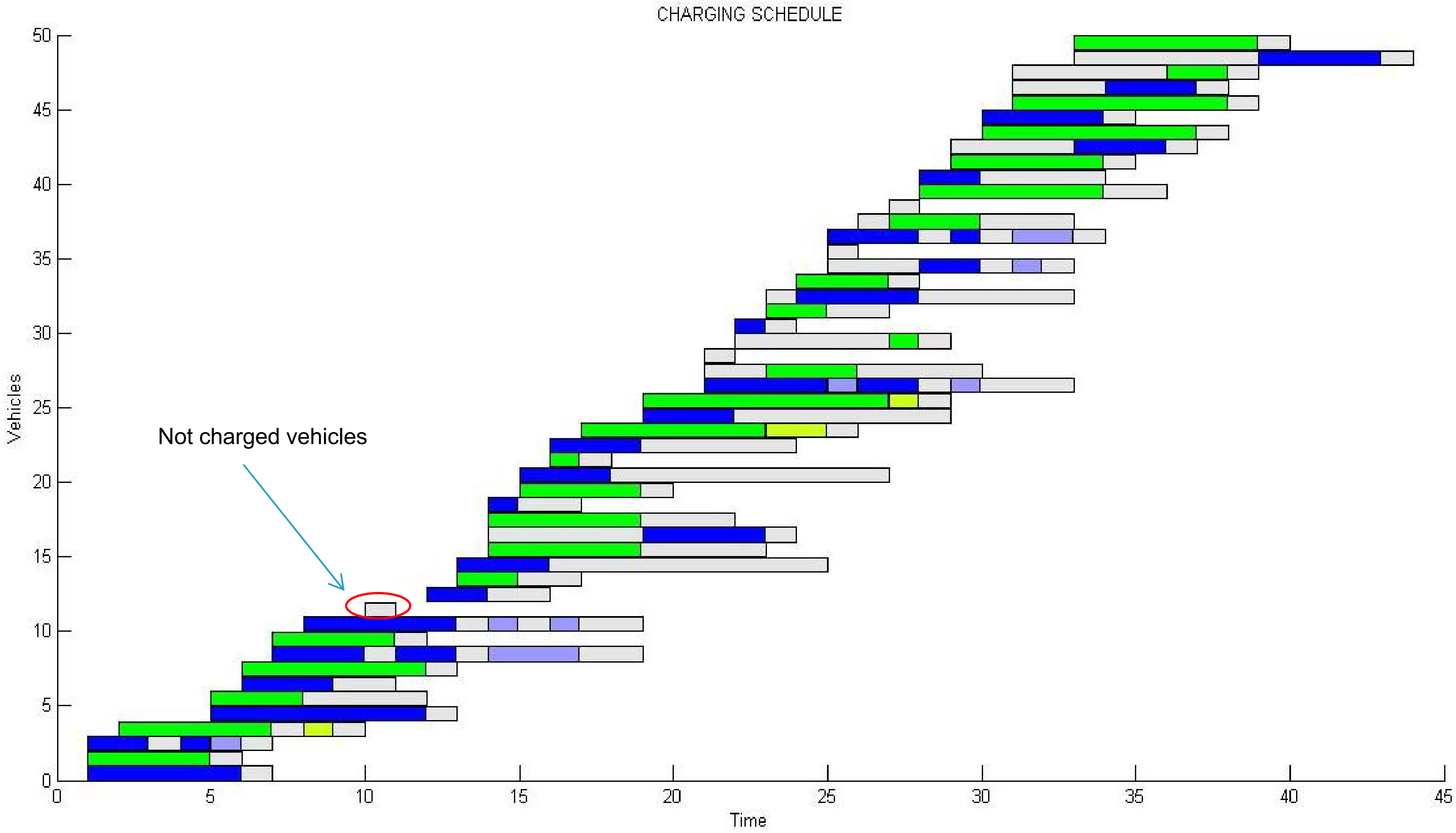
i	*cars*
j	*hours*

RESULTS

Grid limit: L=10

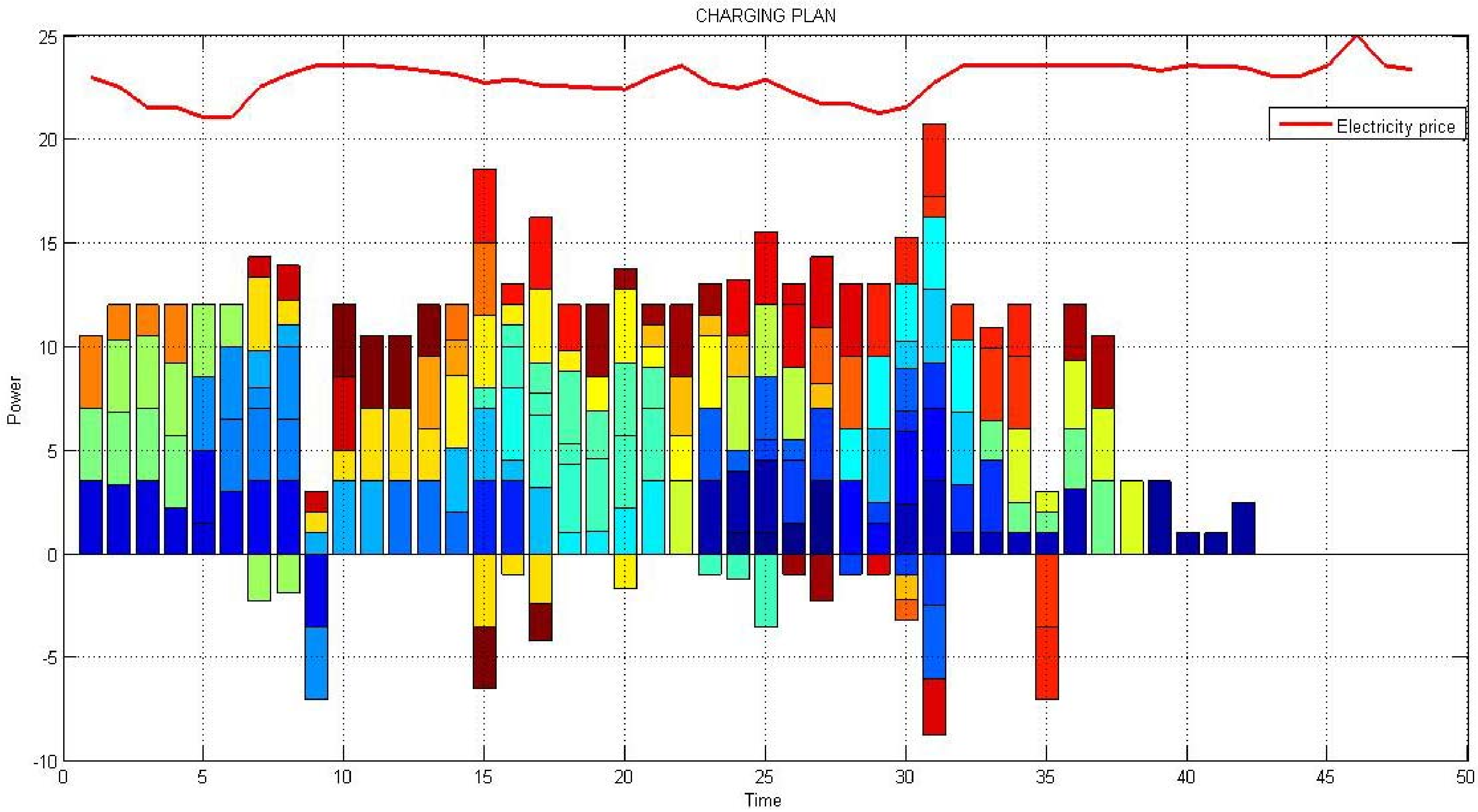


Each colour represents a different vehicle.



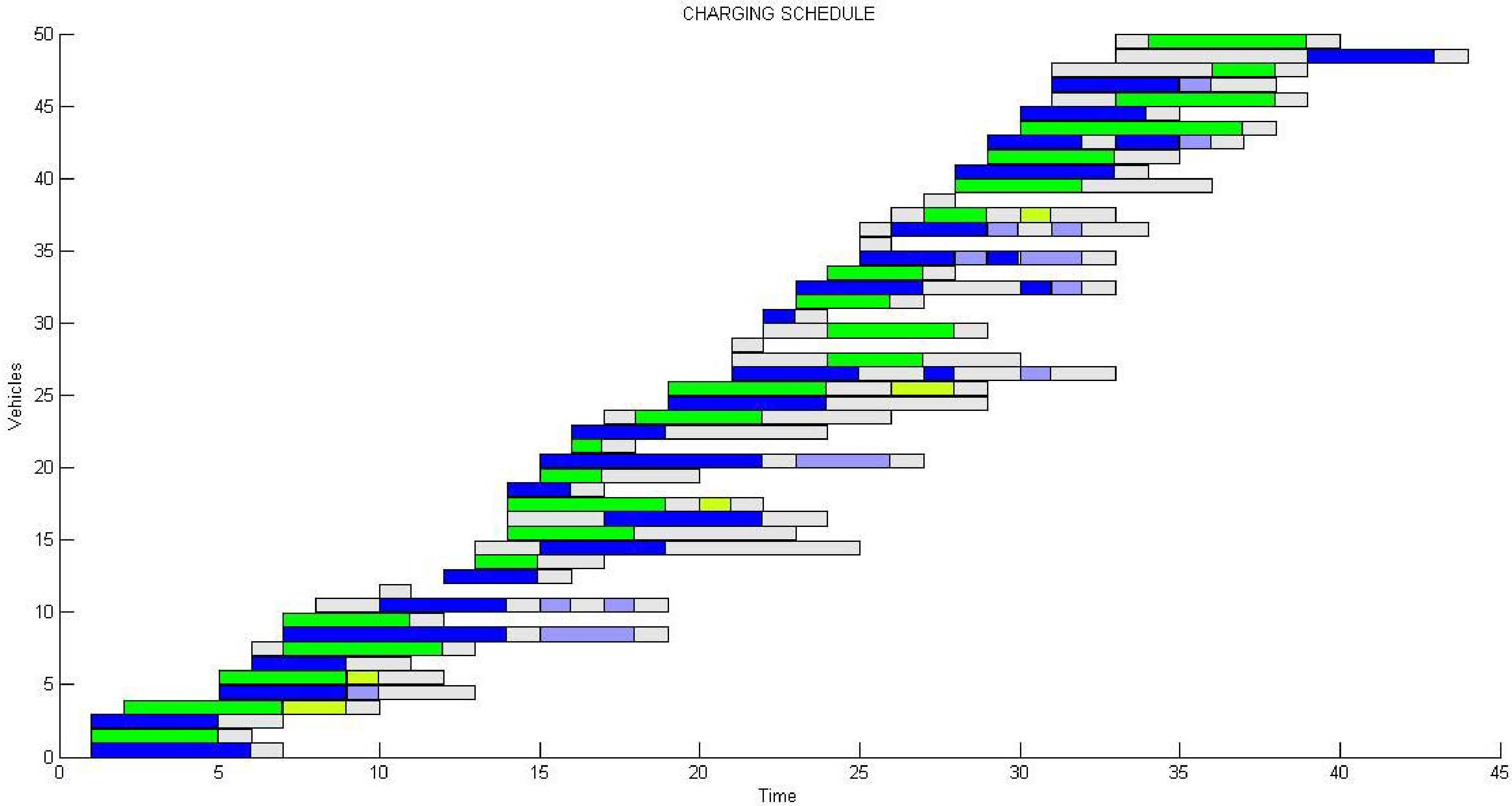
Charging/discharging schedule

Grid limit: L=12



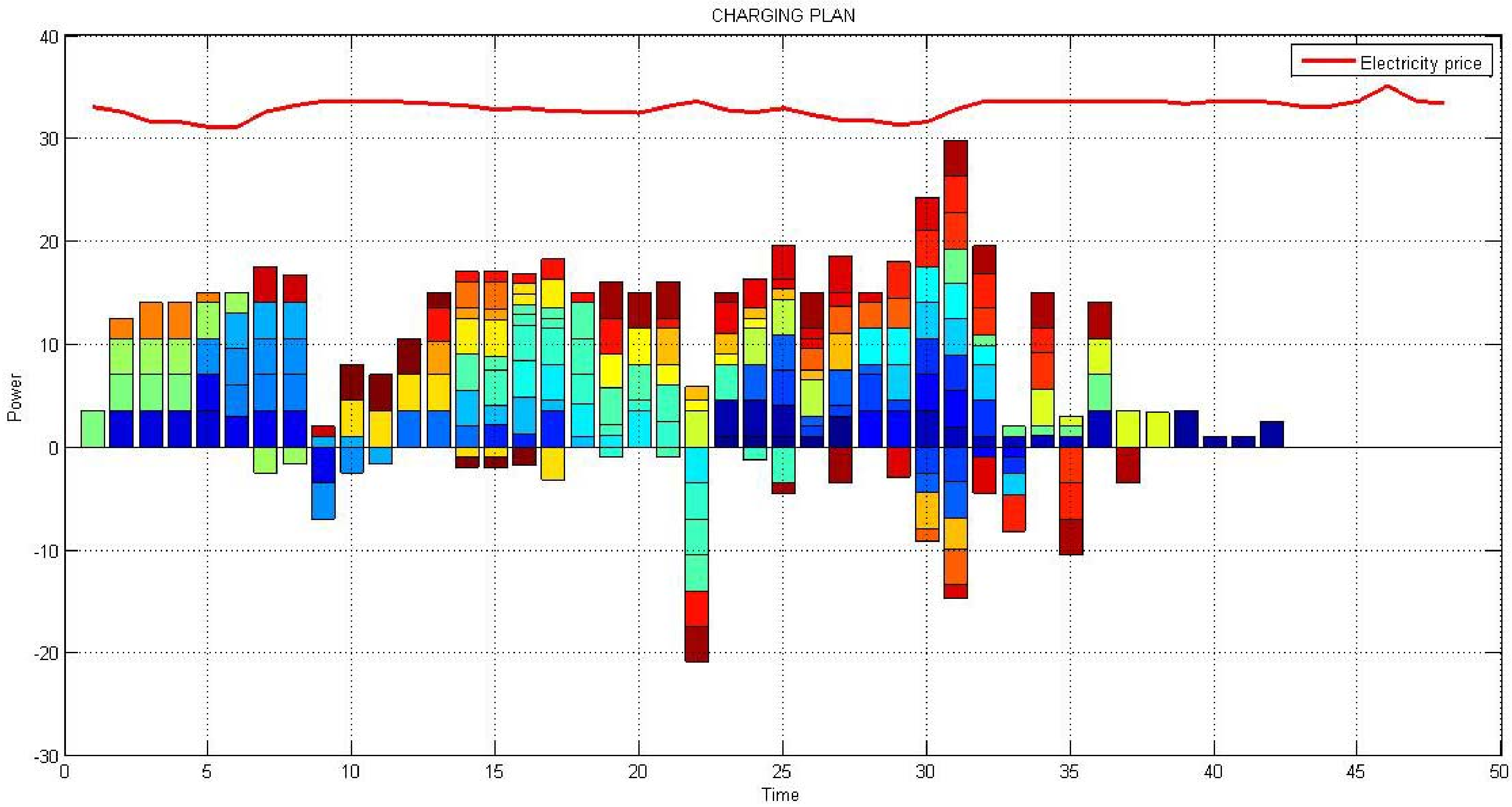
Each colour represents a different vehicle.

Grid limit: L=12



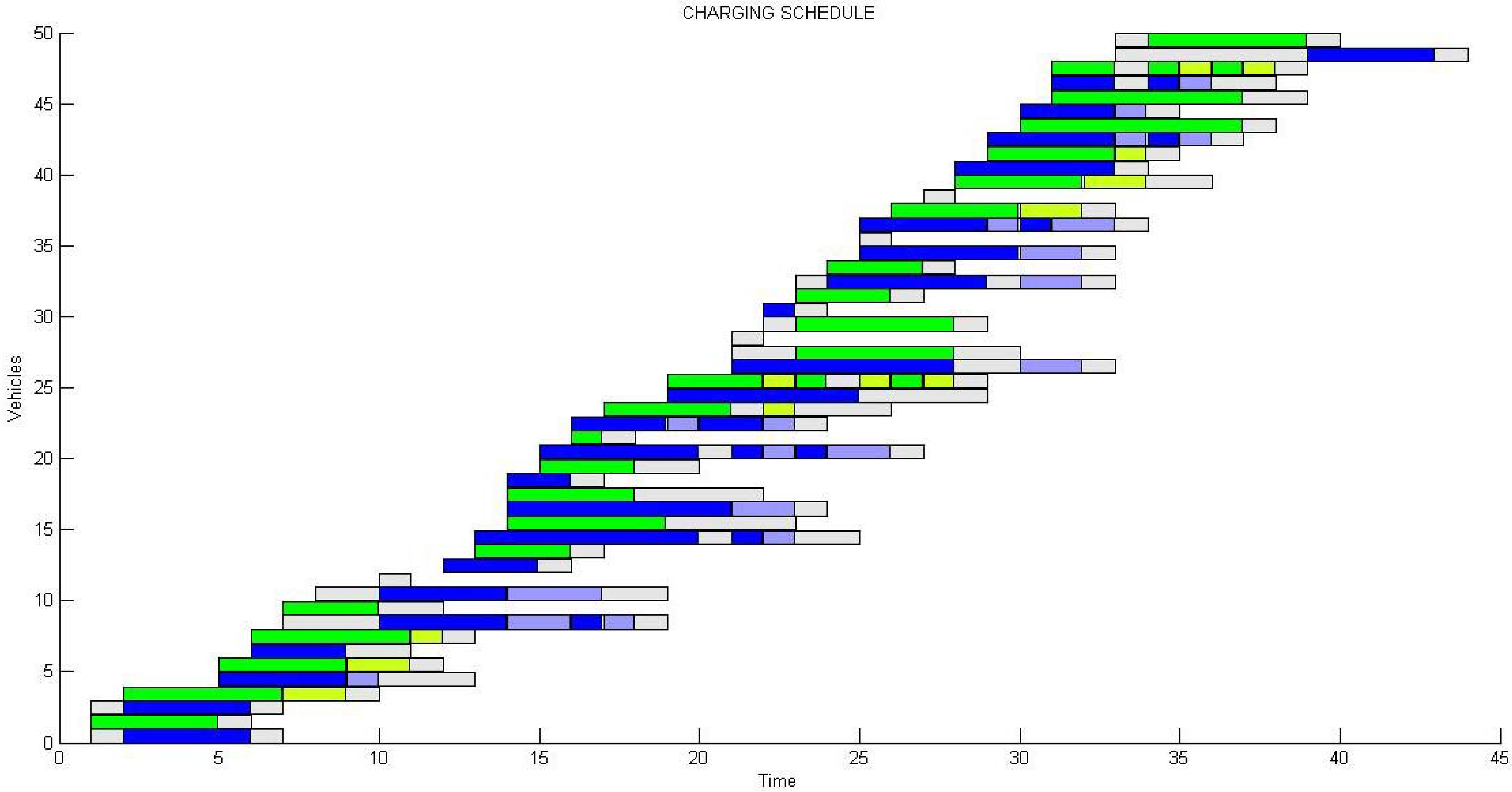
Charging/discharging schedule

Grid limit: L=15



Each colour represents a different vehicle.

Grid limit: L=15



Charging/discharging schedule

¡Gracias!

Grazas!

Thank you!

Спасибо!

Danke!