OPERATIONAL PLANNING REPORT

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1. Expression of ch arge efficiency:

In case of a battery, we know,

The amount of charge in battery in a certain period = efficiency × maximum charging power × period. This can be expressed as:

$$(S_{t+\Delta t} - S_t) = \eta \times \bar{P}_{max} \times \Delta t \dots\dots\dots (1)$$

Where:

$S_t = The\ initial\ charge\ in\ the\ storage\ at\ time\ t$
$S_{t+\Delta t} = The\ final\ charge\ in\ the\ storage\ at\ time\ (t + \Delta t)$
$\bar{P}_{max} = Maximum\ charging\ power$
$\eta = The\ charging\ efficiency$
$\Delta t = The\ time\ interval\ of\ the\ charging$

From equation 1, we can write $\frac{(S_{t+\Delta t} - S_t)}{\Delta t} = \eta \times \bar{P}_{max}$

$when\ \Delta t \to 0, the\ above\ equation\ becomes,$

$$\frac{dS}{dt} = \eta \times \bar{P}_{max}$$

$$or, \eta = \frac{dS}{dt} \times \frac{1}{\bar{P}_{max}} = \frac{dS}{dt} \times \frac{1}{\bar{P}} \dots\dots\dots (2)$$

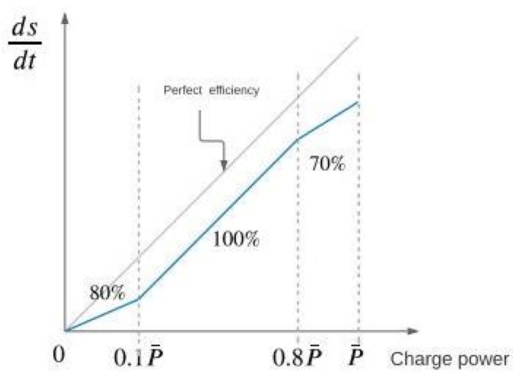


Figure 1: Variation of the state of charge of an EV per unit time as a function of the charge power.

Now, from figure 1, assuming $\frac{dS}{dt} = y$, between point 0 and $0.1\bar{P}$, we can write,

$$\frac{y_1 - 0}{0.1\bar{P} - 0} = 0.8 \ \to y_1 = 0.08\bar{P}$$

Similarly, we can find, $y_2 = 0.78\bar{P}$ and $y_3 = 0.92\bar{P}$

Now, assuming any point named (P,y) on the piecewise functions of the figure 1, we can write,

$$\frac{y_1 - y}{0.1\bar{P} - P} = 0.8 \text{ which yields } \frac{0.08\bar{P} - y}{0.1\bar{P} - P} = 0.8$$

Thus, $y = 0.8P,$ for $0 \leq \text{P} \leq 0.1\bar{P}$

Similarly, we can write,

$$y = P - 0.02\bar{P}, \qquad \text{for} \qquad 0.1\bar{P} \leq \text{P} \leq 0.1\bar{P}$$

$$y = P + 0.22\bar{P}, \qquad \text{for} \qquad 0.8\bar{P} \leq \text{P} \leq \bar{P}$$

Now, putting these values on equation (2) and integrating the functions, we get,

$$\eta = \frac{1}{\bar{P}}[\int_0^{0.1\bar{P}} 0.8P\, dP + \int_{0.1\bar{P}}^{0.8\bar{P}}(P - 0.02\bar{P})dP + \int_{0.8\bar{P}}^{\bar{P}}(P + 0.22\bar{P})dP]\text{=0.9275}$$

Plot η(p):

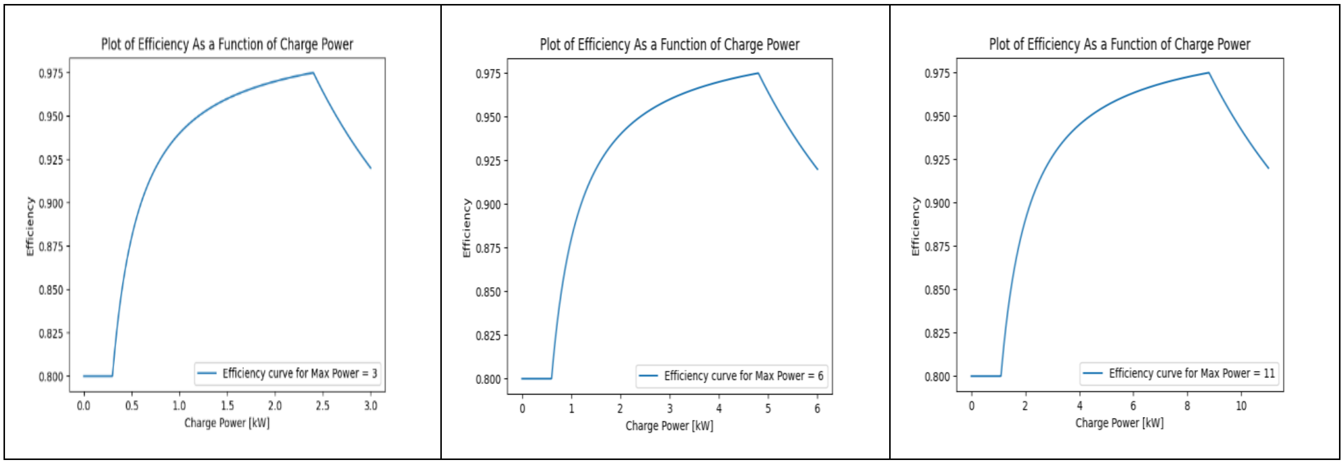


Figure 2: Efficiency vs Power for different values of maximum power.

2. Model of optimization for each time step as a MILP:

The objective of this project was to minimize the cost by considering the costs of the electricity purchased and measuring the penalty of the project. Overall, we can write the Objective Function as:

$$min \sum_{t=current\ time}^{T=t+n\Delta t} [Import\ cost_{dt} - export\ revenue_t + cost\ of\ penalty_t]$$

Or,

$$min \sum_{t=t_0}^{t=t_0+n\Delta t} \left[\left(\pi_{grid}^{imp}\right)_t \times \left(\bar{P}_{grid}^{imp}\right)_t \times \Delta t - \left(\pi_{grid}^{exp}\right)_t \times \left(\bar{P}_{grid}^{exp}\right)_t \times \Delta t + \alpha\left(\left|S_{desired}^d - S_{actual}^d\right|\right) \times \left(\frac{T_e^d - T_e^d}{\bar{C}_e}\right) \times \left(\pi_e^{cha}\right)\right]$$

Where:

t_o= current time
Δt= time step
n= control horizon

e= index for the car
α= trade-off coefficient

To minimize the objective function, we had to consider some constraints as well. The constraints are given below.

Constraint 1:

In our microgrid, the energy comes from the PV generation using the forecast and the grid import. The energy was then sent away for either charging the EVs or exported back to the grid. The energy balance thus creates this constraint:

$$\forall t, e\ ;\ \bar{P}_{grid}^{imp} + \bar{P}_{PV}^{gen} = \bar{P}^{cha} + \bar{P}_{grid}^{exp}$$

Constraint 2:

The amount of import from the grid had to be equal or lower than that of the grid limitations. Thus, we can write:

$$\forall t, e\ ;\ \bar{P}_{grid}^{imp} \leq \bar{P}_{grid}$$

Constraint 3:

Like the previous case, the amount of export from the grid has to be equal of lower than that of the grid limitations. Thus, we can write:

$$\forall t, e\ ;\ \bar{P}_{grid}^{exp} \leq \bar{P}_{grid}$$

Constraint 4:

This constraint considers that the microgrid can only either export or import during a certain time interval. Hence, both export and import cannot be done simultaneously.

$$\forall t, e \text{ and } x_i^{bin} \epsilon \{0,1\}\ ;\ \bar{P}_{grid}^{actual} = \bar{P}_{grid}^{exp}\left(1 - x_i^{bin}\right) + \bar{P}_{grid}^{imp} . x_i^{bin}$$

Constraint 5:

For this constraint, we had to consider that the amount of the PV that is generated using the PV forecast is either used to charge the cars, exported to the grid or both simultaneously within a time step.

$$\forall t, e;\ \bar{P}_{PV}^{gen} = \bar{P}^{cha} + \bar{P}_{grid}^{exp}$$

Constraint 6:

This constraint ensured that an EV had to charge between the current time and the departure time of the EV. If an EV comes before the opening of the microgrid (current time), we had to make sure that the charging only starts when the microgrid starts operating. Also, we had to make sure that if a car comes after the current time, the EV gets the charge between its arrival time and the departure time. But the microgrid operates during the control horizon. So, if the departure time of the EV is beyond the control horizon, the car only gets charged between the arrival time and the end of the control horizon.

3. Running the controller with test values:

We tested our controller by considering three EVs with different characteristics like arrival time, departure time, arrival state of charge, desired departure state of charge, capacity, max charging power and price the owner is willing to pay for the charging.

In our optimization problem, the main objective function was:

$$min \sum_{t=current\ time}^{T=t+n\Delta t} [Import\ cost_{dt} - export\ revenue_t + cost\ of\ penalty_t]$$

Or,

$$min \sum_{t=t_0}^{t=t_0+n\Delta t} \Bigg[\left(\pi_{grid}^{imp}\right)_t \times \left(\bar{P}_{grid}^{imp}\right)_t \times \Delta t - \left(\pi_{grid}^{exp}\right)_t \times \left(\bar{P}_{grid}^{exp}\right)_t \times \Delta t$$
$$+ \alpha\left(\left|S_{desired}^{d} - S_{actual}^{d}\right|\right) \times \left(\frac{T_e^d - T_e^d}{\bar{C}_e}\right) \times \left(\pi_e^{cha}\right)\Bigg]$$

In the part where the cost of the penalty is considered, the priority index is multiplied by the absolute value of the difference between the actual departure state of charge and the desired state of charge. Later on, the trade-off coefficient is multiplied with these terms, that gives the value of the price the microgrid had to consider due to the penalty occurred for not being able to fulfill the customers desired charging outcome.

According to the class EV() which was defined in the code, the following values were considered for testing our controller:

1. $Electricity\ import\ cost,\ \pi_{grid}^{imp} = .25$
2. $Electricity\ export\ cost,\ \pi_{grid}^{exp} = .04$
3. $Grid\ Capacity,\ \bar{P}_{grid} = 10$
4. $Number\ of\ cars = 3$
5. $Arrival\ times, T_e^a = [8,8,7]$
6. $Departure\ times, T_e^d = [14,17,13]$
7. $Arrival\ SOC, S_e^a = [0.7,0.6,0.6]$
8. $Desired\ departure\ SOC, S_e^d = [0.9,0.7,0.85]$
9. $Capacity, \bar{C}_e = [56,66,63]$
10. $Max\ charging\ power, P_e = [6,6,3]$
11. $Price\ willing\ to\ pay, \pi_e^{cha} = [8,7,9]$

After running the code with the values that we picked, we checked how our controller reacts by changing the value of the trade-off coefficient. For different trade-off coefficient values, the outcomes were different in terms how much PV generation is being used for charging the EVs, how much energy is imported and how much energy is being exported. Also, the trade-off coefficient had its impact on the amount of penalty value and cost of penalty as well.

	Trade-off coefficient = 0	Trade-off coefficient = 0.04	Trade-off coefficient = 0.05
Sum of penalty	16.98	16.98	0
Total cost of penalty	0	0.679	0
Sum of import costs	0	0	0
Sum of export revenue	0.86467	0.86467	0.102273
Total cost	-0.86467	-0.185473	-0.102273
Power received by the EVs	No	No	Yes

Table 1: Variation of parameters based on trade-off coefficient

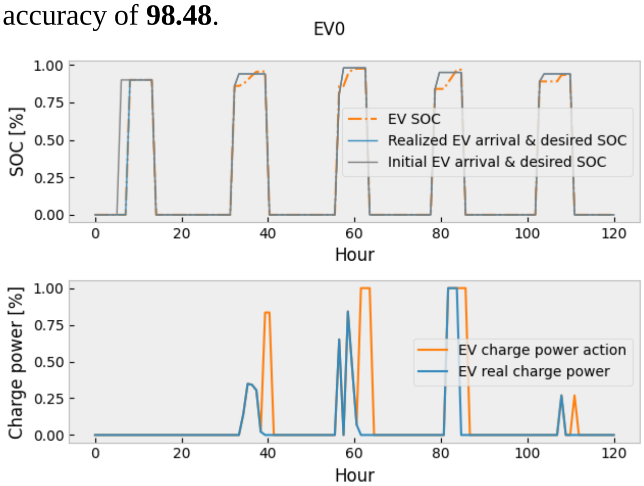
For trade-off coefficient value of 0, the total penalty cost becomes zero from the objective function. Thus, the objective function does not have to consider the penalty. In the penalty term includes the absolute difference between the actual departure state of charge and the desired state of charge. Thus, when there is a penalty term, it tries to minimize the difference. However, as there is no penalty term for trade-off coefficient of zero, there is no penalty term, thus the optimization does not have to minimize the difference. Therefore, the optimization forces the microgrid to export all the PV generation to the main grid.

Later, we increased the value of the **trade-off coefficient value of up to 0.04**. Till this point, the penalty term included a cost, but still it did not supply power to the EVs, instead it supplied all the power to the main grid. We suspected that the penalty term was not significant at this point compared to the export revenue.

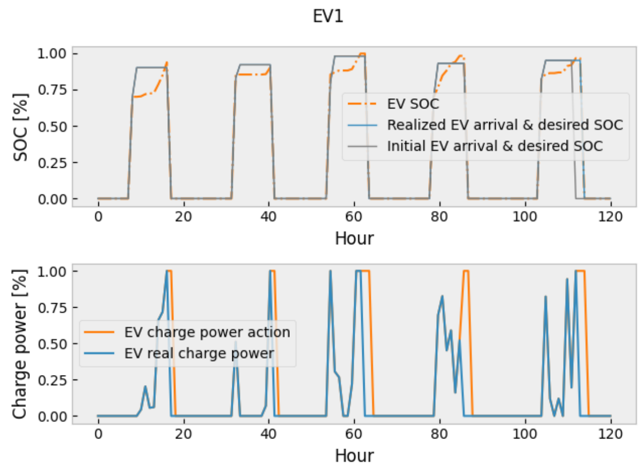
When we increased the value of the **trade-off coefficient value up to 0.05**, we noticed that the microgrid then supplied power to the EVs. The penalty value was zero for this trade-off coefficient, which means it perfectly satisfied the desired departure state of charge for each EV. In addition, the microgrid was exporting power to the grid at the same time to get a revenue, which means the PV generation was sufficient to fulfill the requirements of the customers without importing any power from the main grid.

4. Plots generated on Gradescope using our controller:

Here are the plots which were generated on gradescope after submitting the code on the website with an accuracy of **98.48**.



(a)



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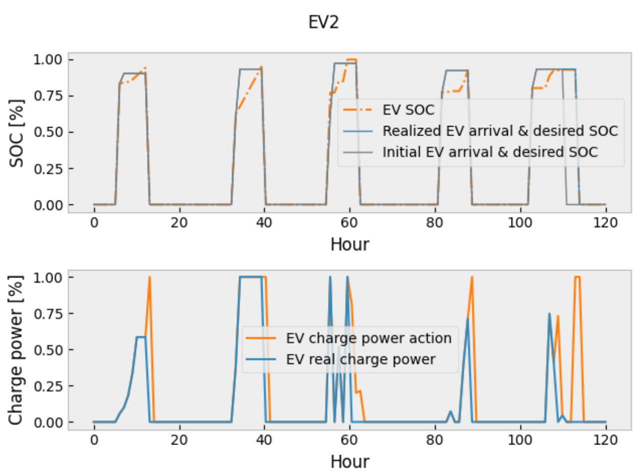

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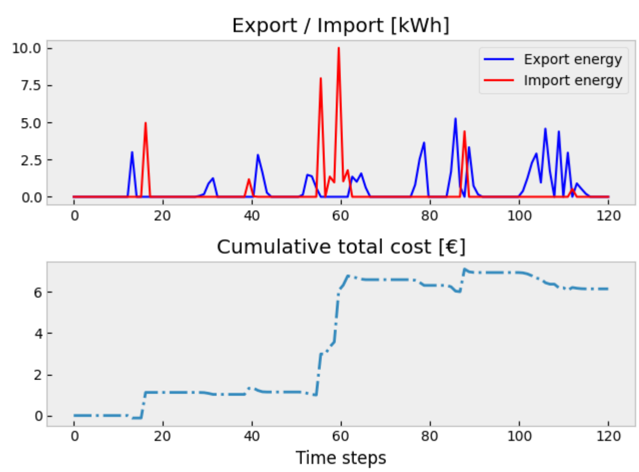

(d)

Figure(s) 3: SOC[%] and Charge power[%]of the EVs, Exported/Imported energy and Cumulative cost over 120 hours period.