Optimal operation of PV and storage: Customers' Perspective

In Denmark, the energy only takes 12% of overall electricity bill **Error! Reference source not found.** while the grid tariffs and taxes take a large proportion. Hence, it is meaningful for residents to optimize its own schedule considering tariffs' impacts. Since there is no input fee for exporting surplus energy. The buy and sell price would be different and thus should be considered. Some binary variables are defined in Table I to indicate the operational status of the battery and the action (buy or sell) of the customer in market participation.

TABLE I. NOTATION EXPLANATION

Variables	Description
P_t^{PV}	The output of PV at time t assuming a MPPT control strategy
δ_t^1	Sell energy in the electricity market, P_t^{pv}-P_t^{load}-$\delta_t^3 P_t^{Ch}$ + $\delta_t^4 P_t^{Dis} \geq 0$
δ_t^2	Buy energy in the electricity market, P_t^{pv}-P_t^{load}-$\delta_t^5 P_t^{Ch}$ + $\delta_t^6 P_t^{Dis} \leq 0$
δ_t^3	Sell energy while the battery is in the charging mode
δ_t^4	Sell energy while the battery is in the discharging mode
δ_t^5	Buy energy while the battery is in the charging mode
δ_t^6	Buy energy while the battery is in the discharging mode

The MILP formulation of the optimization problem from customer's perspective can then be written in the following.
Obj.:

$$Min\left\{-\sum_{t=1}^{T}\left[\delta_t^1\left(P_t^{pv}-P_t^{load}-\delta_t^3 P_t^{Ch}+\delta_t^4 P^{Dis}\right)\mu_t^{FI}+\delta_t^2\left(P_t^{pv,b}-P_t^{load}-\delta_t^5 P^{Ch}+\delta_t^6 P^{Dis}\right)\left(\mu_t^{el}+\mu_t^{DSO}+\mu_t^{TSO}\right)\right]\right\} \quad (1)$$

S.t.:

$$0 \leq P_t^{Ch} \leq P^{+} \quad (2)$$

$$0 \leq P_t^{Dis} \leq P^{-}\eta_{Dis} \quad (3)$$

$$SOC_{min} \leq SOC_t \leq SOC_{max} \quad (4)$$

$$SOC_1 = SOC_{initial} \quad (5)$$

$$\delta_t^1+\delta_t^2=1 \quad (6)$$

$$\delta_t^3+\delta_t^4 \leq 1 \quad (7)$$

$$\delta_t^5+\delta_t^6 \leq 1 \quad (8)$$

$$SOC_{t+1}=SOC_t+\left[\left(\delta_t^1\delta_t^3+\delta_t^2\delta_t^5\right)P_t^{Ch}1\eta_{Ch}-\left(\delta_t^1\delta_t^4+\delta_t^2\delta_t^6\right)P_t^{Dis}1\eta_{Dis}^{-1}\right]E_s^{-1} \quad (9)$$

The bi-linear term can be linearized via the big-M method and then the above problem can be reformulated in the following.

Obj.: $$Min\left\{-\sum_{t=1}^{T}\left[\delta_t^1\left(P_t^{pv}-P_t^{load}\right)-z_t^1+z_t^2\right]\mu^{FI}-\sum_{t=1}^{T}\left[\delta_t^2\left(P_t^{pv}-P_t^{load}\right)-z_t^3+z_t^4\right]\left(\mu^{el}+\mu^{DSO}+\mu^{TSO}\right)\right\} \quad (10)$$

S.t.: (2)-(8)

$$SOC_{t+1}=SOC_t+\left[\left(z_t^1+z_t^3\right)1\eta_{Ch}-\left(z_t^2+z_t^4\right)1\eta_{Dis}^{-1}\right]E_s^{-1} \quad (11)$$

Constraints that added due to the big-M method:

$$M^{Ch}=0\,,\, m^{Ch}=-P^{+}\,,\, M^{Dis}=0\,,\, m^{Ch}=-P^{-}\eta_{Dis}$$

$$z_t^1+M^{Ch}\left(\delta_t^1+\delta_t^3\right)\le P_t^{Ch}+2M^{Ch} \tag{12}$$

$$z_t^1\le P_t^{Ch}+M^{Ch} \tag{13}$$

$$-z_t^1-m^{Ch}\left(\delta_t^1+\delta_t^2\right)\le -P_t^{Ch}-2m^{Ch} \tag{14}$$

$$-z_t^1\le -P_t^{Ch}-m^{Ch} \tag{15}$$

$$z_t^1+\delta_t^1 m^{Ch}\le 0 \tag{16}$$

$$z_t^1+\delta_t^3 m^{Ch}\le 0 \tag{17}$$

$$-z_t^1-\delta_t^1 M^{Ch}\le 0 \tag{18}$$

$$-z_t^1-\delta_t^3 M^{Ch}\le 0 \tag{19}$$

$$z_t^2+M^{Dis}\left(\delta_t^1+\delta_t^4\right)\le P_t^{Dis}+2M^{Dis} \tag{20}$$

$$z_t^2\le P_t^{Dis}+M^{Dis} \tag{21}$$

$$-z_t^2-m^{Dis}\left(\delta_t^1+\delta_t^4\right)\le -P_t^{Dis}-2m^{Dis} \tag{22}$$

$$-z_t^2\le -P_t^{Dis}-m^{Dis} \tag{23}$$

$$z_t^2+\delta_t^1 m^{Dis}\le 0 \tag{24}$$

$$z_t^2+\delta_t^4 m^{Dis}\le 0 \tag{25}$$

$$-z_t^2-\delta_t^1 M^{Dis}\le 0 \tag{26}$$

$$-z_t^2-\delta_t^4 M^{Dis}\le 0 \tag{27}$$

$$z_t^3+M^{Ch}\left(\delta_t^2+\delta_t^5\right)\le P_t^{Ch}+2M^{Ch} \tag{28}$$

$$z_t^3\le P_t^{Ch}+M^{Ch} \tag{29}$$

$$-z_t^3-m^{Ch}\left(\delta_t^2+\delta_t^5\right)\le -P_t^{Ch}-2m^{Ch} \tag{30}$$

$$-z_t^3\le -P_t^{Ch}-m^{Ch} \tag{31}$$

$$z_t^3+\delta_t^2 m^{Ch}\le 0 \tag{32}$$

$$z_t^3+\delta_t^5 m^{Ch}\le 0 \tag{33}$$

$$-z_t^3-\delta_t^2 M^{Ch}\le 0 \tag{34}$$

$$-z_t^3-\delta_t^5 M^{Ch}\le 0 \tag{35}$$

$$z_t^4+M^{Dis}\left(\delta_t^2+\delta_t^6\right)\le P_t^{Dis}+2M^{Dis} \tag{36}$$

$$z_t^4 \leq P_t^{Dis} + M^{Dis} \tag{37}$$

$$-z_t^4 - m^{Dis}\left(\delta_t^2 + \delta_t^6\right) \leq -P_t^{Dis} - 2m^{Dis} \tag{38}$$

$$-z_t^4 \leq -P_t^{Dis} - m^{Dis} \tag{39}$$

$$z_t^4 + \delta_t^2 m^{Dis} \leq 0 \tag{40}$$

$$z_t^4 + \delta_t^6 m^{Dis} \leq 0 \tag{41}$$

$$-z_t^4 - \delta_t^2 M^{Dis} \leq 0 \tag{42}$$

$$-z_t^4 - \delta_t^6 M^{Ch} \leq 0 \tag{43}$$

Where $z_t^1 = \delta_t^1 \delta_t^3 P_t^{Ch}$, $z_t^2 = \delta_t^1 \delta_t^4 P_t^{Ch}$, $z_t^3 = \delta_t^2 \delta_t^5 P_t^{Dis}$, and $z_t^4 = \delta_t^2 \delta_t^6 P_t^{Dis}$.