Market Values of Variable Renewable Energy:

Energy and Capacity Value

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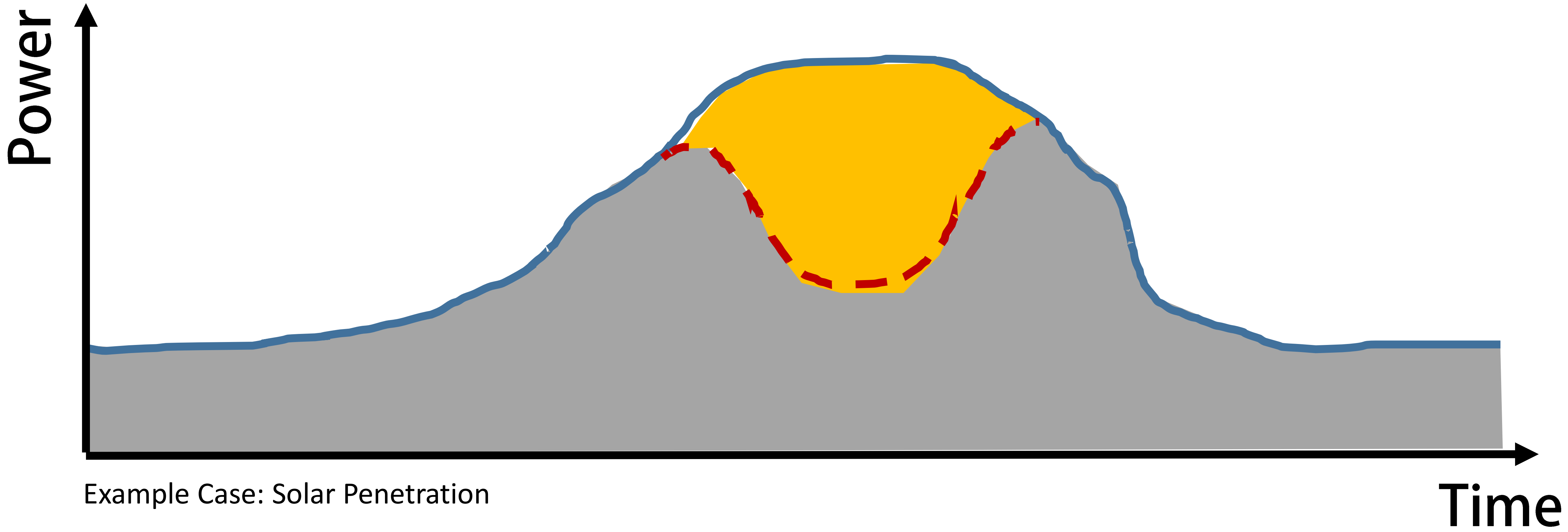
Nomenclature

- MEV = Marginal Energy Value
- MC = Marginal Cost
- CPP = Conventional Power Plants
- RL = Residual Load
- CF = Capacity Factor
- DL = Demand Load
- Cap = Installed Capacity
- AEV = Average Energy Value
- t* : Time of peak RL occurrence
- MCV = Marginal Capacity Value
- ACV = Average Capacity Value
- VRE = Variable Renewables
- DLDC = DL Duration Curve
- RLDC = RL Duration Curve
- _i : Technology type / retailer i
- P = Power
- CAPEX = Capacity Expenditure
- (M)RO = (Marginal) Reserve Obligation

Market Value: Energy Value

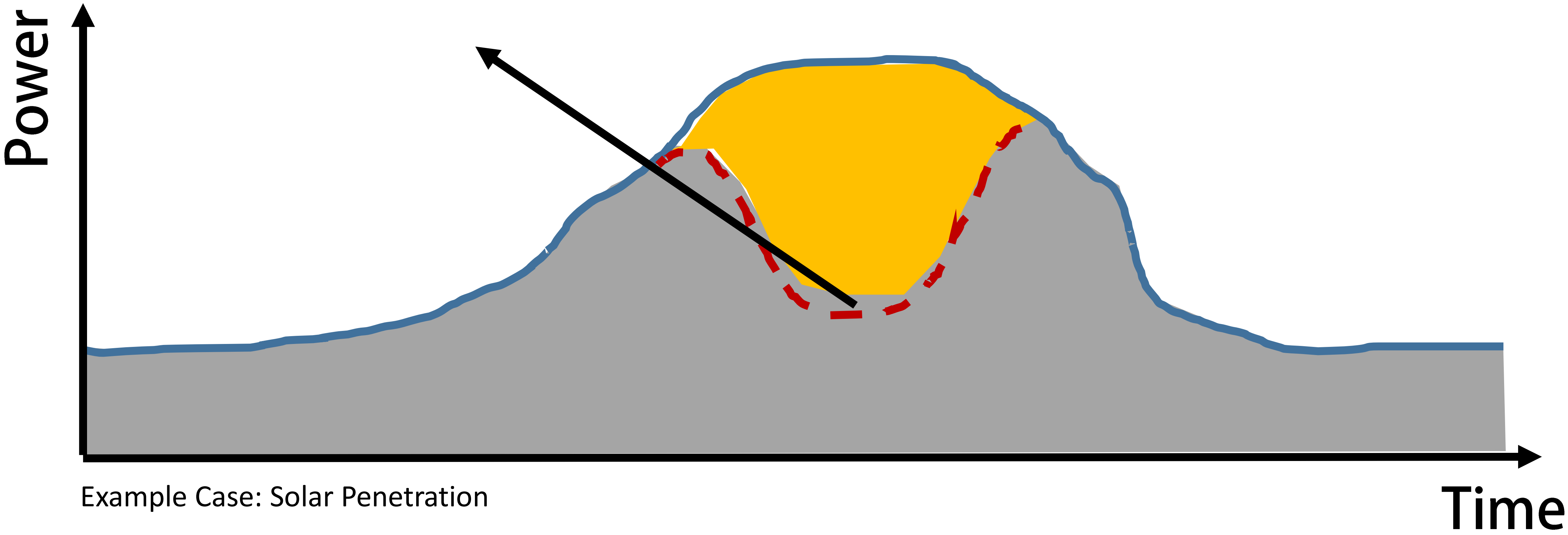


Example Case: Solar Penetration

Market Value: Energy Value

MEV per Capacity: $\int MC_{CPP}(RL(t)) \cdot CF(t)dt$

RL(t): $DL(t) - Cap \cdot CF(t)$



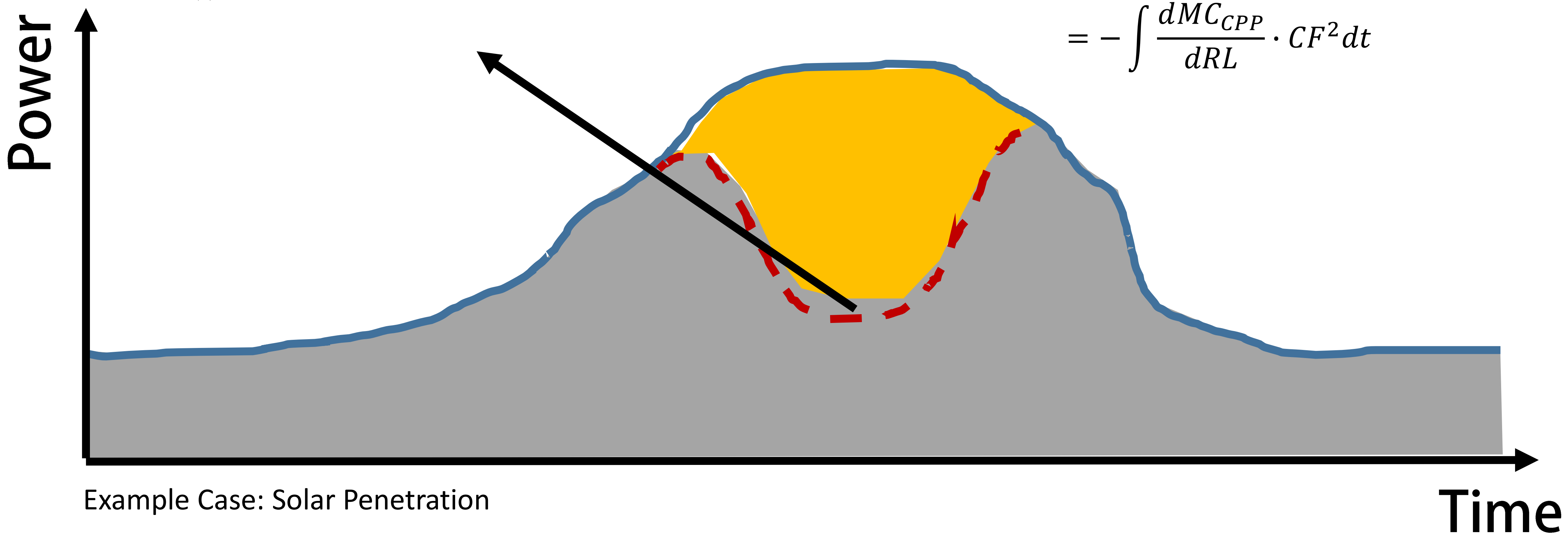
Example Case: Solar Penetration

Market Value: Energy Value

MEV per Capacity: $\int MC_{CPP}(RL(t)) \cdot CF(t)dt$

RL(t): $DL(t) - Cap \cdot CF(t)$

$$\frac{dMEV}{dCap} = \int \frac{dMC_{CPP}}{dRL} \cdot \frac{\partial RL}{\partial Cap} CFdt$$
$$= -\int \frac{dMC_{CPP}}{dRL} \cdot CF^2 dt$$



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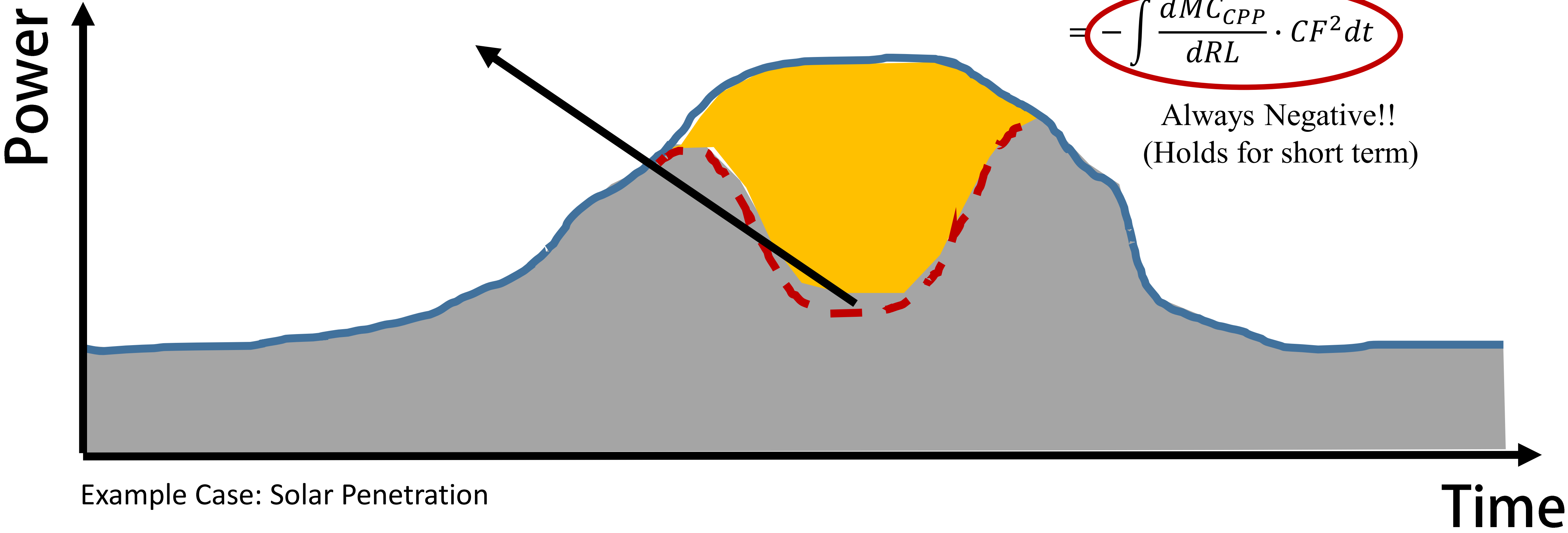
Always Negative!!

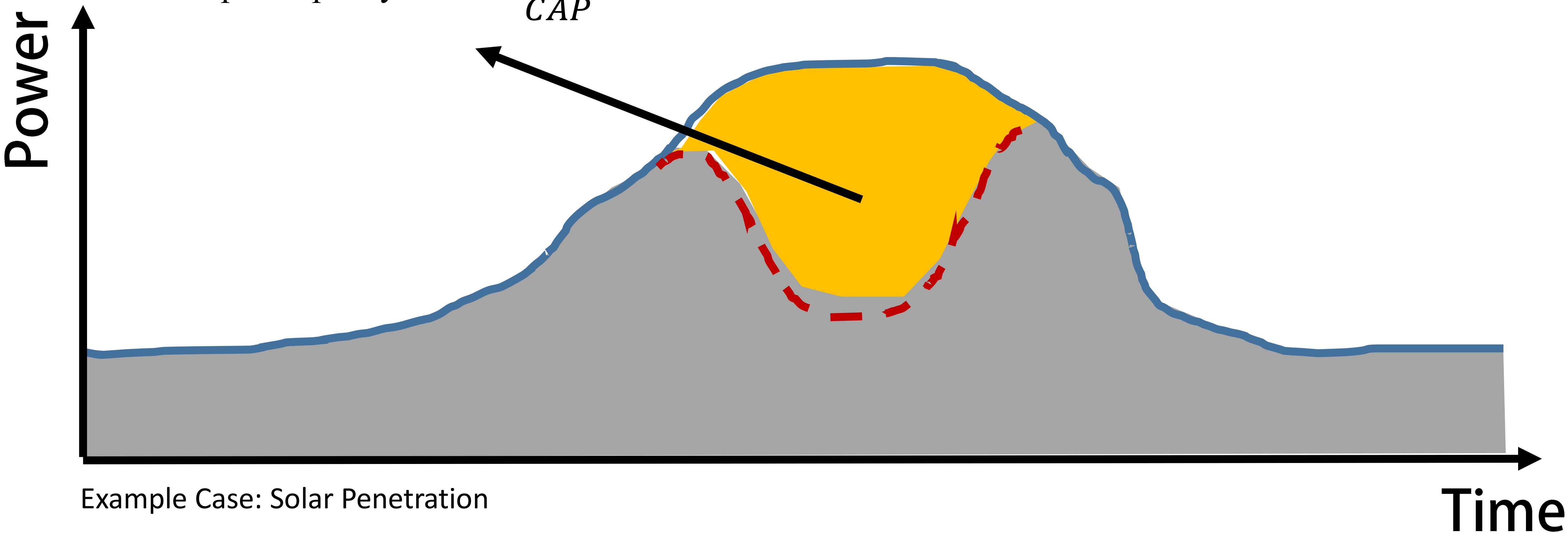
(Holds for short term)



Example Case: Solar Penetration

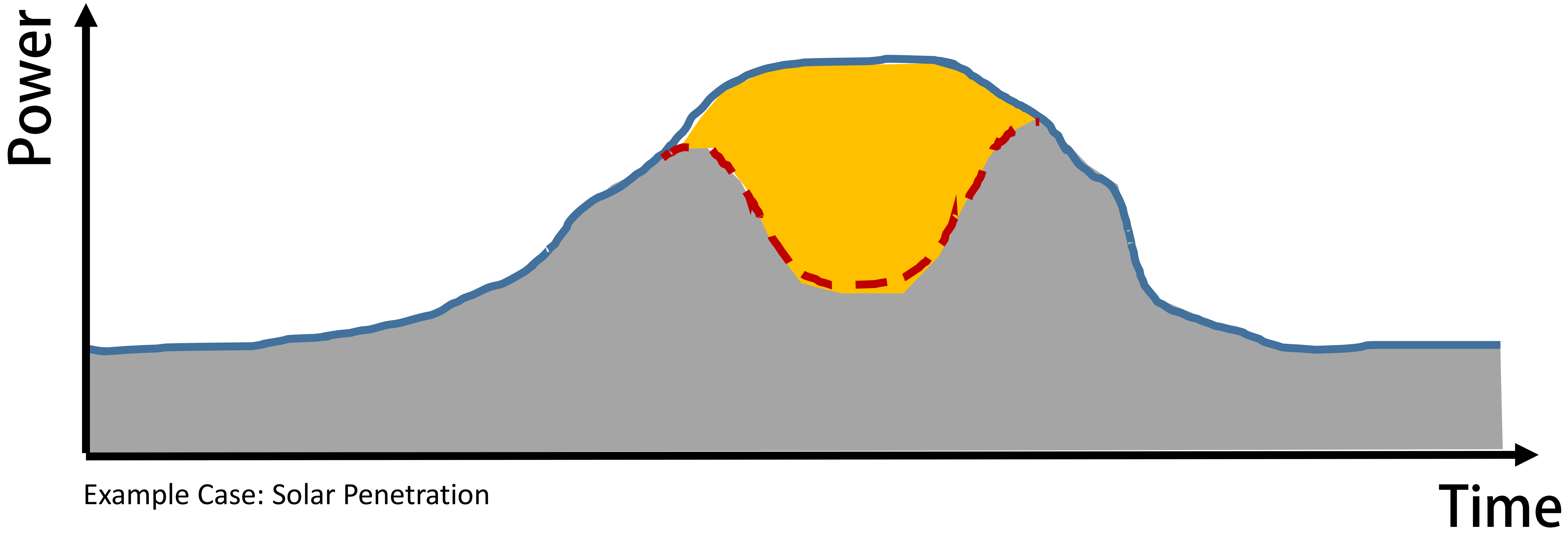
Market Value: Energy Value

AEV per Capacity: $\dfrac{\int_0^{CAP} MEV(k)dk}{CAP}$



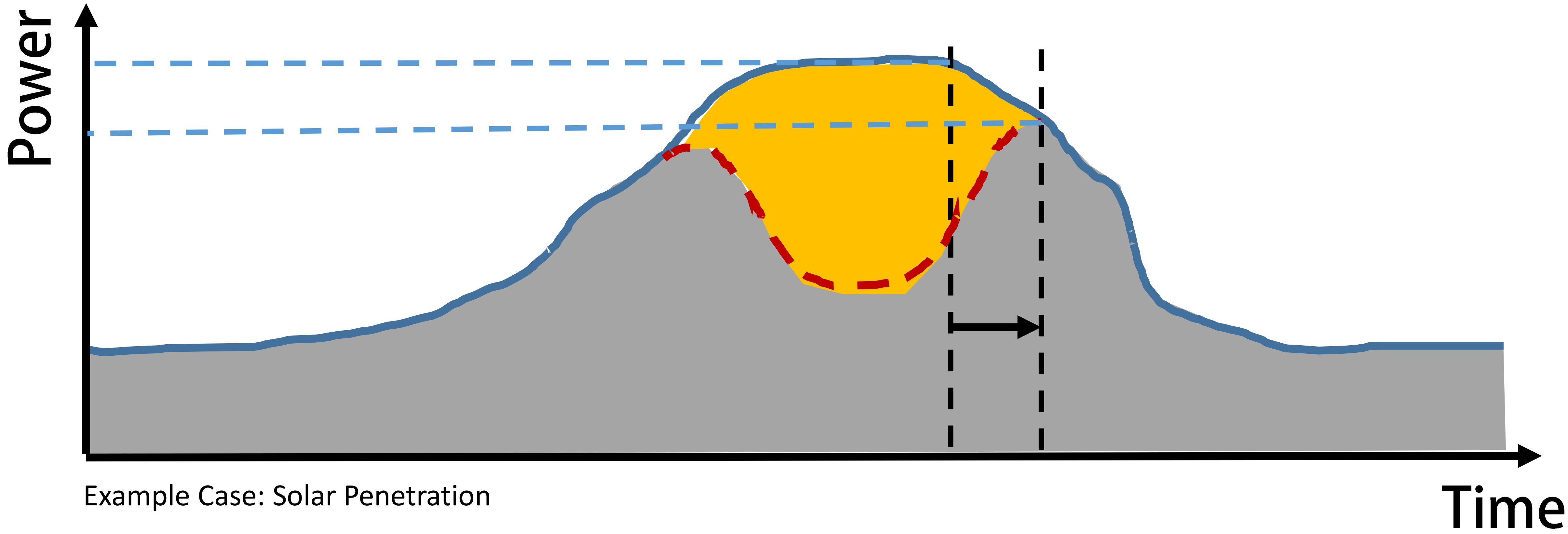
Example Case: Solar Penetration

Market Value: Capacity Value



Example Case: Solar Penetration

Market Value: Capacity Value



Example Case: Solar Penetration

Market Value: Capacity Value

➢At peak RL, $\begin{cases} \left.\dfrac{\partial RL}{\partial t}\right|_{t^*(Cap)} = \left.\dfrac{dDL}{dt}\right|_{t^*(Cap)} - Cap \cdot \left.\dfrac{dCF}{dt}\right|_{t^*(Cap)} = 0 \\ \left.\dfrac{\partial^2 RL}{\partial t^2}\right|_{t^*(Cap)} = \left.\dfrac{d^2 DL}{dt^2}\right|_{t^*(Cap)} - Cap \cdot \left.\dfrac{d^2 CF}{dt^2}\right|_{t^*(Cap)} < 0 \end{cases}$

➢After an infinitesimal increment of capacity, $\frac{\partial RL}{\partial t}$ at peak RL is still 0,

so $\dfrac{dt^*}{dCap} = -\dfrac{\left.\frac{\partial^2 RL}{\partial t \partial Cap}\right|_{t^*(Cap)}}{\left.\frac{\partial^2 RL}{\partial t^2}\right|_{t^*(Cap)}} = \dfrac{\left.\frac{dCF}{dt}\right|_{t^*(Cap)}}{\left.\frac{d^2 DL}{dt^2}\right|_{t^*(Cap)} - Cap \cdot \left.\frac{d^2 CF}{dt^2}\right|_{t^*(Cap)}}$

Market Value: Capacity Value

- Meanwhile $\frac{dCF(t^*)}{dCap} = \left.\frac{dCF}{dt}\right|_{t^*(Cap)} \frac{dt^*}{dCap} = \frac{\left(\left.\frac{dCF}{dt}\right|_{t^*(Cap)}\right)^2}{\left.\frac{d^2DL}{dt^2}\right|_{t^*(Cap)} - Cap \cdot \left.\frac{d^2CF}{dt^2}\right|_{t^*(Cap)}}$

- Since CF(t*) is MCV, we can conclude that MCV always decreases as the capacity of VRE increases.

- Discontinuous jumps of CF(t*) can occur, but the number of which can never exceed the amount of local maxima in the interval.

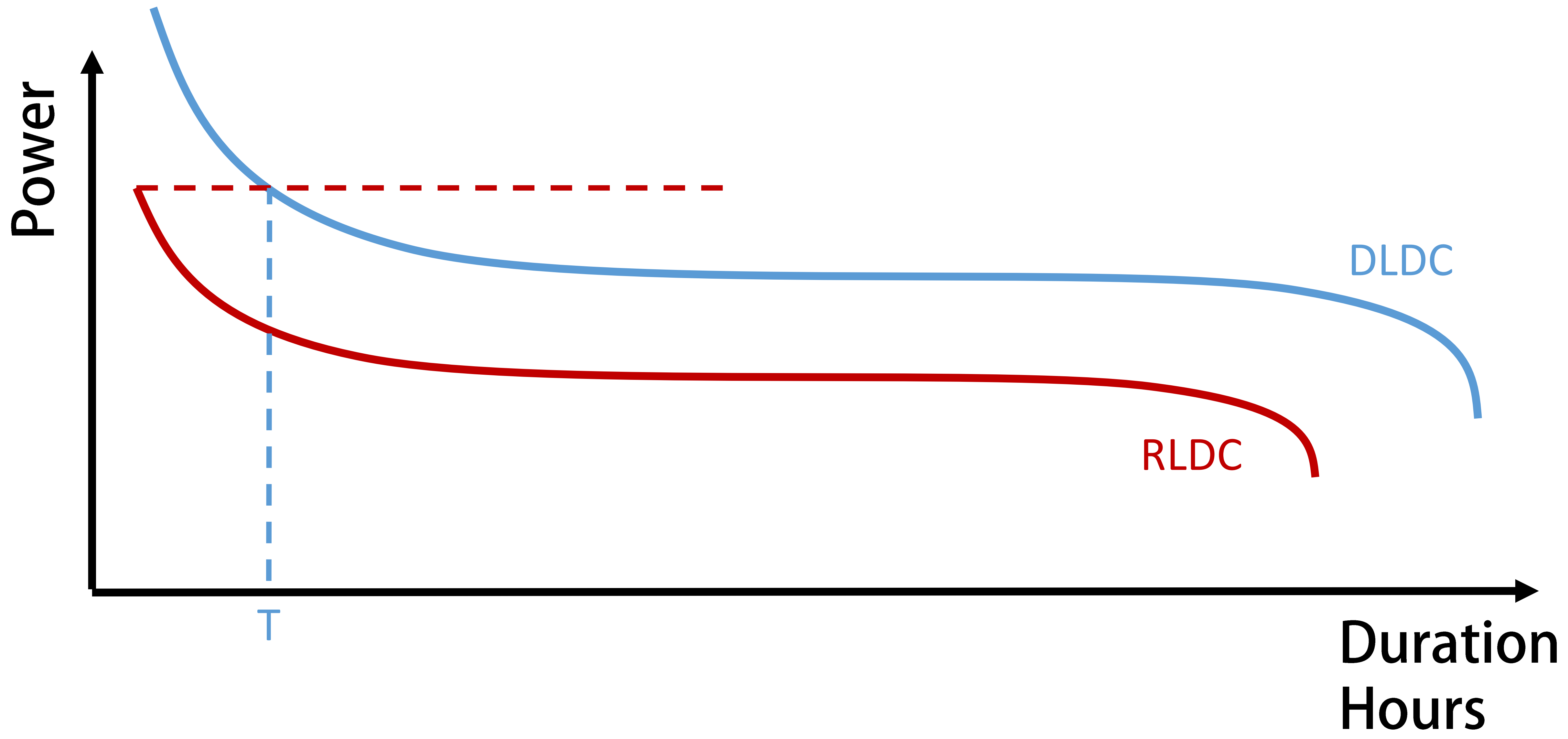
Market Value: Capacity Value

- The ACV of solar in this case is $\frac{\int_0^{CAP} CF(t^*(k))dk}{CAP}$

- However, when two or more VRE technologies coexist in the power system, the contribution of each VRE technology to peak RL reduction will not be straight forward

- Principle of Equipartition of Contribution: We should assume that at times when DL exceeds peak RL, every unit of VRE output contributes equally for the marginal RL reduction at that moment.

Market Value: Capacity Value



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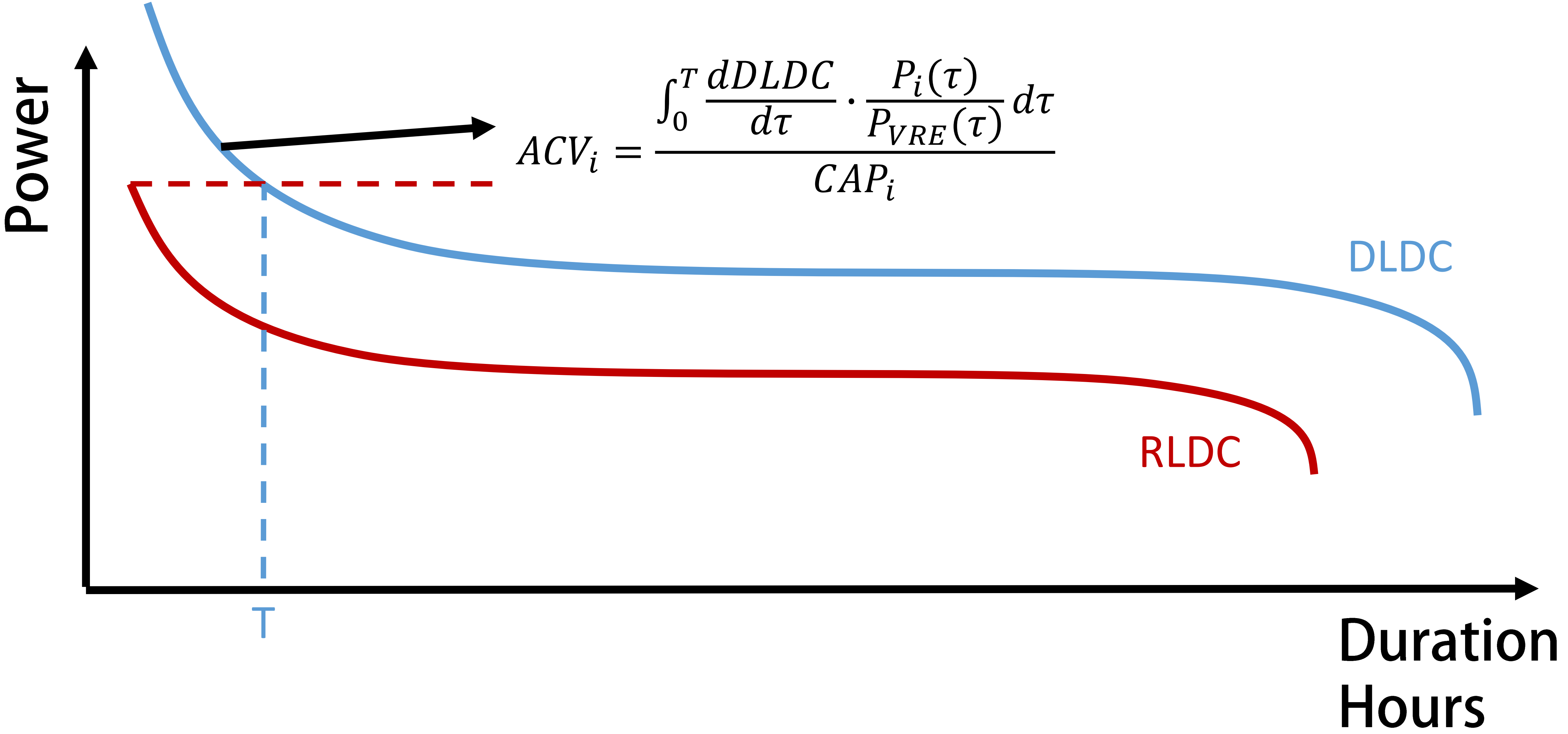

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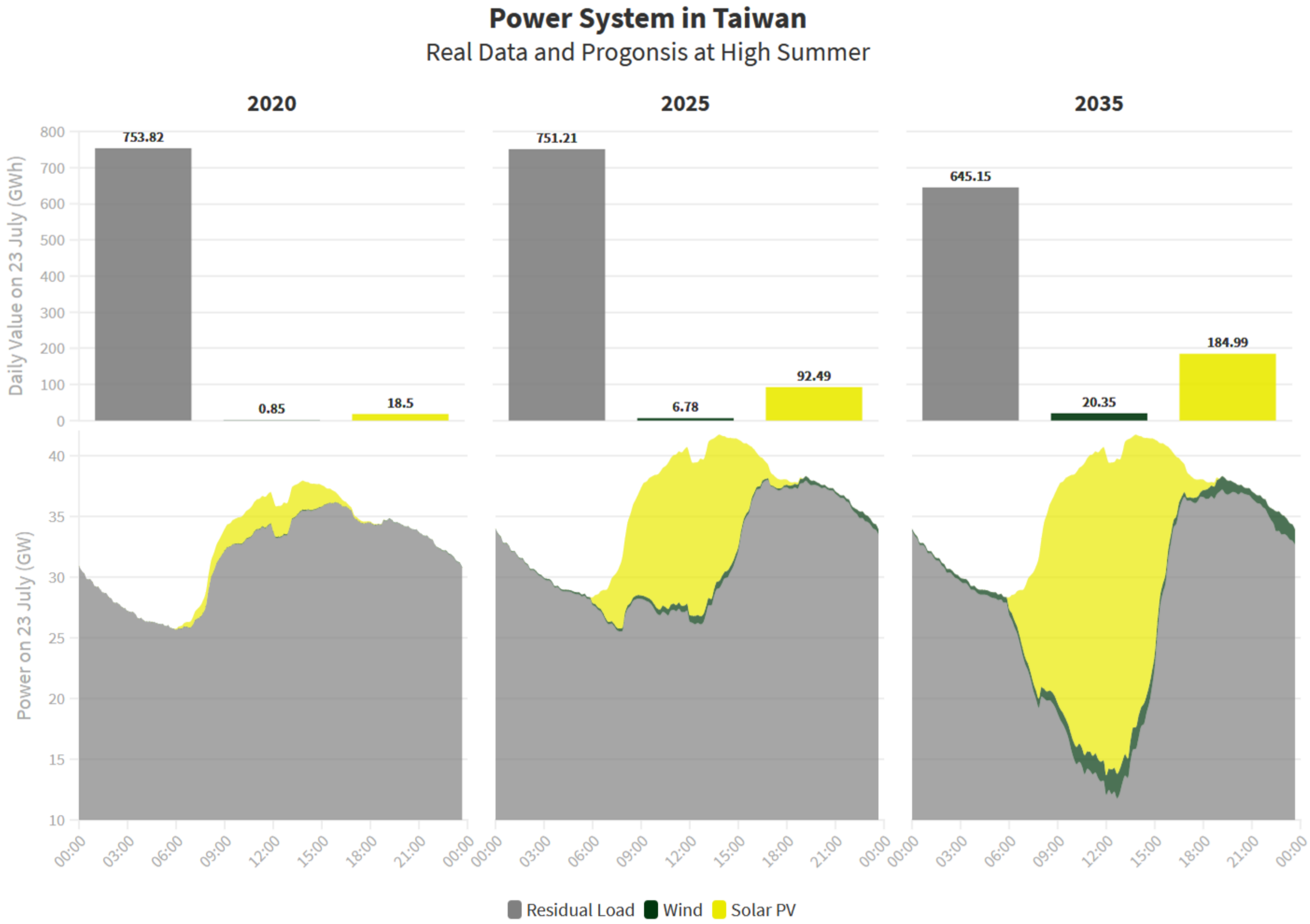


https://public.flourish.studio/visualisation/3351313/
https://public.flourish.studio/visualisation/3321437/

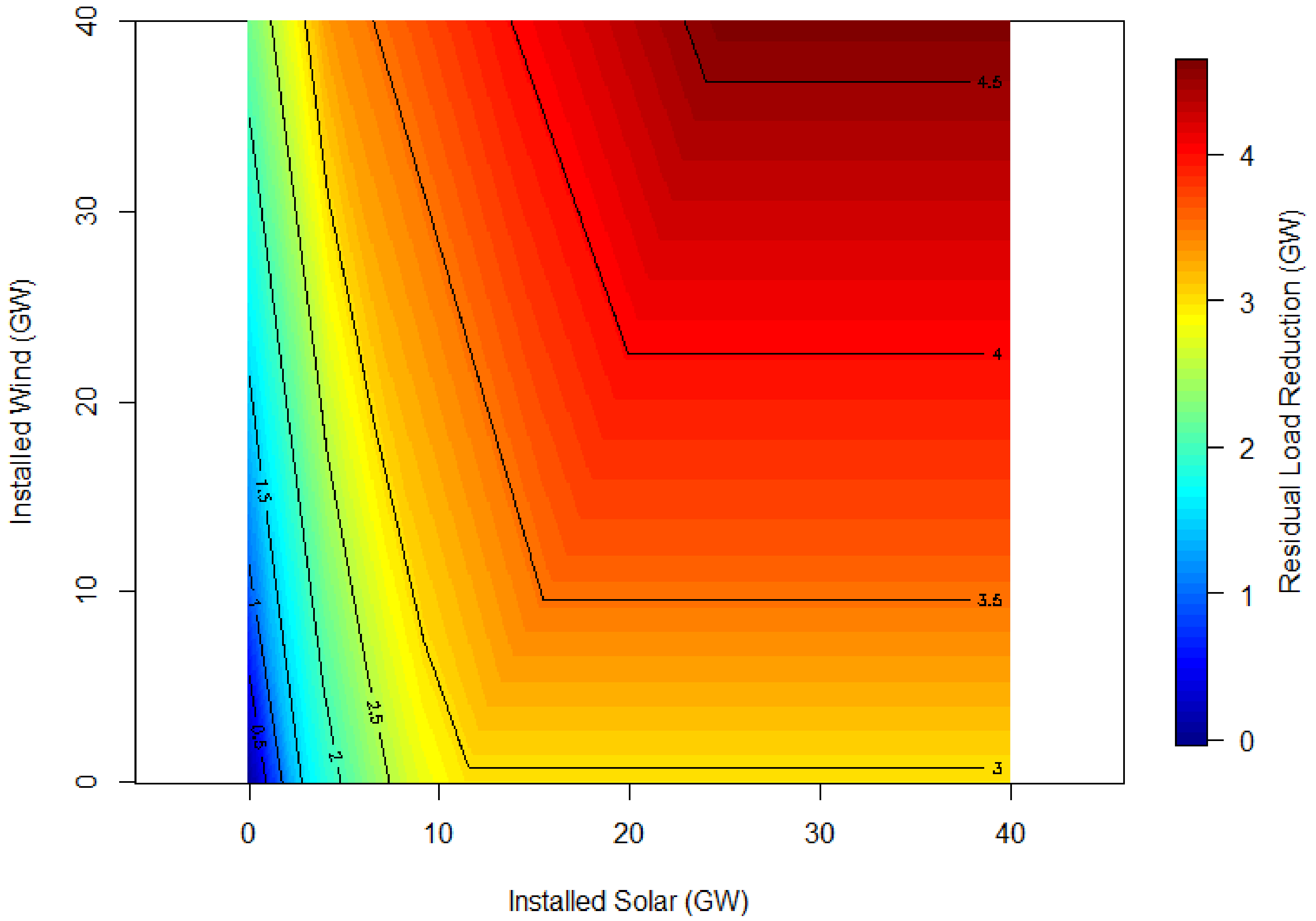
Market Value: Capacity Value

Capacity Values of VRE in Taiwan, Now and Future

	2020		2025		2035	
	Solar	Wind	Solar	Wind	Solar	Wind
Capacity	4,16 GW	0,831 GW	20,8 GW	6,65 GW	41,6 GW	19,9 GW
MCV	20,3%	3,73%	0%	5,66%	0%	3,49%
ACV	41,4%	10,3%	13,9%	6,54%	7,38%	4,22%
Total RL Reduction	1,81 GW		3,34 GW		3,91 GW	

Analysis with real data from 23 and 24 July, 2020
Wind data of 2020 is still highly sensitive to local fluctuation, so its CV may be underestimated.

Market Value: Capacity Value



Market Value: Short Term vs Long Term

- In the short term equilibrium, CPP portfolio is assumed to be the same, thus MC_CPP does not change. The capacity value of VRE only consists the benefits of increased supply reliability due to less RL.

- In the long term equilibrium, CPP portfolio will be altered due to principle of zero margin profit; CPP with less CAPEX but higher variable costs will be favored. This might result in higher MEV for VRE. On the other hand, the total CPP fleet will be reduced due to less peak RL, which can be translated to the capacity value of VRE under monetary terms.

Market Value: A Word on VRE + Storage

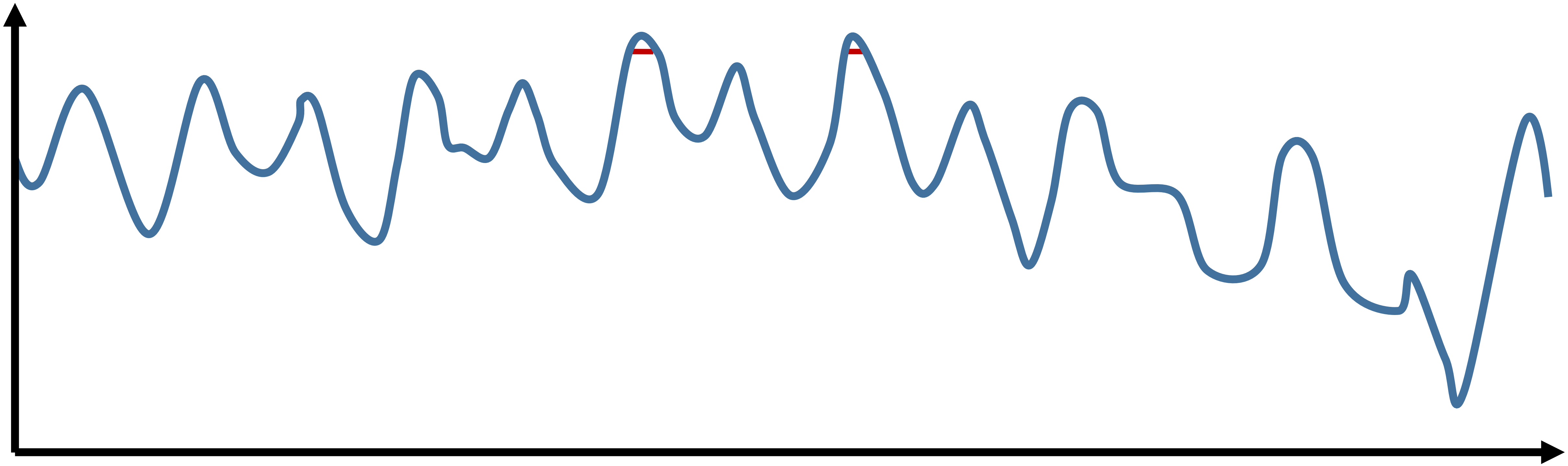
- For every additional marginal reduction of RL by storage, the marginal capacity value of storage is the capacity of the storage.

- The marginal energy value will be the price spread between charge and discharge period. This value depends highly on the operation strategy of the storage.

Market Value: A Word on VRE + Storage

- In addition to the CAPEX per charge / discharge rate, two additional costs should be considered:
  - The minimum required discharge time to achieve RL reduction. Construct two series $\{p_i\}$ $\{n_j\}$, where i represents the i-th continuous interval for which $RL > RL_c$ and j the j-th continuous interval for which $RL < RL_c$; p_i and n_j are the time durations of the continuous intervals. Starting from p_2 and the previous corresponding value in $\{n_j\}$ (n_c), update $p_2 <- \max(p_1 – n_c*eta, 0) + p_2$, and continue this procedure for the rest of the series. Once all $\{p_i\}$ updated, the maximum of the series will be the minimum required discharge time to achieve RL reduction to RL_c.
  - The energy loss due to charging cycle: an additional demand of (1/eta - 1) per unit of discharge energy will be needed in total. This can be considered when calculating the MEV.

Market Value: A Word on VRE + Storage



Example Case Data:
RL of Germany in Week 30, 2020
https://www.energy-charts.de/power_de.htm?source=conventional&year=2020&week=30

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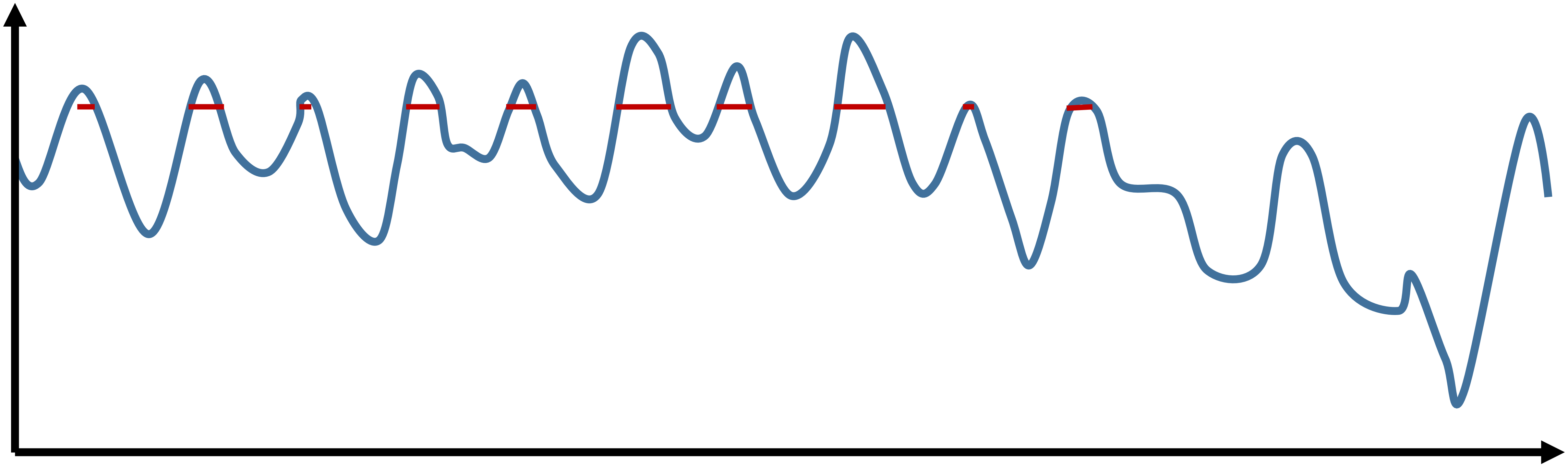

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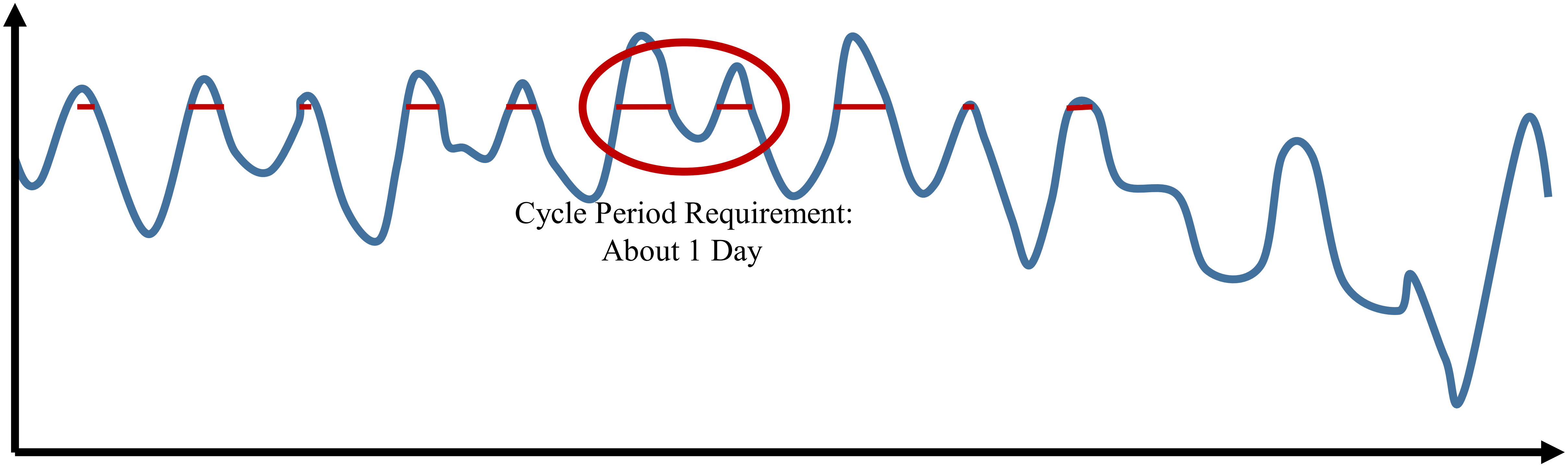

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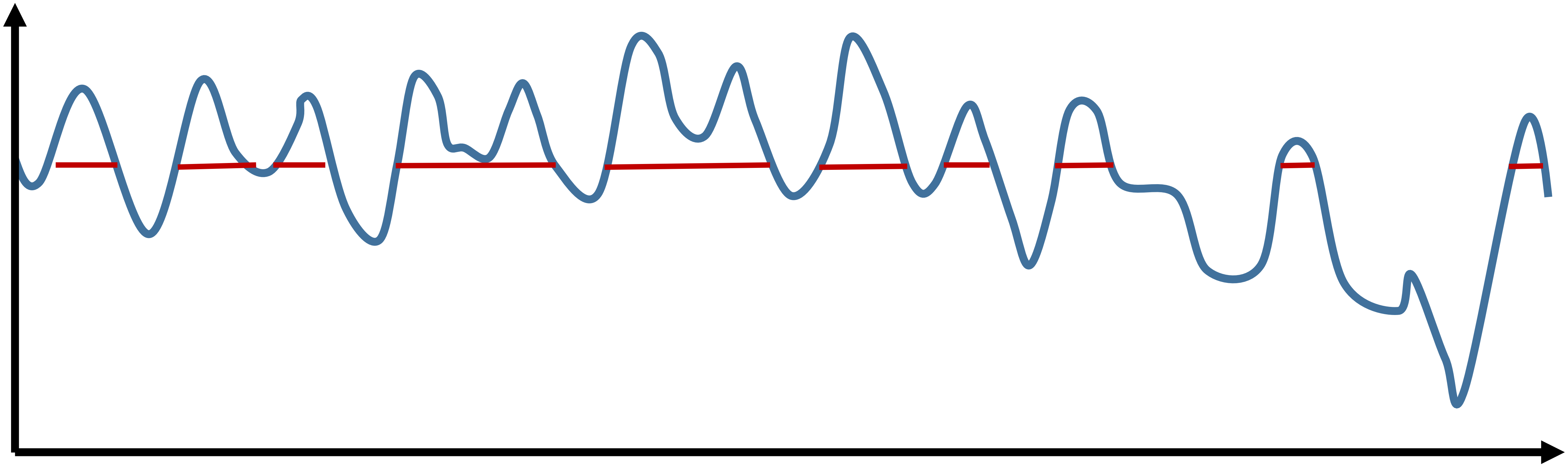

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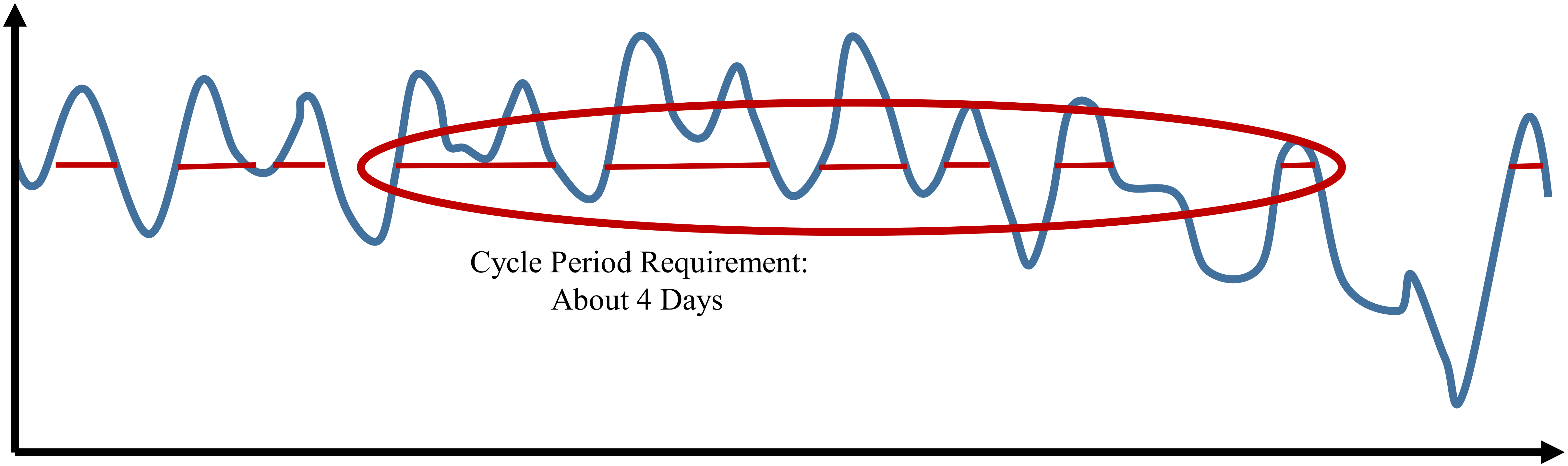

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Market Value: A Word on Fair Reserve Obligation for Retailers