Advanced current control

ST motor drivers are moving the future

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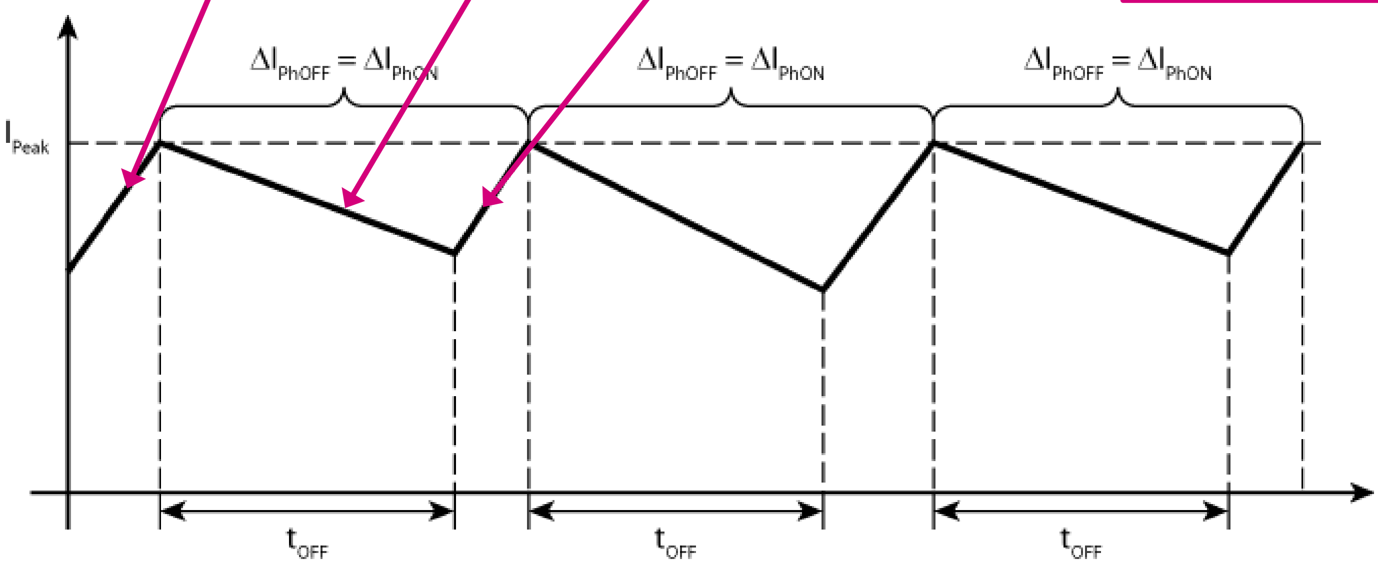
PWM current control basic sequence

1. Charge the current in the motor coil until the target value is reached

2. **Current decay** for a fixed OFF time

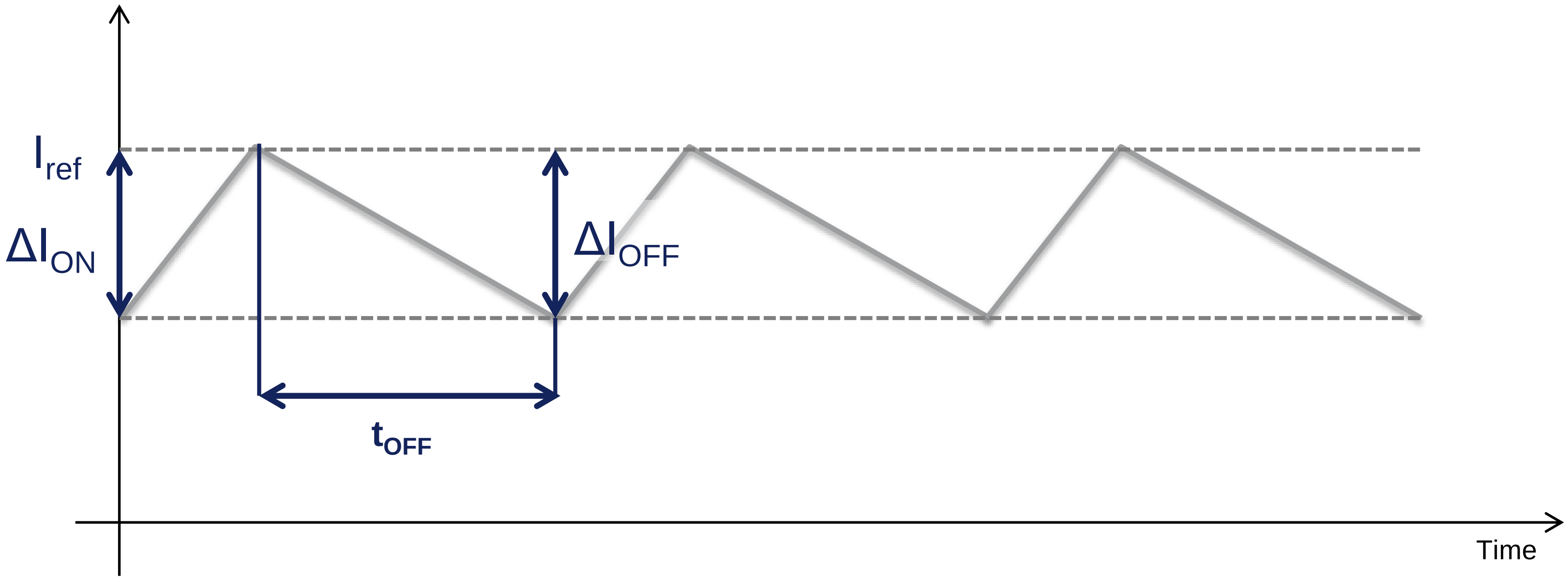
3. Return to charge the current



PWM current control basic equation

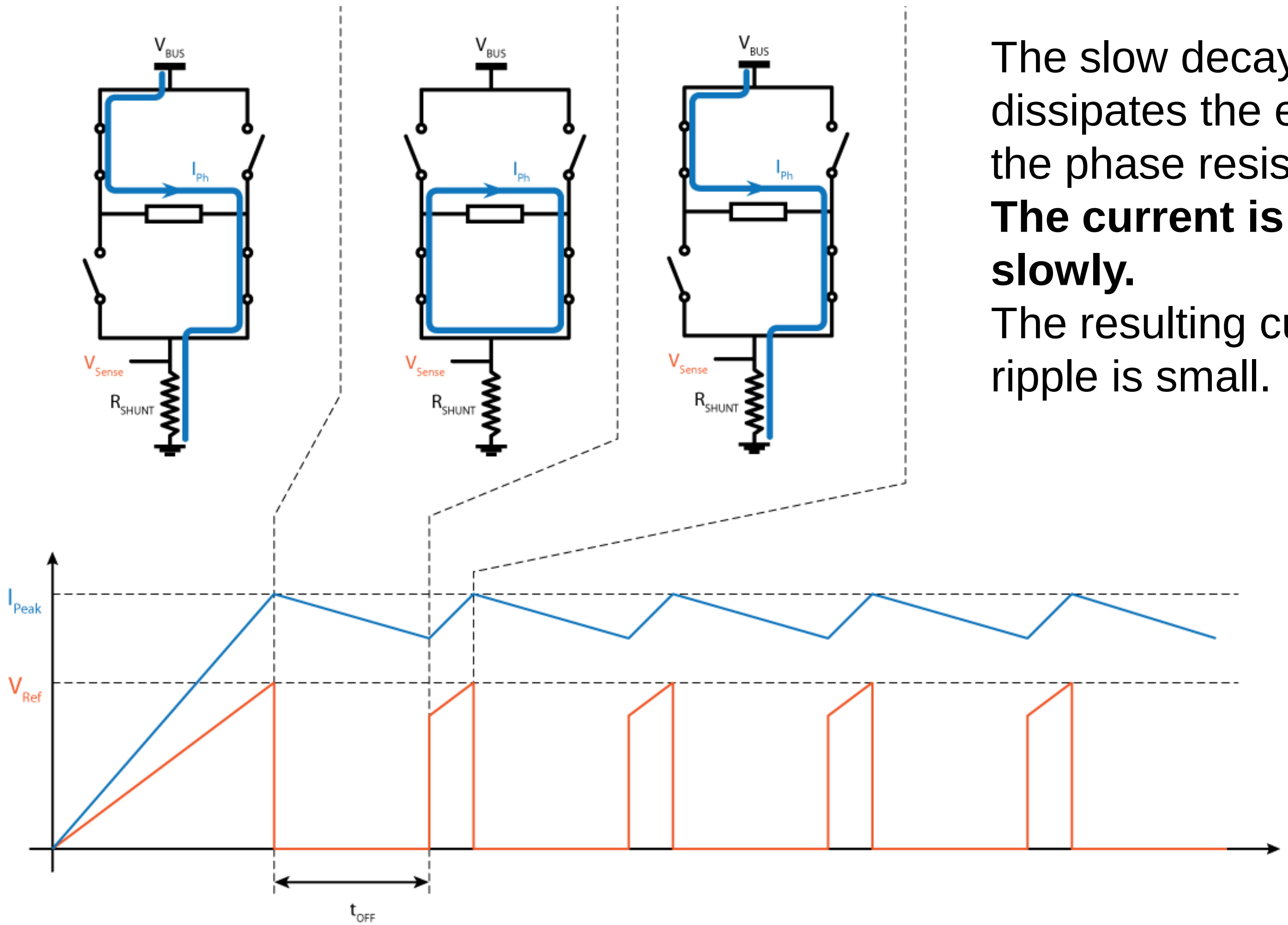
The current control works properly as long as the following condition is satisfied:

$$\Delta I_{ON} = \Delta I_{OFF}$$



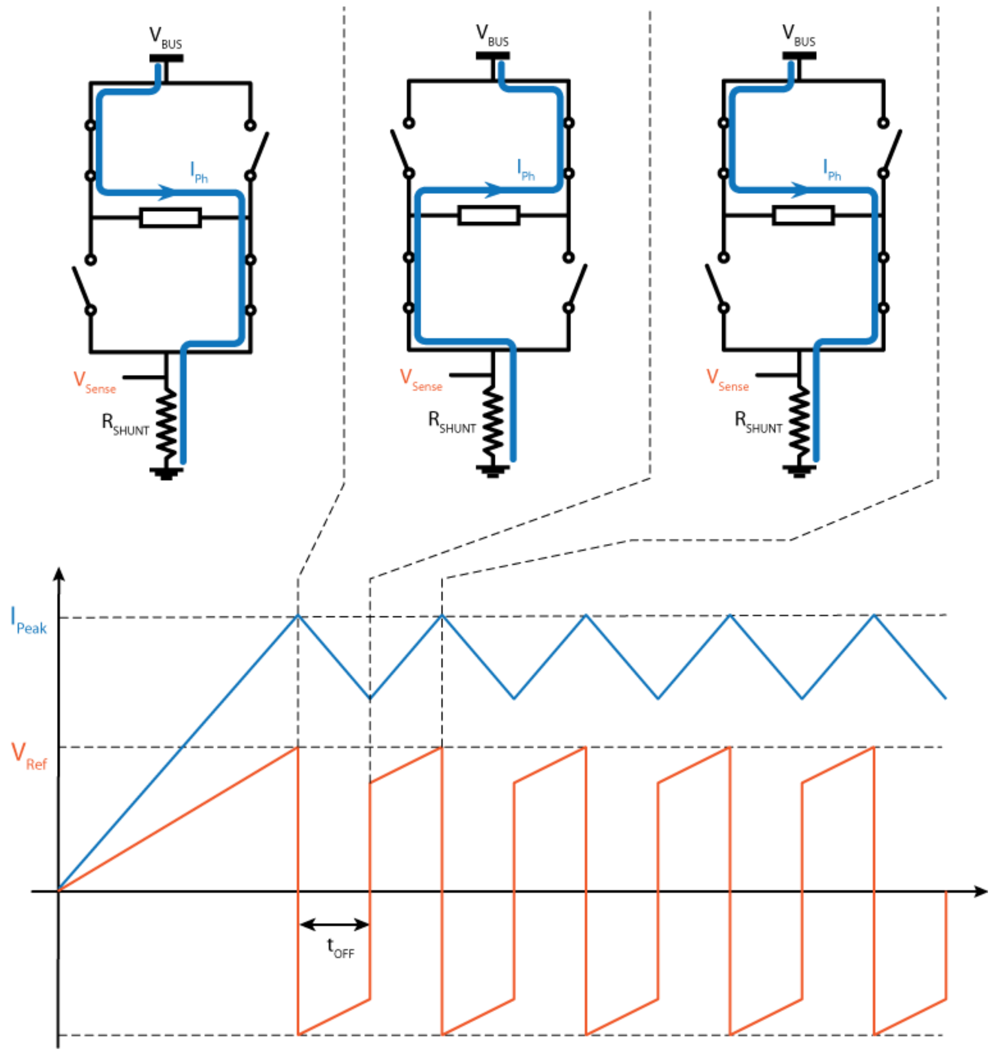
During the ON time, the current is charged of the same value it is discharged during the OFF time.

What decay: slow



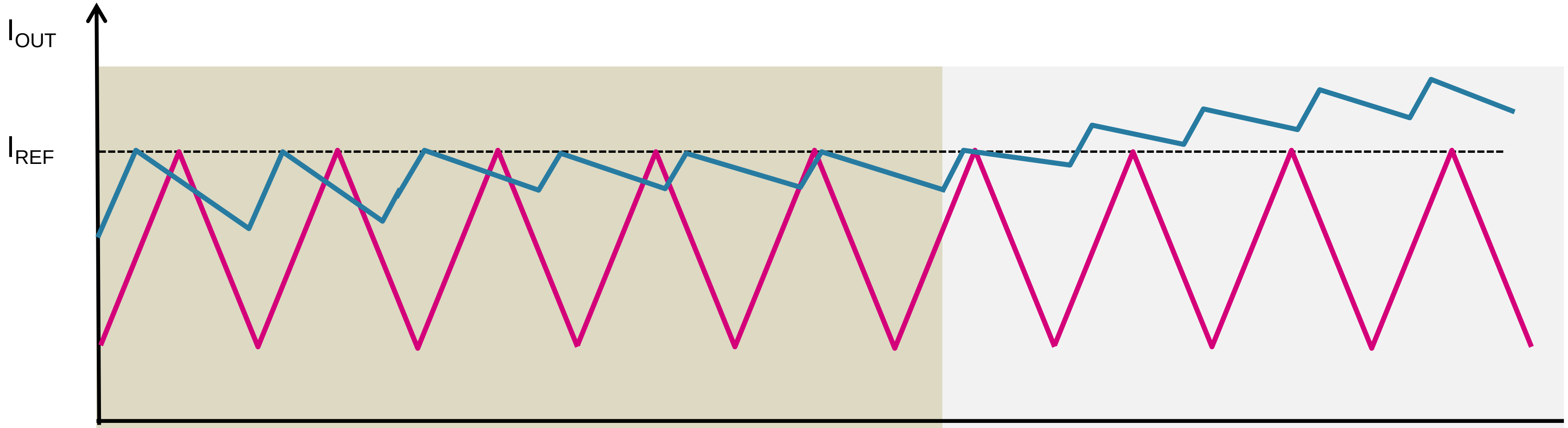
The slow decay dissipates the energy in the phase resistance.
The current is reduced slowly.
The resulting current ripple is small.

What decay: fast



The fast decay sinks the energy from the phase using the bus voltage. **The current is reduced quickly.** The resulting current ripple is big.

Challenges to perform the right decay

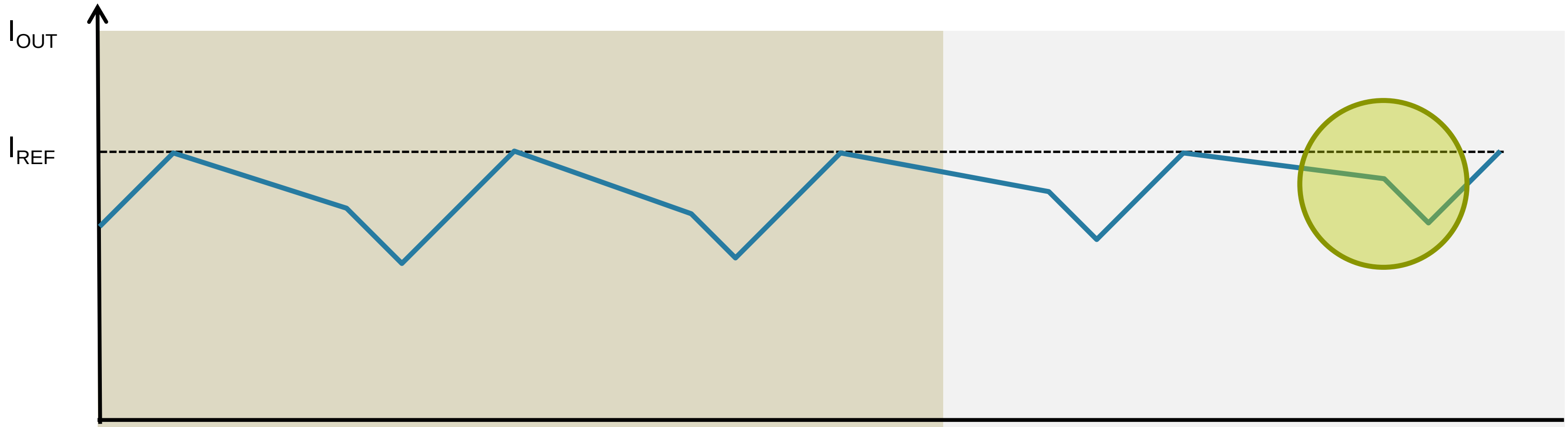


In some cases, a **SLOW DECAY** gives better performance thanks to the lower current ripple and **the motor is more silent.**

In other cases, a **FAST DECAY** is the only way to keep the **current under control**.

Challenges to perform the right decay

One possible solution is to use a combination of the two decay modes: **mixed decay**



In the region where the simple slow decay could be enough to keep the current under control, there is an **extra ripple**.

In other cases, the fast part of the decay helps to keep the current under control

The best solution is to select the right decay for each specific time.

STSPIN
Advanced current control

- **Automatic selection of the decay mode**
  Stable current control in all conditions, in particular with microstep driving

- **Slow decay and fast decay balancing**
  Reduced current ripple

- **Predictive current control**
  Average current control

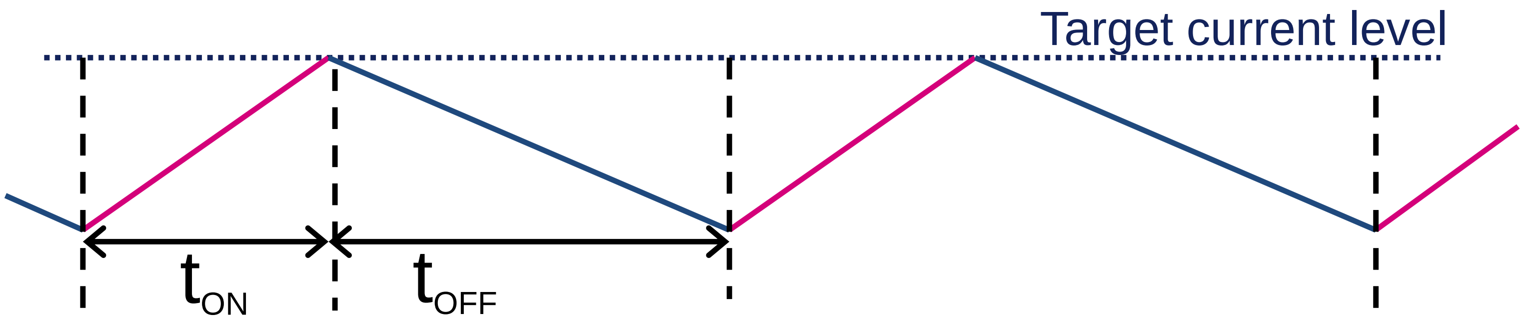
Automatic decay adjustment

Auto-adjusted decay

In a PWM current control with fixed OFF time, the slow decay is always the preferred method in order to minimize the current ripple.

In order to **discriminate a good control condition** (current can be controlled through the slow decay) **from a potentially unstable condition** (fast decay is needed), the t_{ON} of each single control cycle is monitored.

When the control is **stable** ($t_{ON} > t_{ON\_MIN}$), the system applies a slow decay of t_{OFF}.



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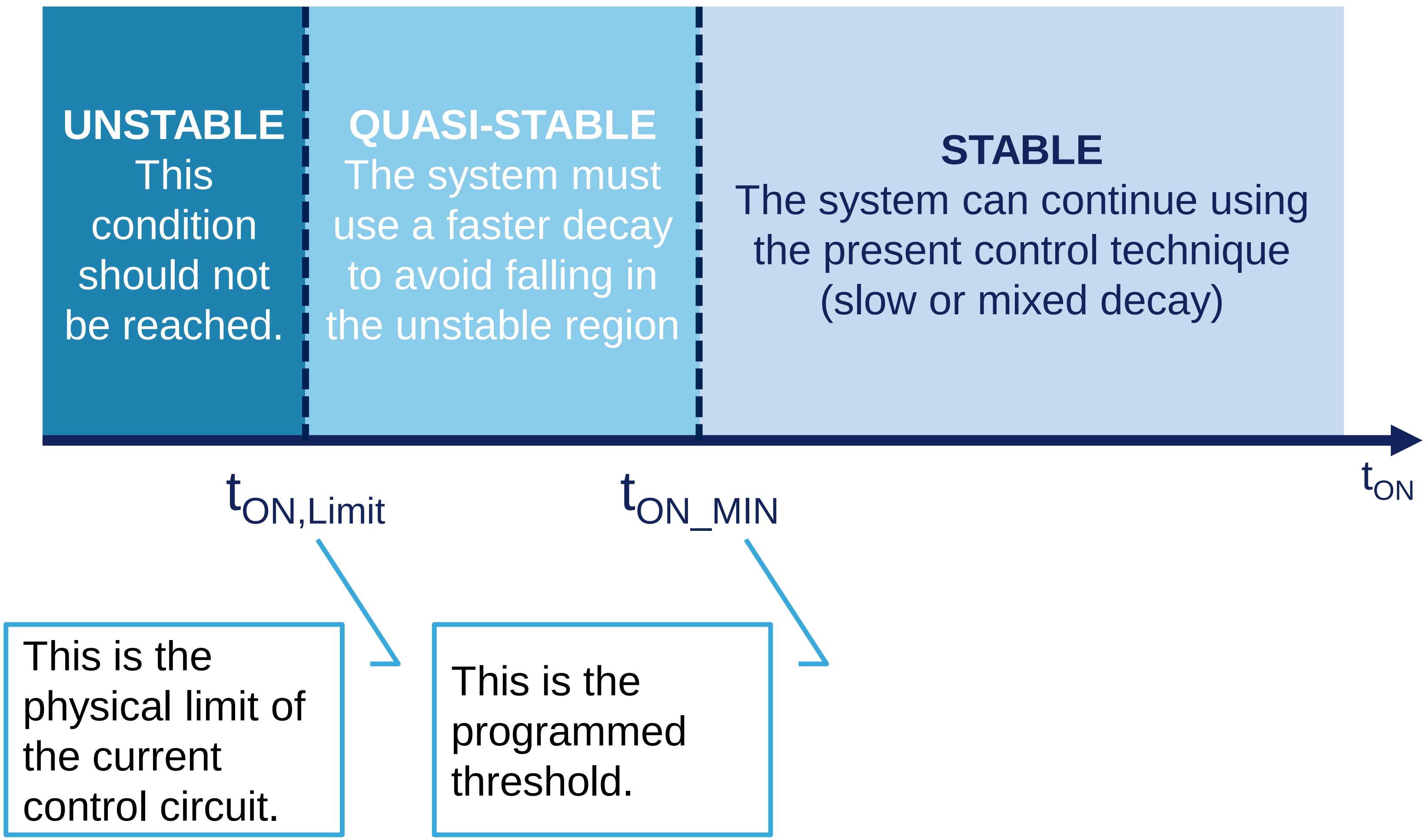
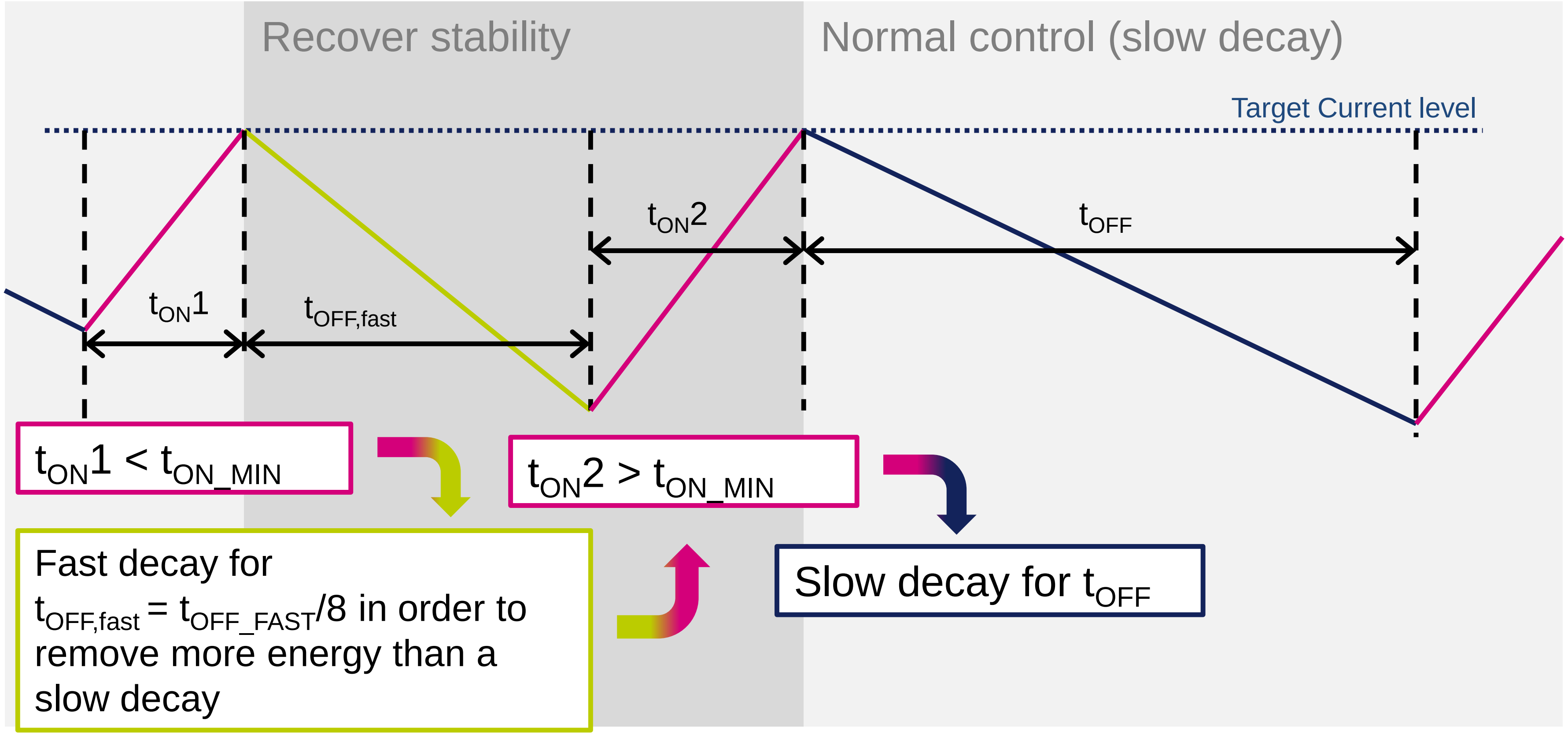
Auto-adjusted decay



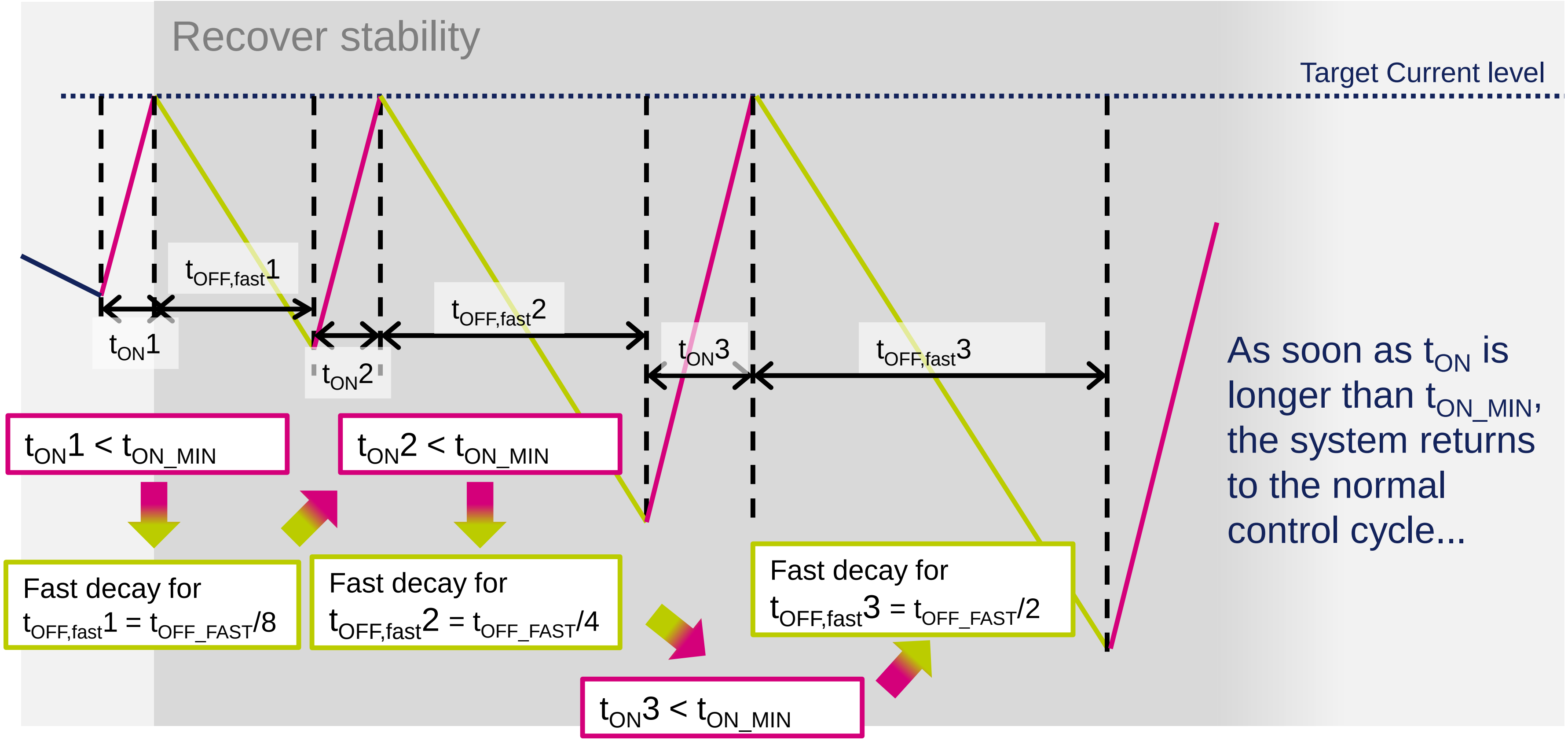
Auto-adjusted decay

When the control is **potentially unstable** ($t_{ON} < t_{ON\_MIN}$), the system applies a **single fast decay** for a short time ($t_{OFF\_FAST}/8$).



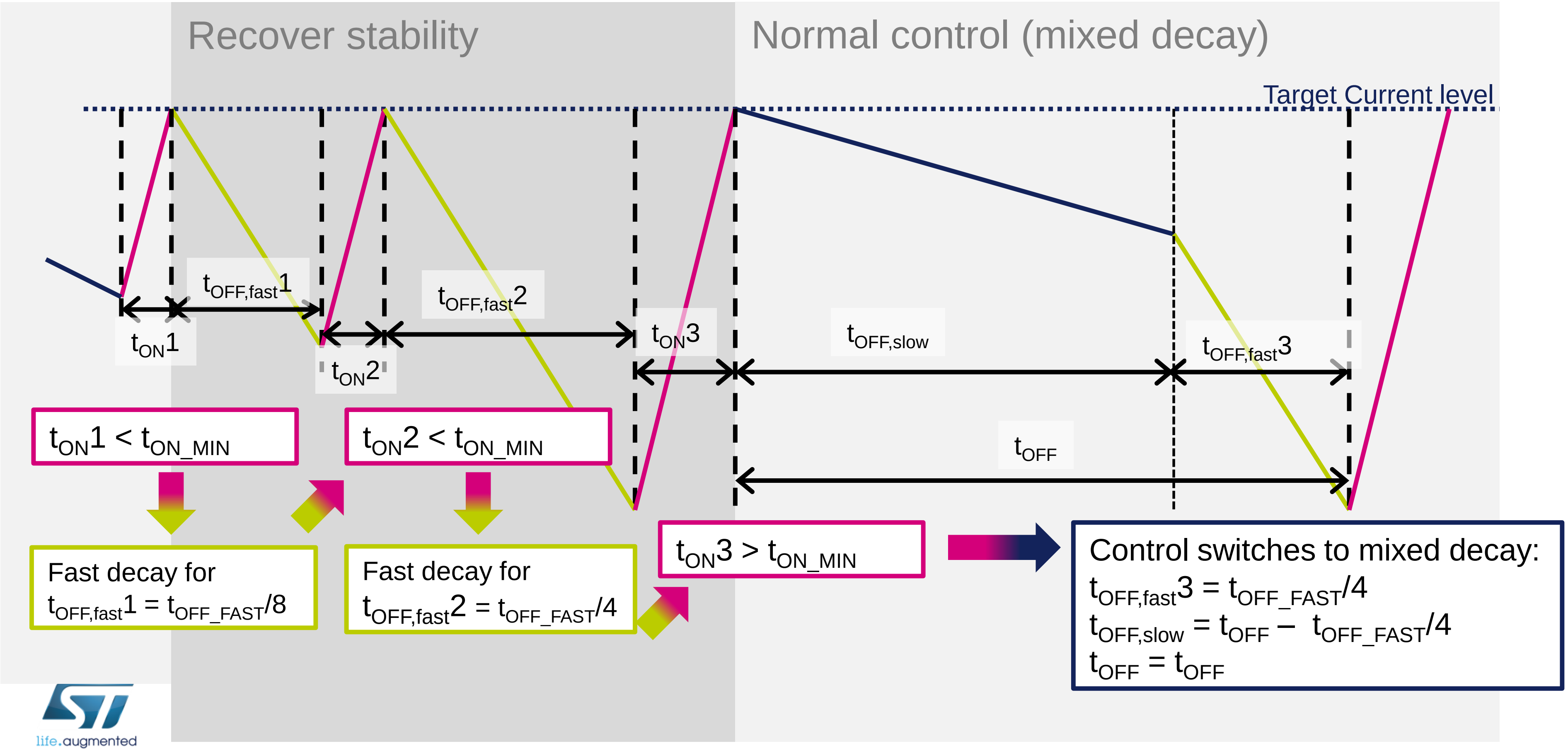
Auto-adjusted decay

When the control is **potentially unstable** ($t_{ON} < t_{ON\_MIN}$) for more than one time, the system applies more **fast decays** incrementing the duration each time.



Auto-adjusted decay

If **two or more potentially unstable** conditions occur, a **mixed decay** is used when the control returns to normal mode.



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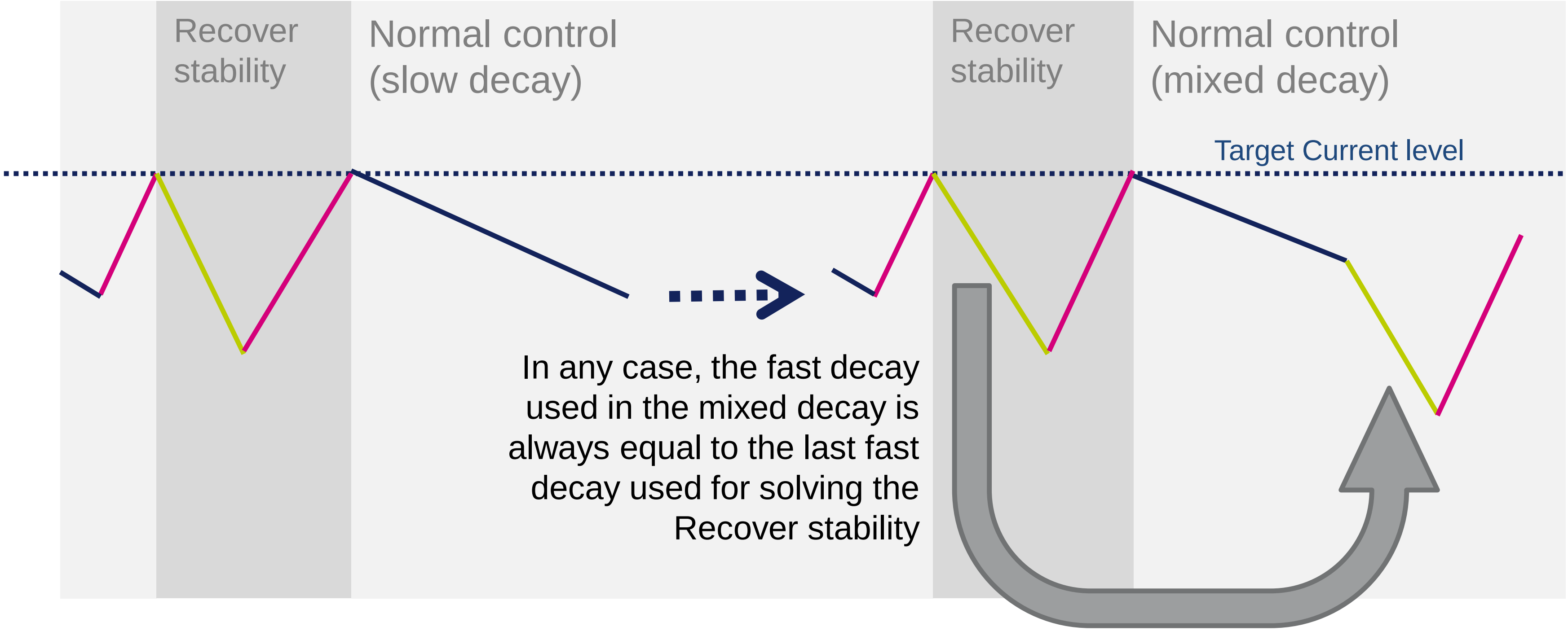
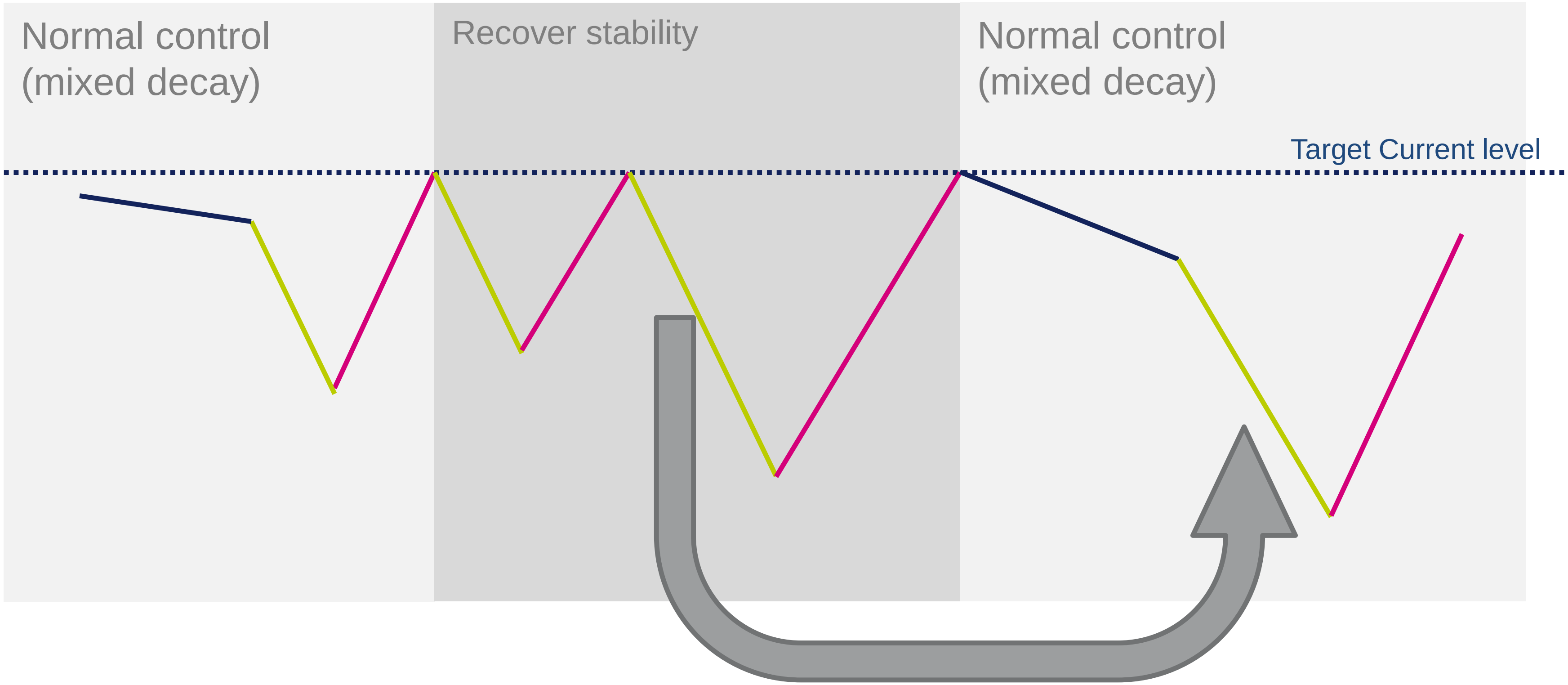
Auto-adjusted decay

The two potentially unstable conditions triggering the mixed decay operation can also be non subsequent.



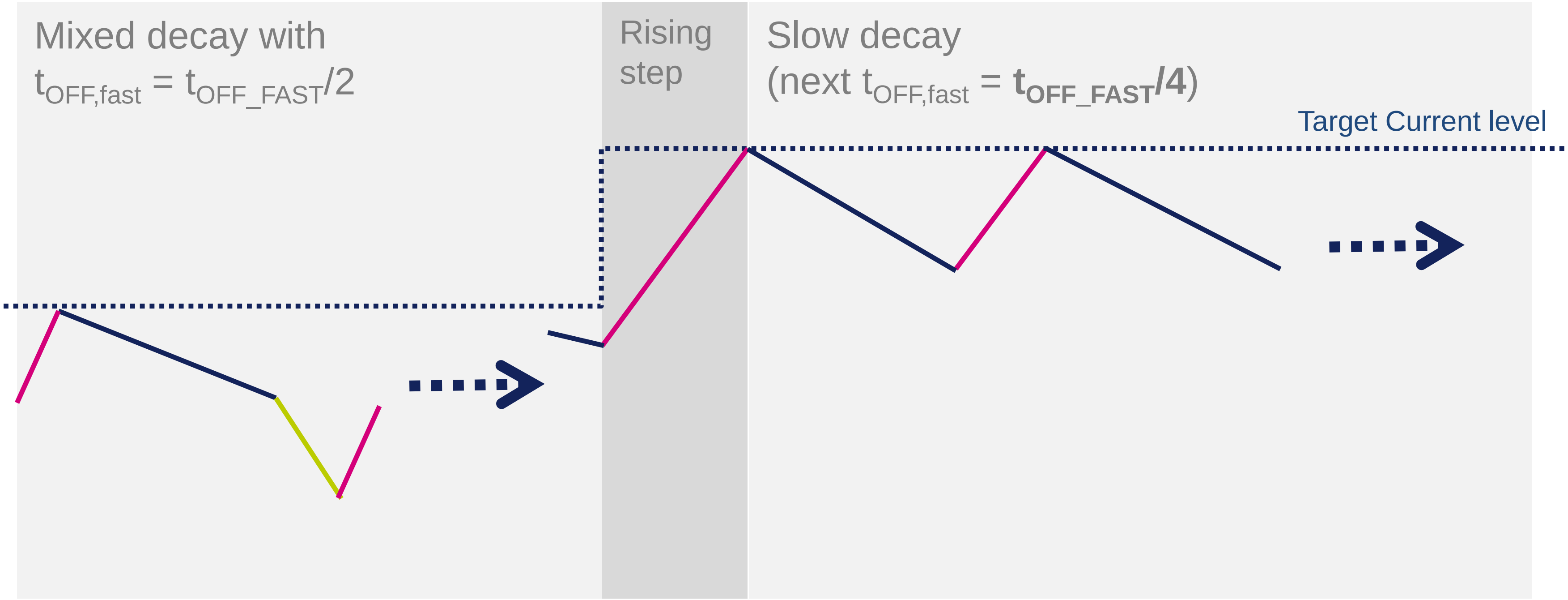
Auto-adjusted decay

If a new sequence of potentially unstable conditions causes an increase of the fast decay, the new value is used from this time on.



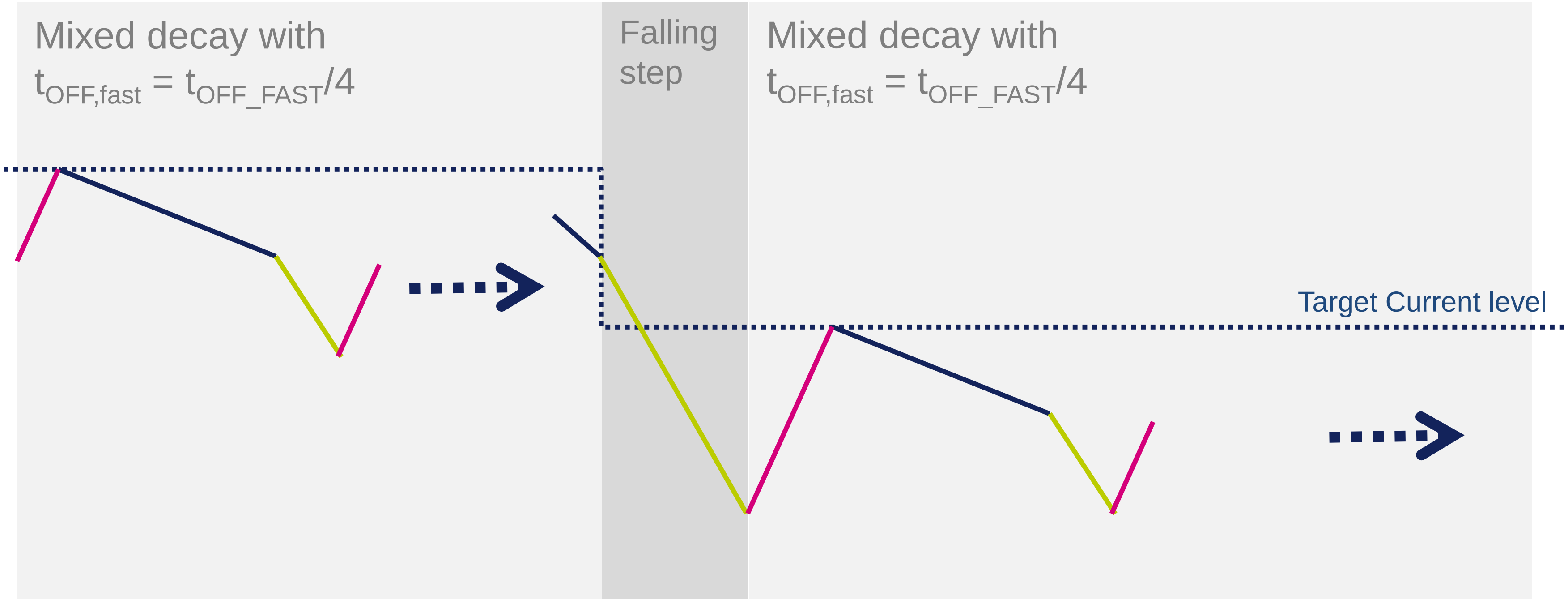
Auto-adjusted decay

When the reference increases to a higher value (rising step), the system returns to the **slow decay** method (higher current → slow decay is more effective) and the **fast decay value is halved**.



Auto-adjusted decay

When the reference deceases to a lower value (falling step), both the **decay mode** and the **fast decay value are kept unchanged**.

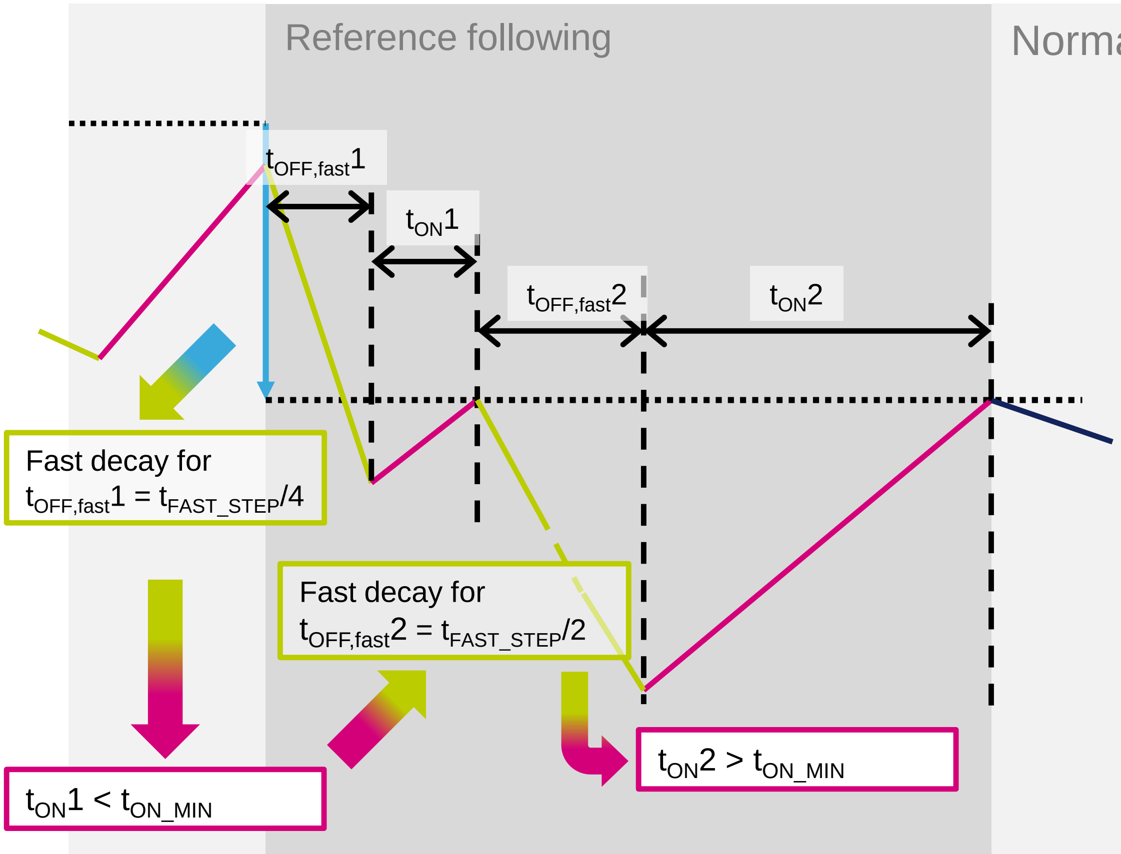


Summary

- A **fast decay is used only when it is needed** to guarantee the control stability (the programmed t_{ON_MIN} limit is reached).
- The **fast decay duration is gradually increased** from $t_{OFF\_FAST}/8$ up to t_{OFF_FAST} (doubled at each consecutive fast decay).
- A **mixed decay** (fast and slow decay combination) is used when the t_{ON_MIN} threshold is reached twice (not necessarily consecutively).
- When the current reference increases (rising step), the slow decay mode is forced and the next fast decay duration is reduced.
- When the current reference decreases, the decay mode and the fast decay duration are kept unchanged.

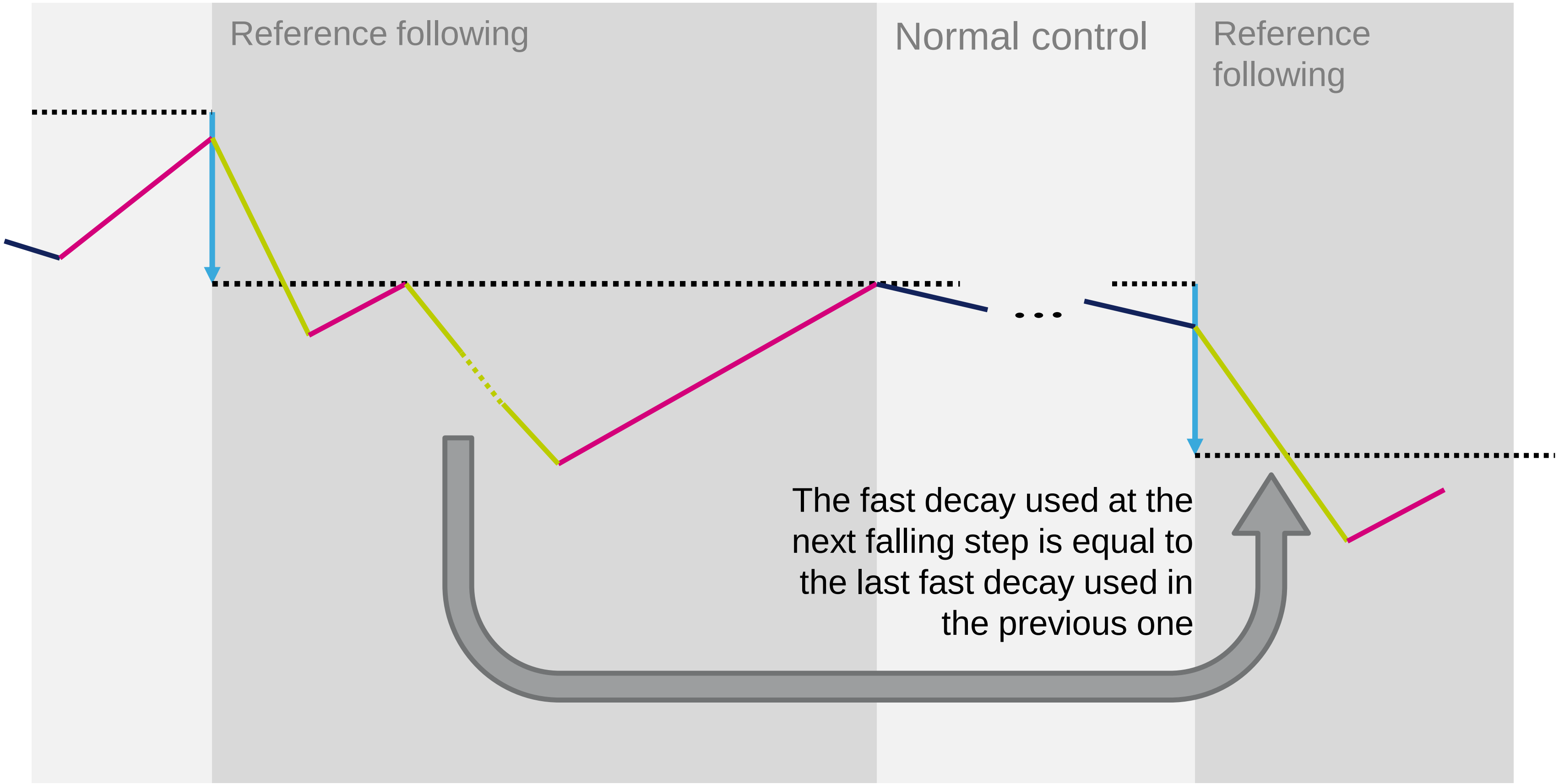
Auto-adjusted fast decay at falling step

The same principle of the auto-adjusted decay is applied when the system needs to follow a **decreasing reference** value (falling step).



The parameter for the tuning of the fast decay in this case is $\mathbf{t_{FAST\_STEP}}$

Auto-adjusted fast decay at falling step



Summary

- A **fast decay sequence** is performed as soon as the **reference current is reduced** (falling edge). The sequence is stopped when the t_{ON_MIN} limit is satisfied.

- The **fast decay duration is gradually increased** from $t_{FAST\_STEP}/4$ up to t_{FAST_STEP}
(doubled at each consecutive fast decay).

- At the **next falling edge**, the **last fast decay** duration is used.

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Tuning parameters of the control algorithm

The advanced control system is based on the following parameters:

Parameter name	Function
t_{ON_MIN}	**Target minimum ON time:** the control system tries to force an ON time which is always longer than this value.
t_{OFF_FAST}	**Maximum fast decay:** defines the maximum duration of a fast decay when it is performed to control the peak current value.
t_{OFF}	**Fixed OFF time:** the duration of the OFF time during a normal control cycle.
t_{FAST_STEP}	**Maximum step decay:** defines the maximum duration of a fast decay when it is performed to change the current level to a new reference value.

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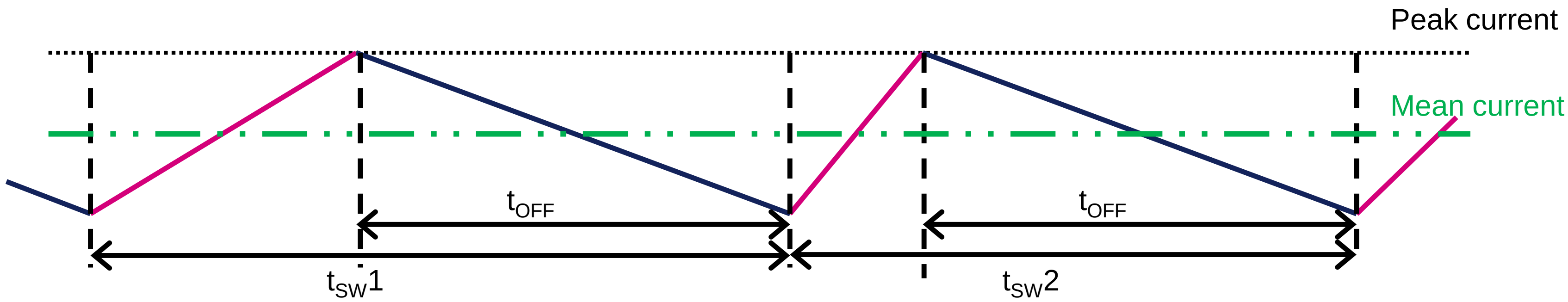
Tuning parameters of the control algorithm

Lower values		Higher values
• Less frequent use of the fast decay • Lower ripple • Higher probability of control fail	t_{ON_MIN}	• More frequent use of the fast decay • Higher ripple • Higher control stability
• Higher switching frequency • Lower ripple • Higher probability of control fail	t_{OFF}	• Lower switching frequency • Higher ripple • Higher control stability
• Lower ripple • Longer on-fast sequences • Higher probability of control fail	t_{OFF_FAST}	• Higher ripple • Shorter on-fast sequences • Higher control stability
• Longer on-fast sequences during falling steps	t_{FAST_STEP}	• Shorter on-fast sequences during falling steps

Predictive current control

Predictive current control



The peak current control with fixed OFF time has two main cons:

- The average current (actual motor position) could be significantly different from the controlled peak current
- The switching frequency can vary significantly

The predictive current algorithm allows to control the average current and reduces the switching frequency variation.

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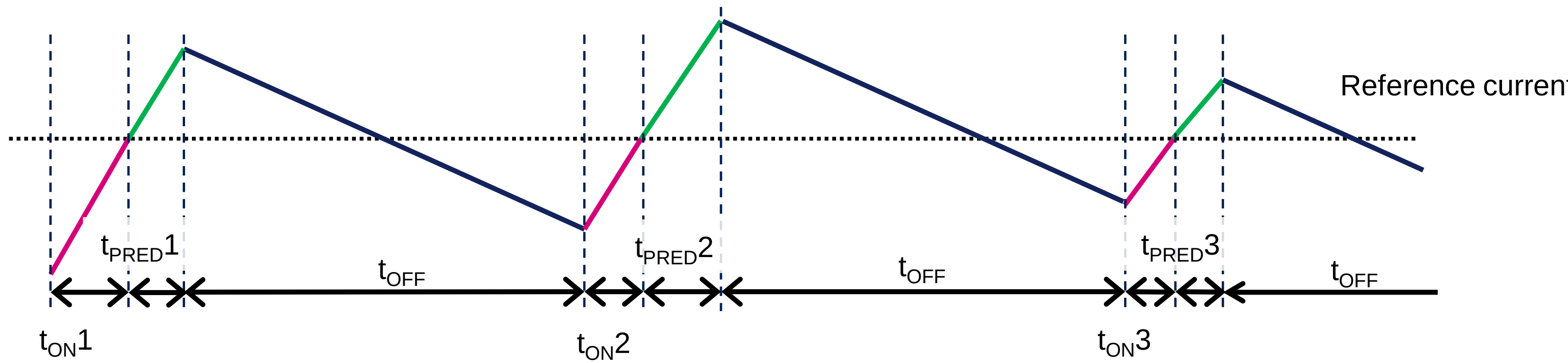
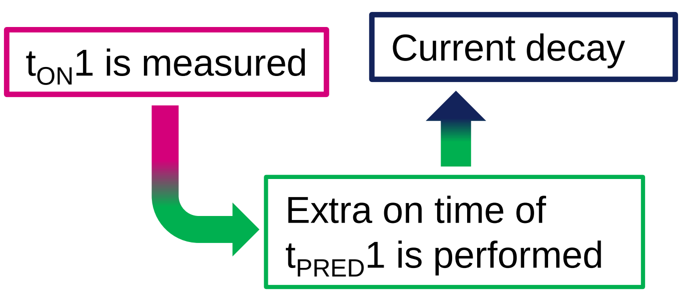
Predictive current control



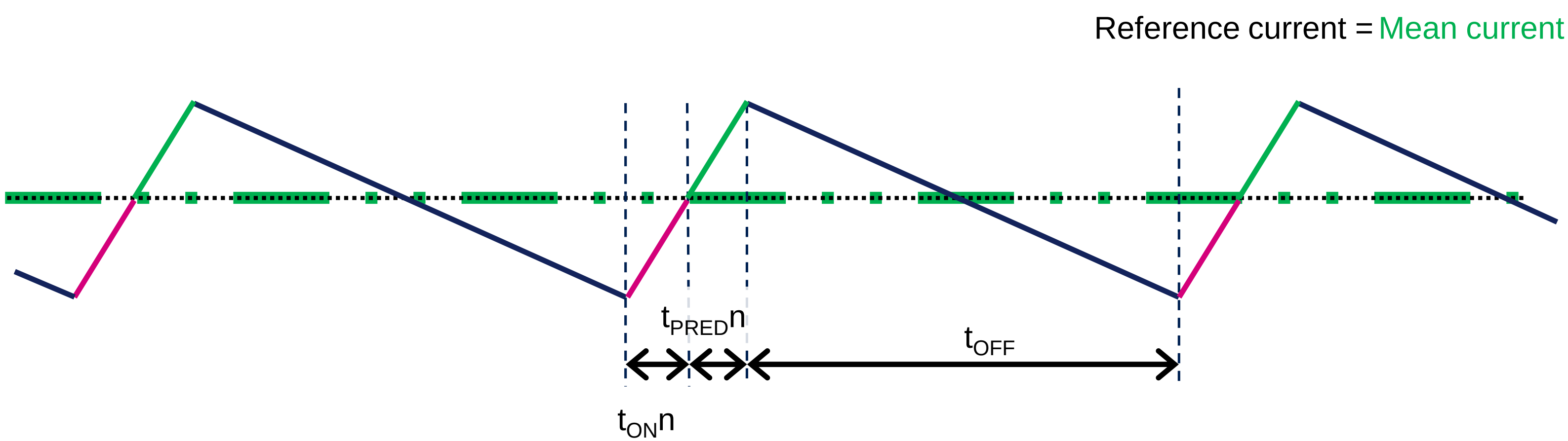


The extra on time is calculated cycle-by-cycle using the following formula:

$t_{PRED}n = (t_{ON}n\text{-}1 + t_{ON}n)/2$

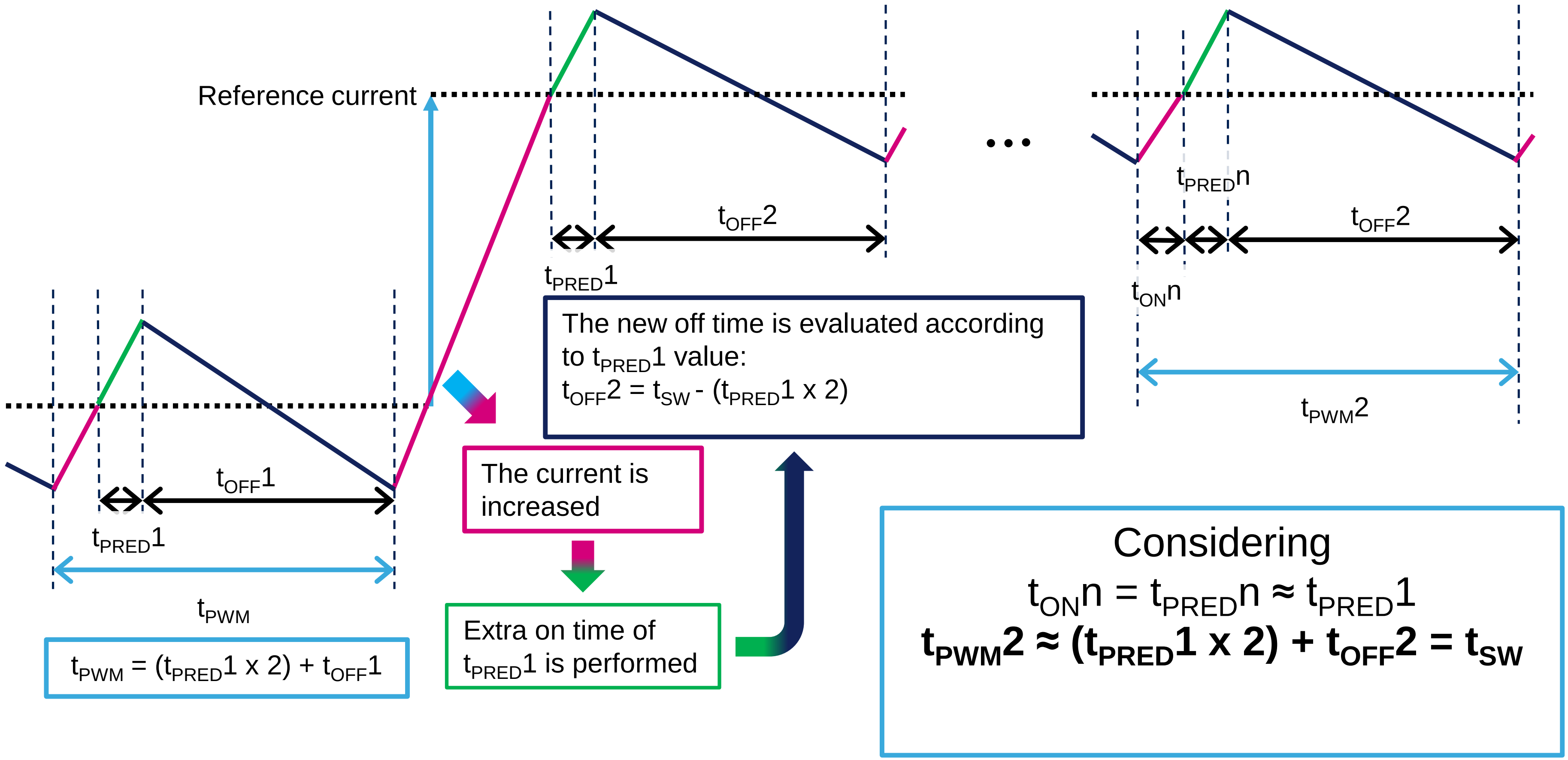
Note: the t_{ON_MIN} limit of the current control is checked on t_{ON} time only.
If $t_{ON} < t_{ON\_MIN}$, no extra on time is performed and the decay adjustment sequence is performed.

Predictive current control



When the system reaches the stability → $t_{PRED}n = t_{ON}n$
In this case, the average current is equal to the reference: the system implements a control of the average value of the current.

Predictive current control



NOTE: t_{SW} replaces the t_{OFF} parameter of the non-predictive current control.
A saturation threshold of the t_{OFF} ($t_{OFF:MIN}$) is added in order to avoid the OFF time decreasing too much.

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Summary

- An extra on time (t_{PRED}) is added after current threshold crossing.
- The duration of the extra on time is equal to the two step average of the previous on times.
  When the system reaches stability, t_{PRED} should be equal to t_{ON}.
- At every change of current reference, the off time is adjusted in order to keep the switching time almost equal to t_{SW}.

Further information and full design support can be found at www.st.com/stspin

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