Dynamic Power Measurement and How It Can Be Used for Test Optimization

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Generating efficiency maps

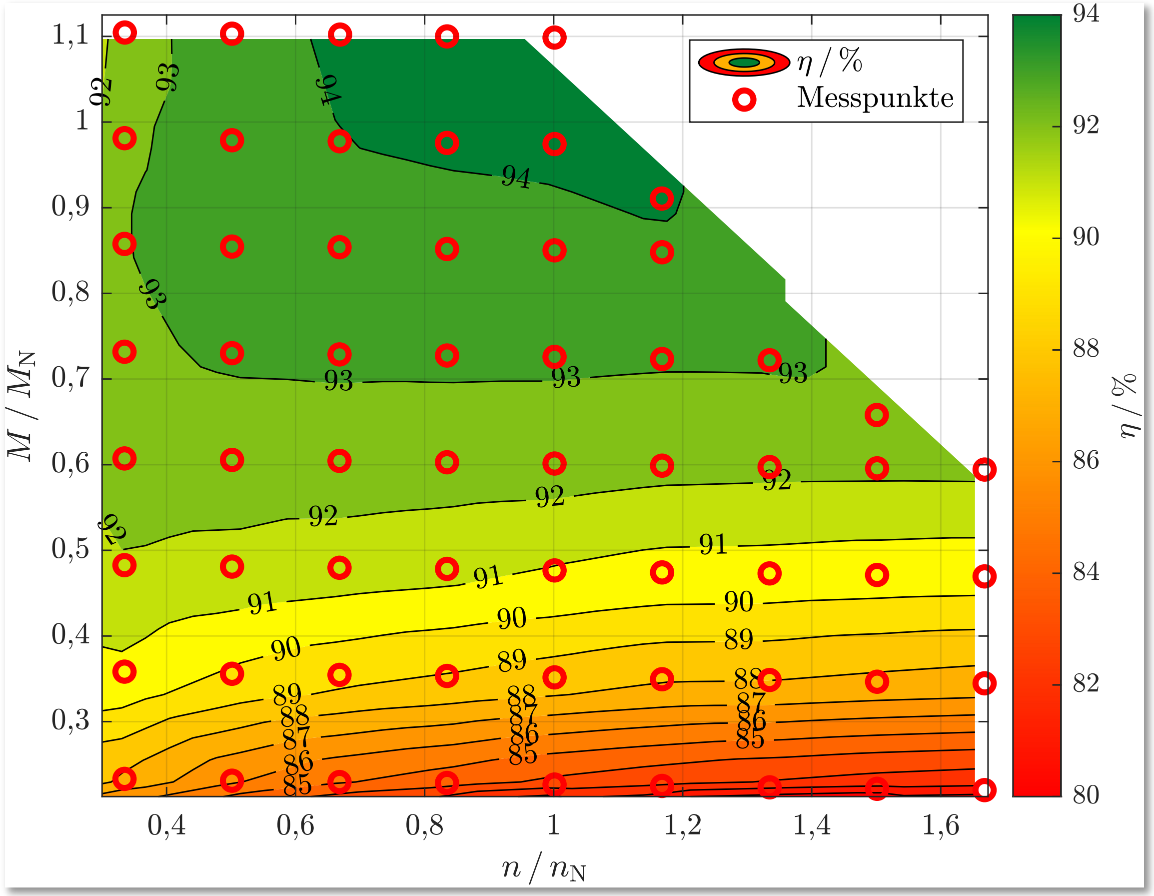
Efficiency maps for motors and drive trains

- Range and Cost are conflicting design criteria for an EV
- More efficient powertrain allow companies to meet these design criteria
- EV Powertrain operate in a variety of states and operation points
- Efficiency Maps are a key tool to understand efficiency at all points
- In the design and drive optimization process, it is therefore important to be able to create and understand many efficiency maps in a short period of time

Efficiency maps for motors and drive trains

- To be able to determine the efficiency for real use cases, the efficiency is determined in the form of efficiency maps:
  - Efficiency versus torque and speed
  - Different maps for different temperature and voltage combinations

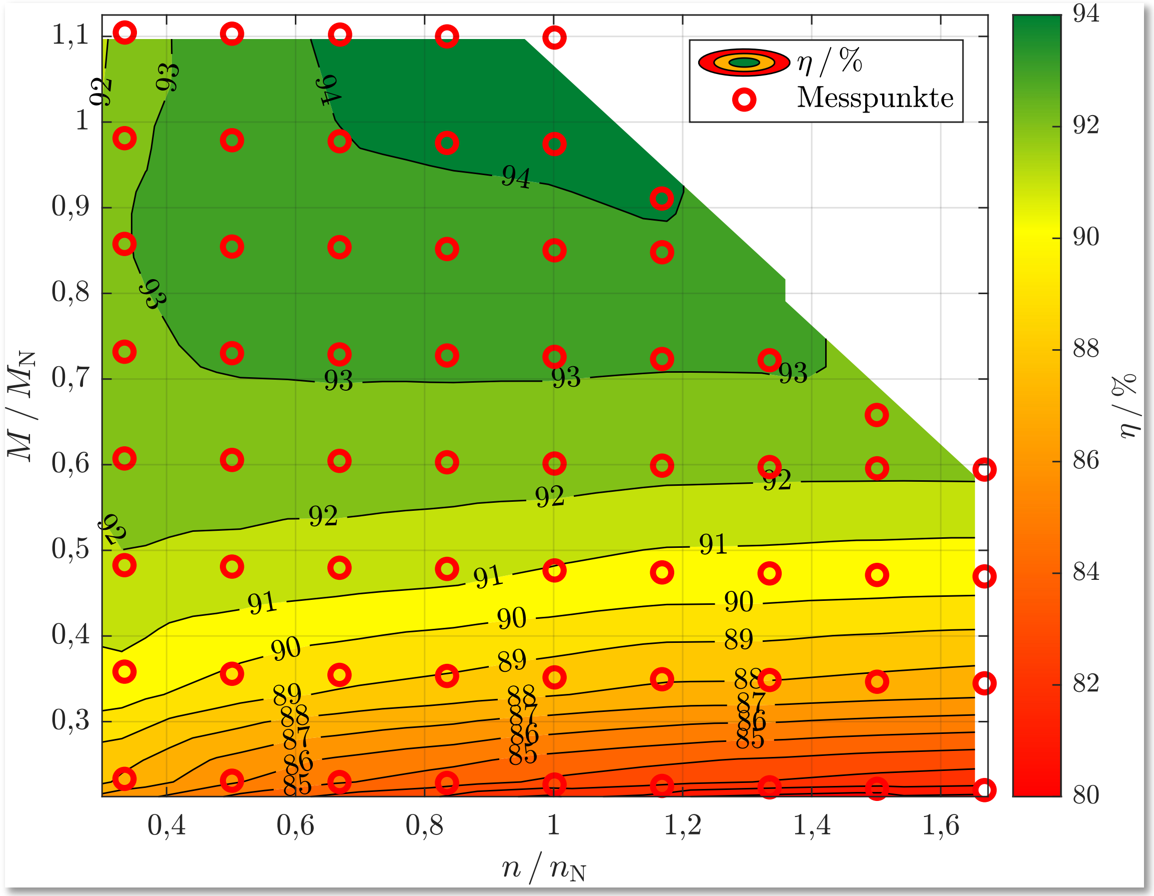
- The conventional approach:
  - Take a grid of setpoints where the system is in steady-state
  - Interpolate between the measured points to get a continuous efficiency map



Stock, A.: „*Messtechnische Analyse der Energieverluste von stromrichtergespeisten Antriebssystemen im nichtstationären Betrieb*". Dissertation (submitted, not yet published). München: University of the German Federal Armed Forces, 2021

Efficiency maps for motors and drive trains

- The conventional approach typically contains the following steps
  - Measurement: determine the efficiency of the setup in a single steady-state point
  - Transition: move the setup to the next (torque-speed) setpoint and wait until steady-state is reached
  - Change of parameters: e.g., cooling the system, changing the battery voltage



- The question:

"How can we reduce the time and cost for generating efficiency maps?"

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Measurement Time for Efficiency – Example

States
- 5 temperatures
- 5 battery voltages
- 25 maps

Measurement
- 10 sec with PLL
- 2 sec with cycle detect

Transitions
- 5 sec

Heating up & cooling down
- 100 sec (every 60 seconds)

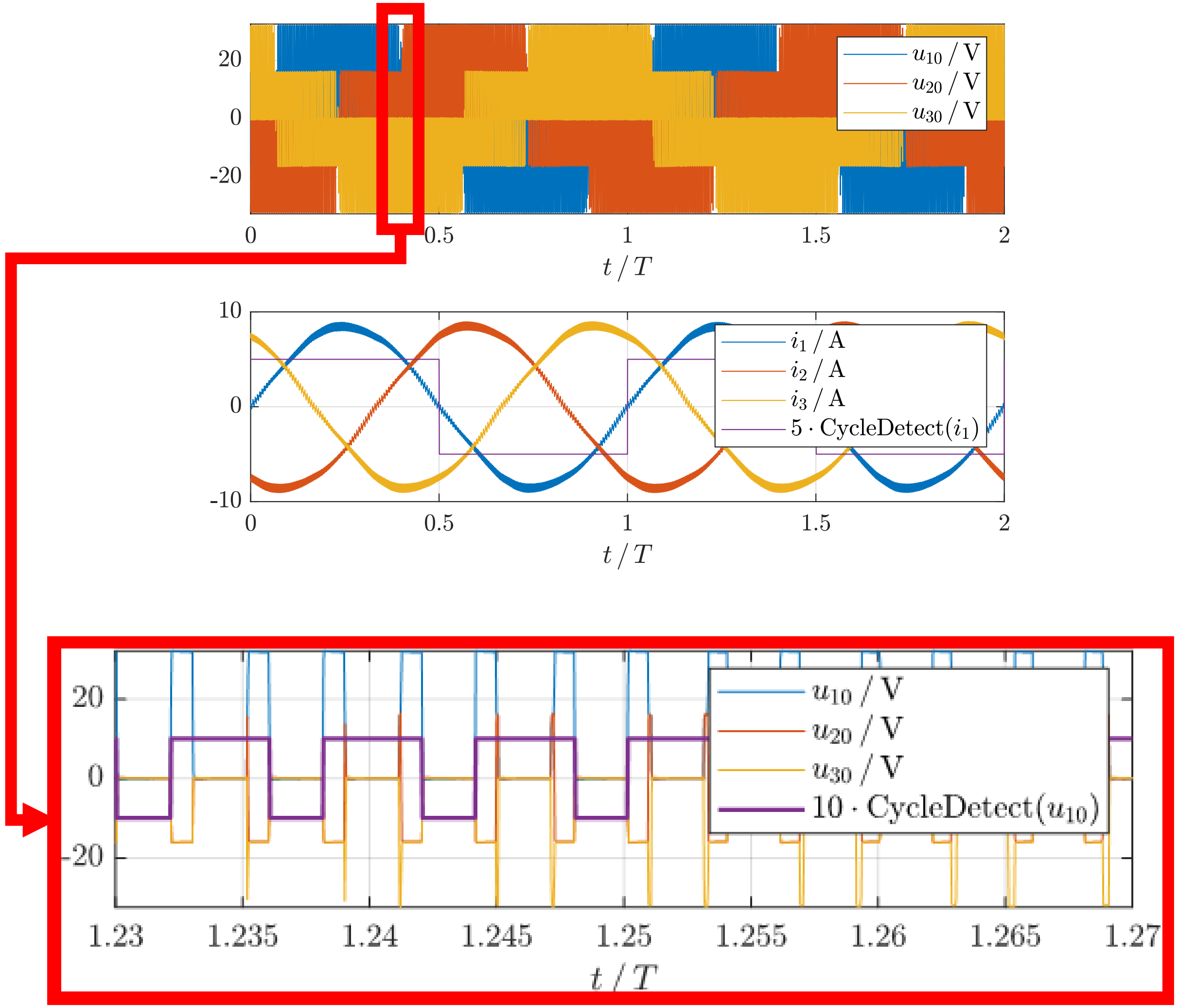
Other Tests & Downtime

Points/map	10 second Measurement	2 second Measurement
200	46.2 hours	15 hours
600	138.5 hours	45.2 hours
2000	462.0 hours	150.1 hours

Dynamic Testing to Reduce Time → Dynamic Power

Using Dynamic Power Measurements [1]

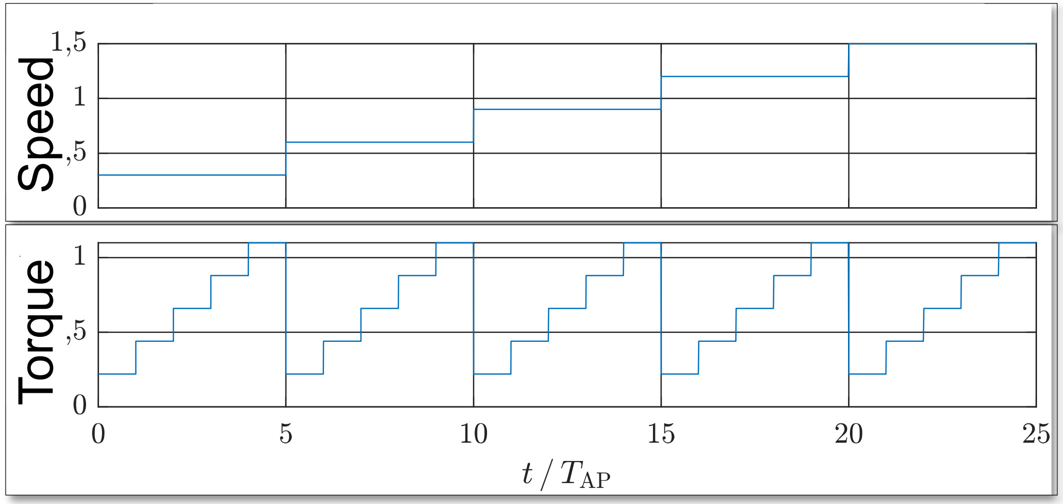
- Conventional Power Measurement
  - Power is based on fundamental frequency
  - the system is brought into steady-state before a measurement is done
  - Power is averaged over ½ or more cycles

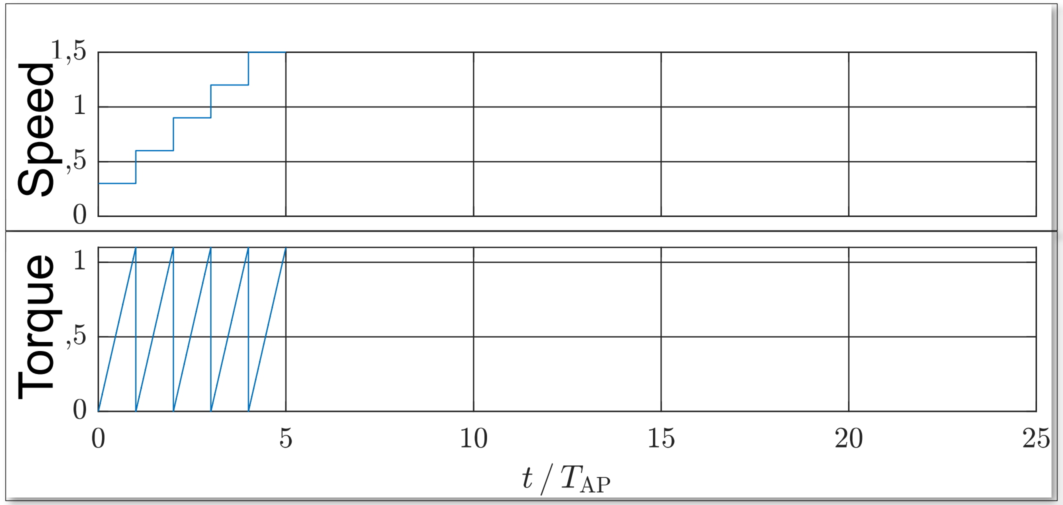


- In *Dynamic Power Measurements*
  - Power is based on 1 or several *switching periods* of the inverter (think a few ms)
  - The system moved in a continuous way through the torque-speed curve
  - Not as accurate but FAST

[1] Stock, A.: „*Messtechnische Analyse der Energieverluste von stromrichtergespeisten Antriebssystemen im nichtstationären Betrieb*“. Dissertation. München: University of the German Federal Armed Forces, 2021

Using Dynamic Power Measurements [1]





- Conventional method
  - Steady state setpoint values of speed and torque are driven sequentially
  - Conventional active power and mechanical power are calculated based on the fundamental cycle
  - Efficiency is calculated
- Dynamic method
  - Steady state state setpoint values of speed are driven sequentially
  - For each speed, the torque is ramped up continuously
  - Active power and mechanical power are calculated based on the inverter switching cycle
- **Significant time savings!**

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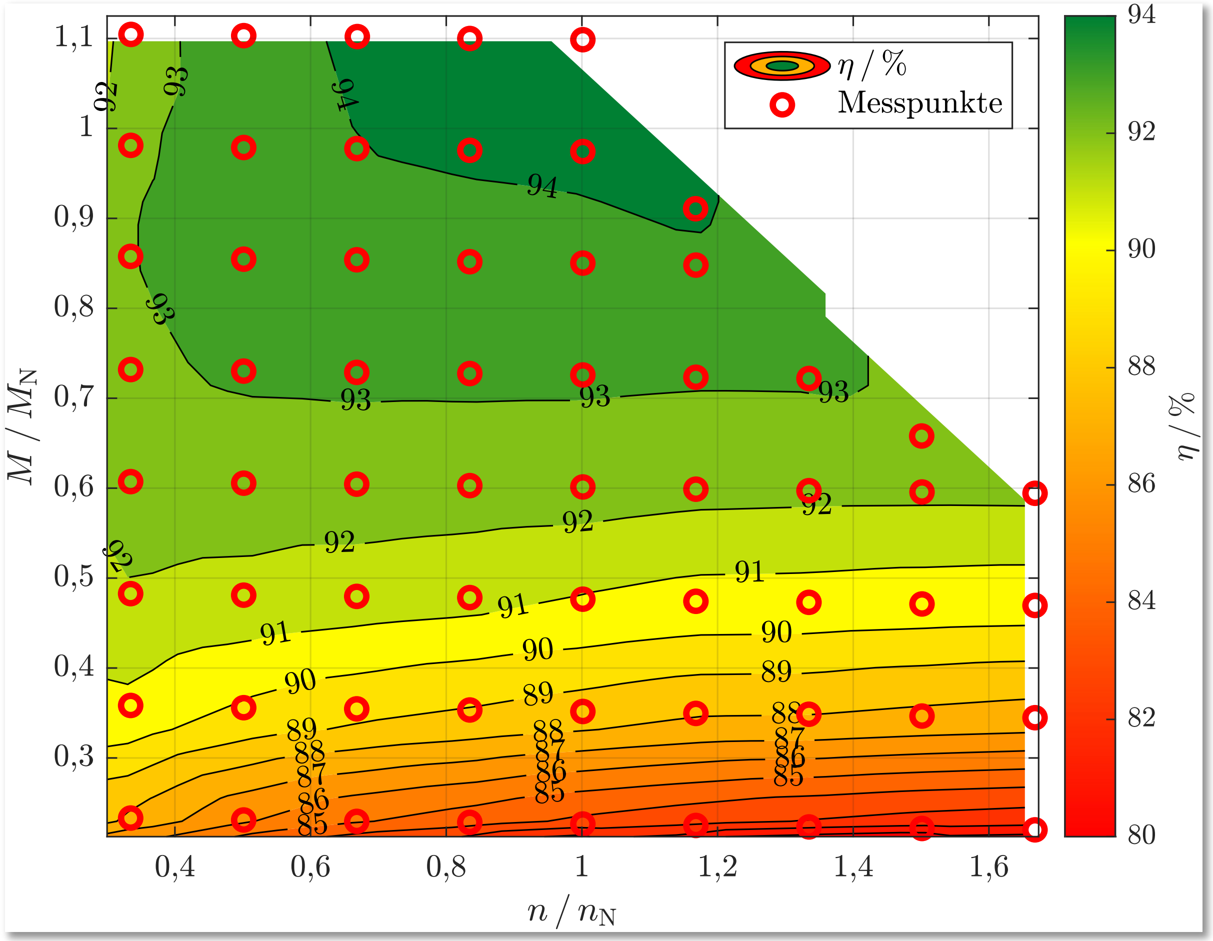
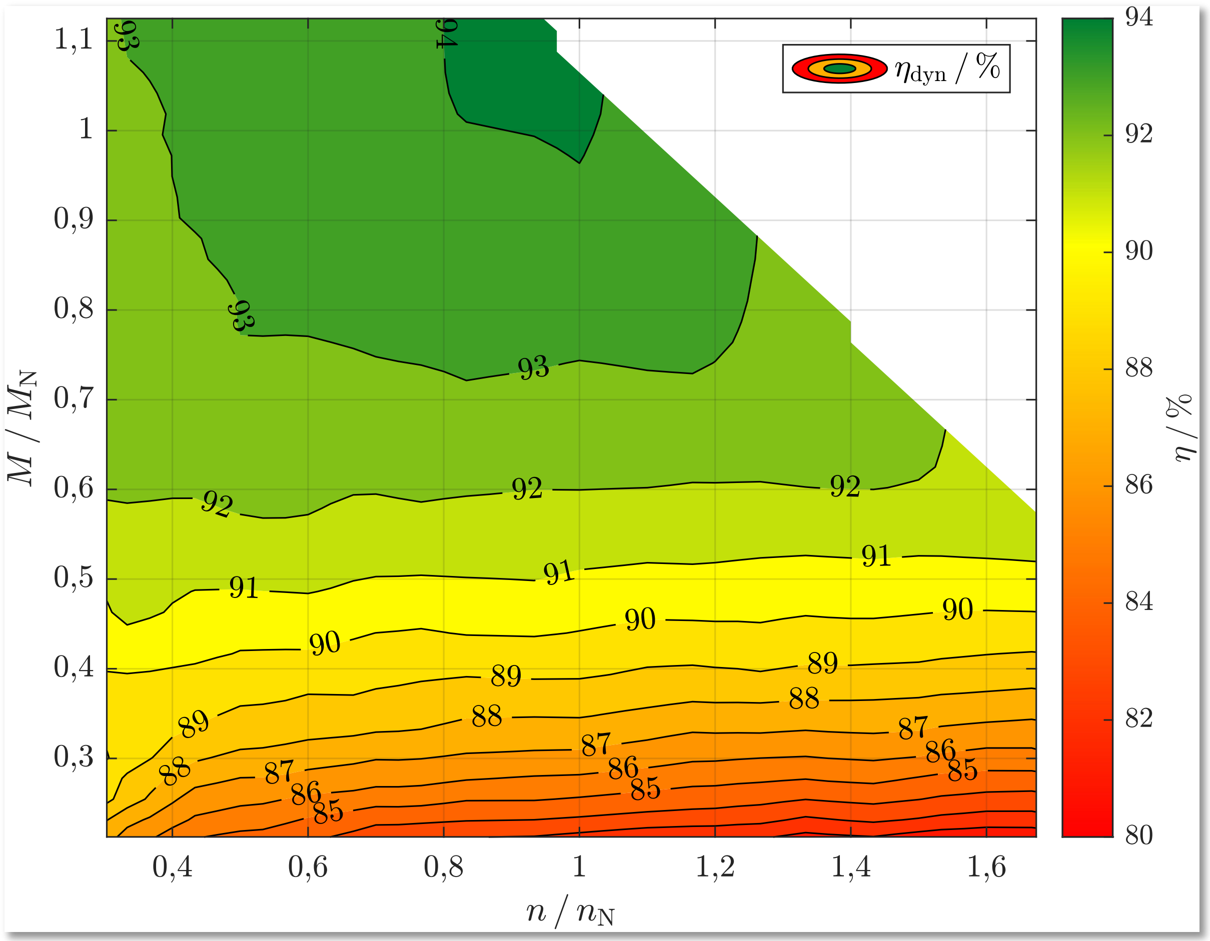
Using Dynamic Power Measurements [1]

Conventional Method



Dynamic Method



High level of similarity and enormously reduced measurement time

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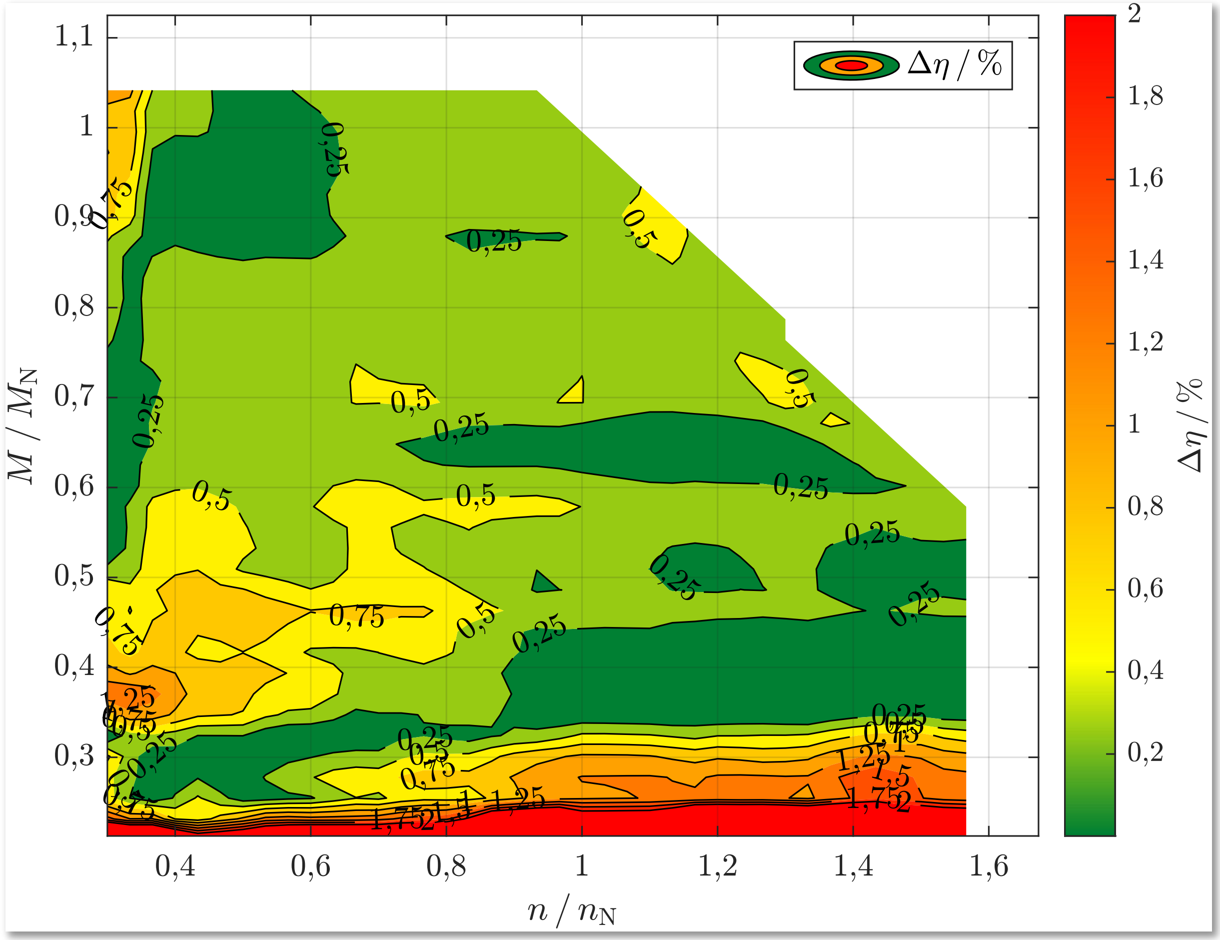
Using Dynamic Power Measurements [1]

- Very small deviation between both methods
  - Small deviation from conventional method is inevitable
  - Not suitable for the highest accuracy requirements
- Accelerated measurement is suitable for
  - End of line tests (pass/fail)
  - **Quickly getting a very good estimate of the efficiency plot**
- Can also be used for dyno WLTP
  - no additional efficiency measurement necessary

Deviation of Conventional and Dynamic Method



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Dynamic Testing to Reduce Time → Optimization

Reducing the number of steady-state setpoints

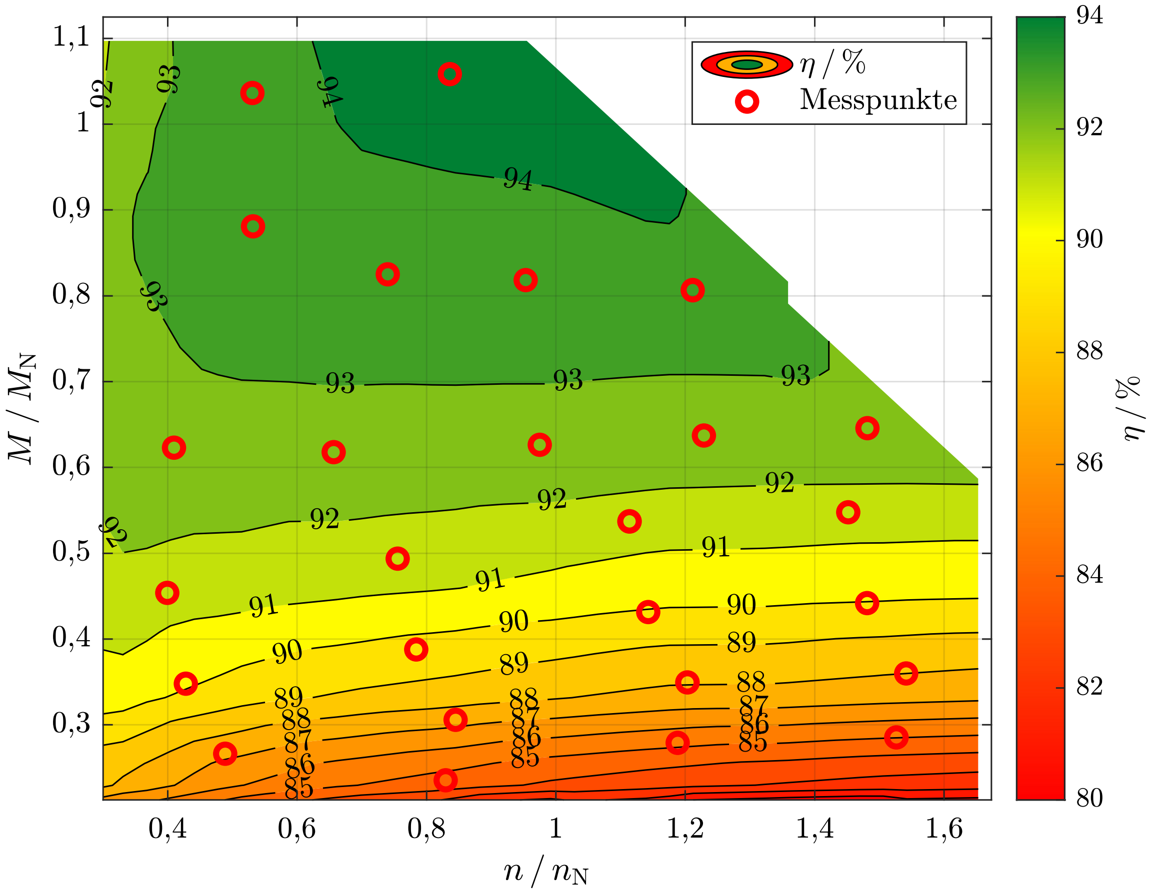
- Conventional methods use a grid of setpoints and interpolate between them

- This gives high accuracy efficiency values

- The total accuracy of the plot depends on how many and where the grid points are chosen

- “More is better”
  - Longer
  - More expensive

- **HBK is developing methods that choose the setpoints more efficiently, leading to fewer measuring points but the same accuracy for the efficiency plot**



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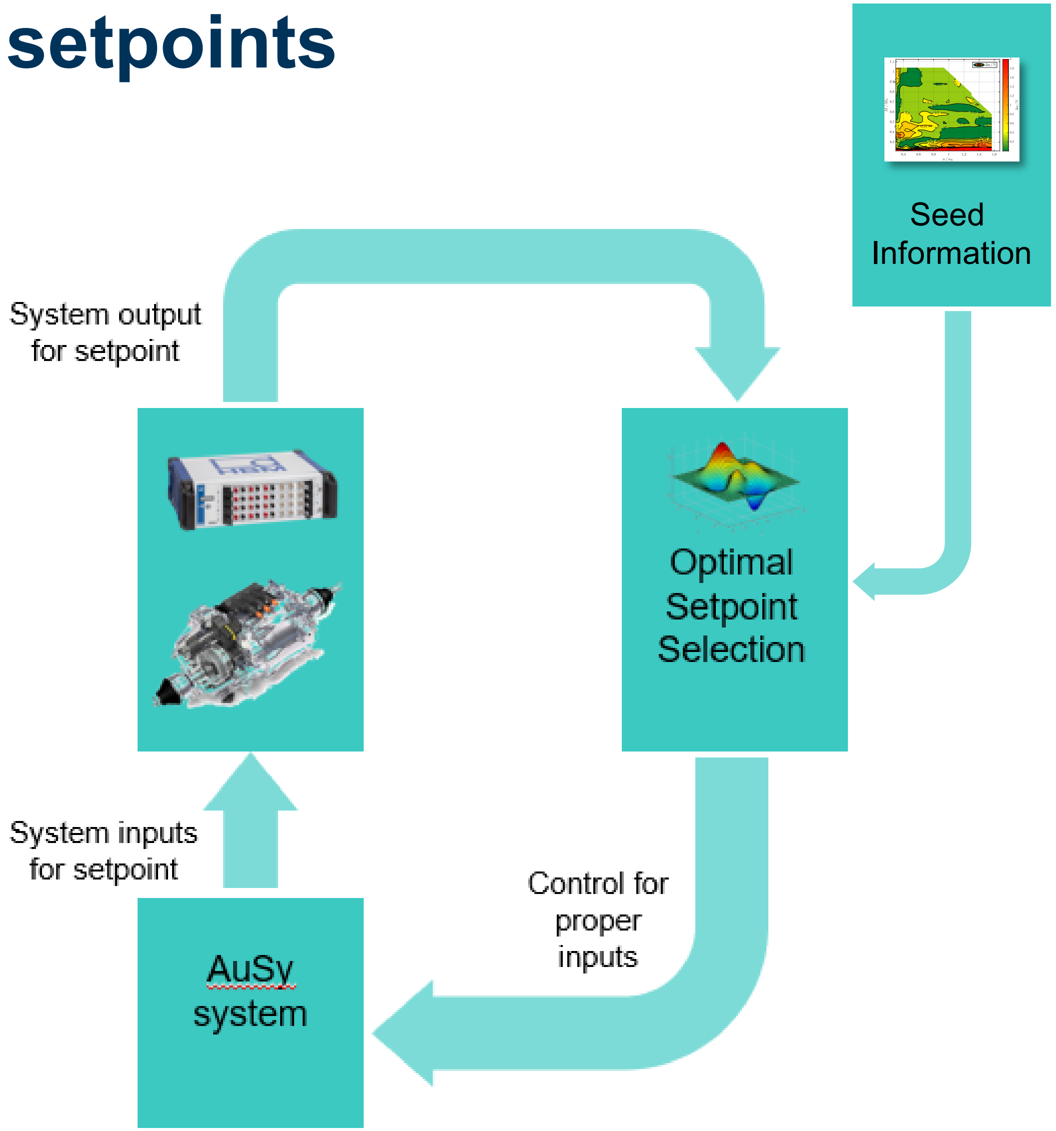
Reducing the number of steady-state setpoints

- Developing a dedicated tool interacting with eDrive and an automation system (AuSy)
- The tool intelligently chooses optimal setpoints which are then sent to the AuSy
- The tool uses seed values and live measurements to select the next point
  - Machine parameters
  - **Fast efficiency sweep**
  - Drive cycles
  - Models & simulation



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Measurement Time for Efficiency – Point Reduction

- 30% point reduction

- Conditions
  - States
    - 25 maps
  - Measurement
    - 2 sec with cycle detect
  - Transitions
    - 5 sec
  - Heating up & cooling down
    - 100 sec (every 60 seconds)
  - Other Tests & Downtime

- How many tests do you run a year?

Equivalent Points/map	Non - Optimized	30% Reduction	Savings at $2500/day
200	15 hours	10.5 hours	$1,412.76
600	45.2 hours	31.6 hours	$4,238.28
2000	150.1 hours	105.5 hours	$14,127.60

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Discussion

- We sketched two approaches to reduce the time and cost for generating efficiency maps

- What are your thoughts?
  - Any feedback on the proposed methodologies?
  - Would those methods work practically in your environment? (Think of the machine heating up during Dynamic Power measurements)
  - Is the efficiency accuracy equally important over the whole plot, or do you want higher accuracy in certain areas?
  - …

- Future
  - Model correlation
  - Model refinement
  - Automated Tuning

Thank you!