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Motor controllers: Input current vs. Motor current = Power conversion

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Topic

There is sometimes the discussion why the motor current reported by the motor controller differs strongly from the current reported by the power supply. This seems to be surprising for a lot of users especially because the motor current is often much higher than the input current of the motor controller.
What is the secret behind this and which current value is correct?

Solution

A motor controller's power stage is like a power converter or a kind of electronic transformer.
This means that you have to **compare the input power** (= "Supply voltage" x "Input current") provided by the power supply **against the output power** (= "Motor voltage" x "Motor current") supplied to the motor by the motor controller's power stage. If you just compare the "Input current" and the "Motor current" this is misleading and has no meaning at all.

The power stage of modern motor controllers (like maxon's ESCON, EPOS, or MAXPOS) are based on a so-called PWM (= Pulse Width Modulation) controlled motor voltage. The motor voltage is turned on and off at a high frequency (of typically 50 - 100 kHz) by the motor controller's logic. The power on time (= so-called "PWM duty cycle") within each PWM cycle (of 0.01 ms in case of 100 kHz) determines the actually present level of motor voltage. The resulting motor voltage can vary in between 0V up to almost the supply voltage in both directions. The motor voltage (resp. the PWM duty cycle) is adjusted within each current control cycle (of typ. 0.1 - 0.01 ms) of the motor controller depending on the currently demanded operating point (i.e. speed and torque) of the motor. Based on the power equation this means that the motor current can (and typically will) be much higher than the input current of the motor controller. The reason for this is that the permanently PWM adapted motor voltage (depending on speed and torque) is lower than the fixed supply voltage (of a battery or power supply).

Power conversion formula:

$$P_{El.Motor} = P_{Input} - P_{Electronics}$$

- $P_{El.Motor} = U_{Motor} * I_{Motor}$
  - U_{Motor} = Voltage applied to the motor. This voltage …
    … is controlled by the PWM duty cycle of the power stage.
    … depends on the motor's speed plus its back EMF.
    … can typically vary in between ($-U_{Supply}$ * 0.9) … 0 V … ($+U_{supply}$ * 0.9)
  - I_{Motor} = RMS motor current which depends on the currently required torque.
    = "Current actual value" reported by maxon's motor controllers.
- $P_{Input} = U_{Supply} * I_{Supply}$
  - U_{Supply} = Fixed voltage (e.g. 24V DC) provided by a power supply or battery.
    (This is the input voltage of the motor controller).
  - I_{Supply} = Output current of the power supply or battery.
    (This is the input current of the motor controller).
- $P_{Electronics}$ = Power consumed (typ. some Watt) by the controller's internal electronics (e.g. I/Os, processor, memory, external sensors & actuators).

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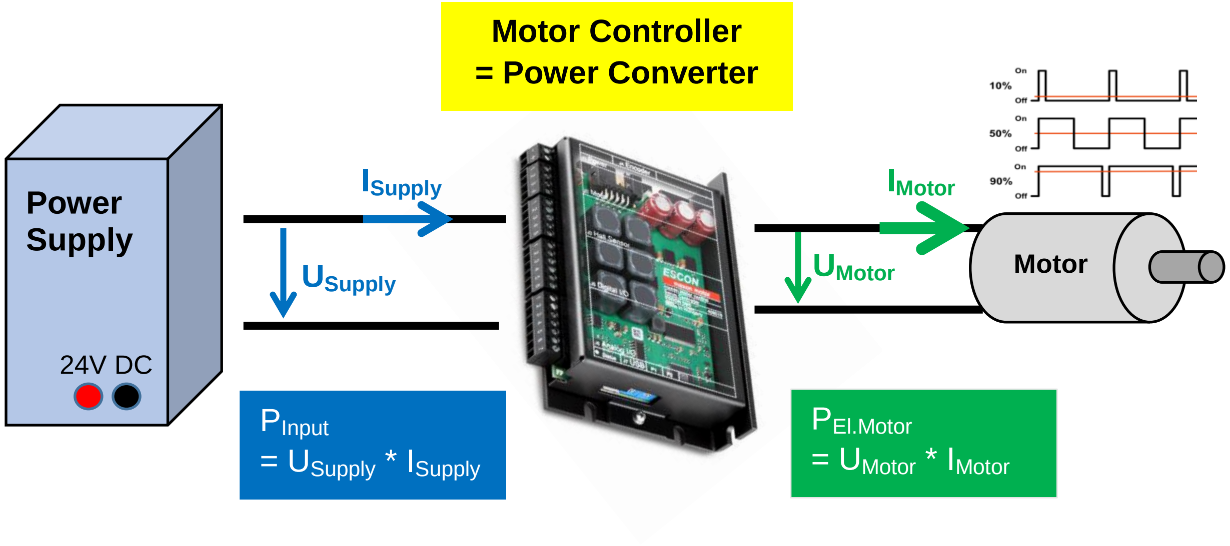
System diagram:



Conclusion / Take-away:

- **The "Input current" of the motor controller** (= output current of the power supply or battery) **does NOT(!!) equal the "Motor current"!**
  - The input current of the motor controller reported by the power supply is correct.
  - The motor current measured and reported by the motor controller is correct.
  - It is not possible to compare these two current values directly because the supply voltage and the motor voltage is different!
- **The power equation counts: $P_{El.Motor} = P_{Input} - P_{Electronics}$**
  - The motor voltage is always lower than the supply voltage.
  - The motor voltage varies permanently at a high frequency and depends on the speed and back-EMF of the motor.
  - The motor current is typically much higher than the current provided by the power supply or battery.

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