Power Ratings and Power Flow through Drives

Variable Frequency Drives are a type of Power Conversion Equipment; therefore understanding the power flow is important.

-- Jim Crook

Sr Staff Electrical Engineer

Overall Principle: Conservation of Energy

- You can’t get more power out than what you put in.

- The source has to supply as much power as you put out, plus a little bit more to handle the conversion process.

- The ratio of the output power to the input power is the Efficiency and can range from 0 to 0.99999.

Three areas of Power Conversion

- Input side: AC to DC rectification
- Output side: DC to AC Inverter
- Mechanical: AC power to mechanical rotating power

“Begin with the end in mind*”

* Stephen Covey, 7 Habits of Highly Effective People.

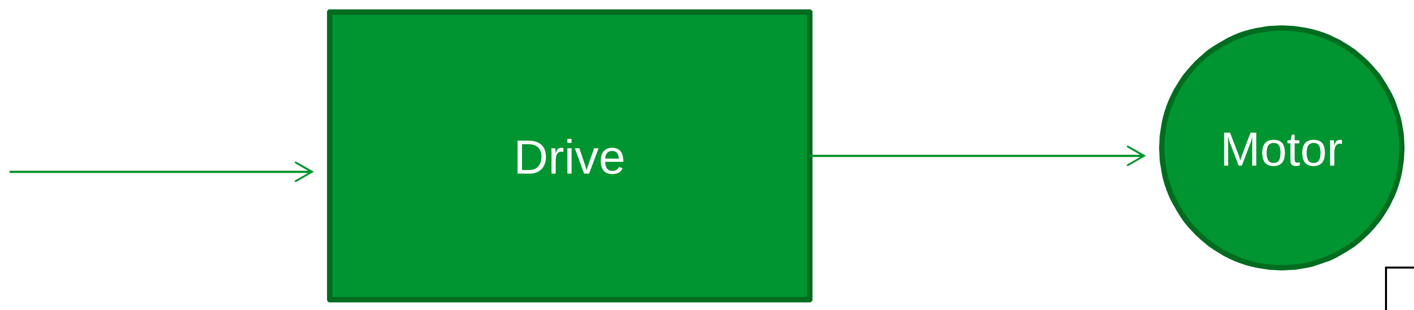
A Motor does electrical to mechanical power conversion

- Mechanical Power:
  - Speed in RPM * Torque in lbf-ft / 5250 => Power in HP
  - Speed in rad/s * Torque in N•m => Power in W

POWER FLOW AT 60 HZ, FULL LOAD

Mechanical Power at full load and speed

- 1750 RPM * 60 lbf•ft / 5250 => 20 HP
- 20 HP * .746 => 14.92 kW



Mechanical Power	
Speed	1750RPM
Torque	60lbf-ft
Power	20HP
Power	14.92kW

Electrical Power to the motor

- Voltage(line to line) * Current * Power Factor * sqrt(3) => Power
- 460 V * 27 A * 0.79 * 1.732 => 16.994 kW   // NEC current
- Motor Efficiency => 14.92 / 16.994 => 87.8%

Electrical Output Power

Voltage	460V
Current	27A
Power Factor	0.79
Power	16.99404kW
Power	22.78021HP

Mechanical Power

Speed	1750RPM
Torque	60lbf-ft
Power	20HP
Power	14.92kW

Power to the Drive

- Voltage * Current * Power Factor * sqrt(3) => Power
- 480 V * 22 A * 0.95 * 1.732 => 17.375 kW //Fundamental of current
- Efficiency => 16.994 / 17.375 => 97.8%

Electrical Input Power

Voltage	480V
Current	22A
Power Factor	0.95
Power	17.37542kW
Power	23.29145HP
Apparent Power	18.28992kVA

Electrical Output Power

Voltage	460V
Current	27A
Power Factor	0.79
Power	16.99404kW
Power	22.78021HP

Mechanical Power

Speed	1750RPM
Torque	60lbf-ft
Power	20HP
Power	14.92kW

Note: input current is less than output current due to PF improvement and higher input voltage.

Input Harmonics affect the RMS current

- The current input of 22 A on the previous slide was for the fundamental frequency only. This is the minimum current to get the power in to the drive. An 18 pulse drive would have a current near this level because of the low harmonics.

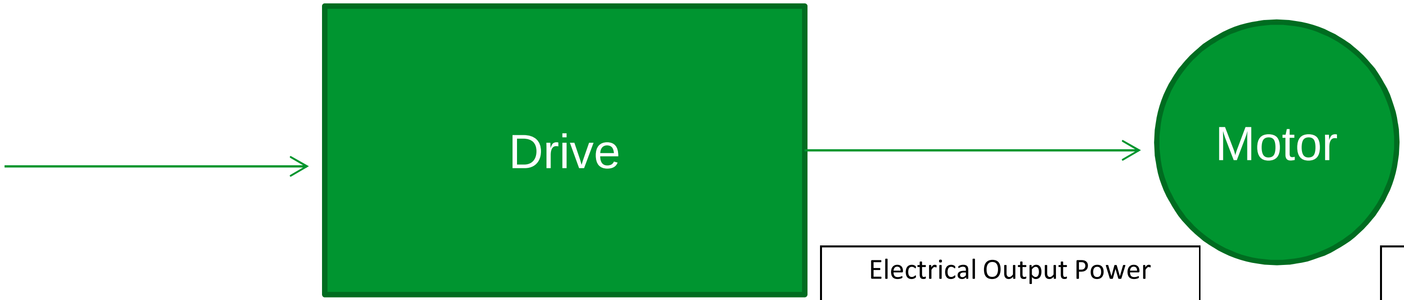
- With the six diode rectification, there will be harmonics, which will add to the rms current.

- Installation Manual for this drive shows a Maximum of 39 A at full load and a 22 kA Prospective short circuit current, running at 480 V ac.

- With a line reactor the actual input current will be between the 22 A minimum and the 39 A maximum, depending on the amount of harmonics in the current waveform.

Single Phase Power to the Drive

- Single phase calculations do not use the sqrt(3).
- Voltage * Current * Power Factor => Power
- 480 V * 38.1 A * 0.95 => 17.374 kW //Fundamental of current
- Efficiency => 16.994 / 17.374 => 97.8%



Electrical Input Power Single Phase	
Voltage	480V
Current	38.1A
Power Factor	0.95
Power	17.374kW
Power	23.289HP
Apparent Power	18.28992kVA

Electrical Output Power	
Voltage	460V
Current	27A
Power Factor	0.79
Power	16.99404kW
Power	22.78021HP

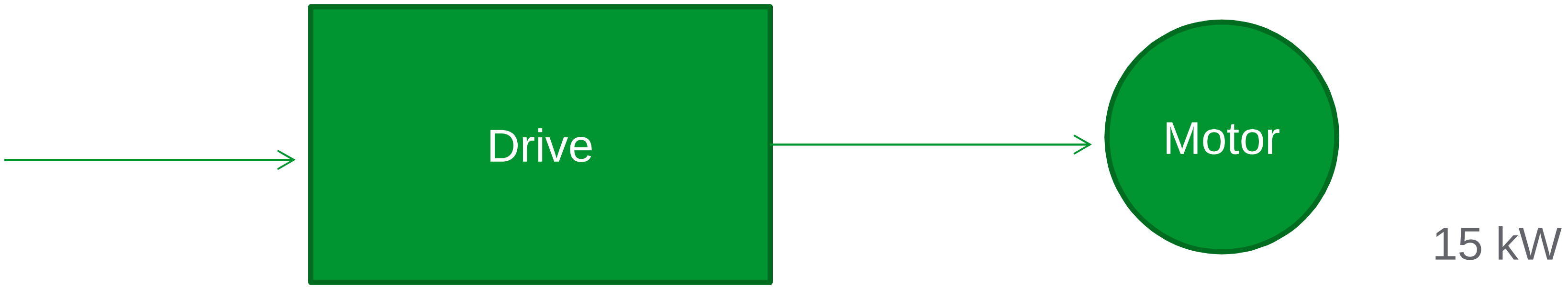
Mechanical Power	
Speed	1750RPM
Torque	60lbf-ft
Power	20HP
Power	14.92kW

Note: Single Phase input current is higher than the 3 phase version by sqrt(3) i.e. 1.732. With the higher harmonics, plan on doubling the size of the rectifier and dc bus capacitance. Some drives may need even more than 2x capacitance.

IEC motors for 400 V, 50 Hz

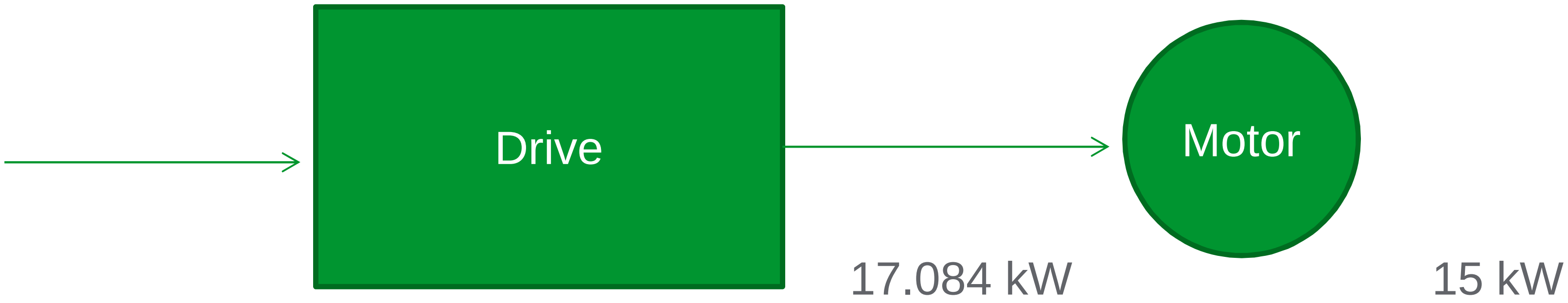
Mechanical Power

- 1458 RPM * 72.4 lbf•ft / 5250 => 20.1 HP
  - Note the Lower speed due to 50 Hz
- 20.1 HP * .746 => 15 kW



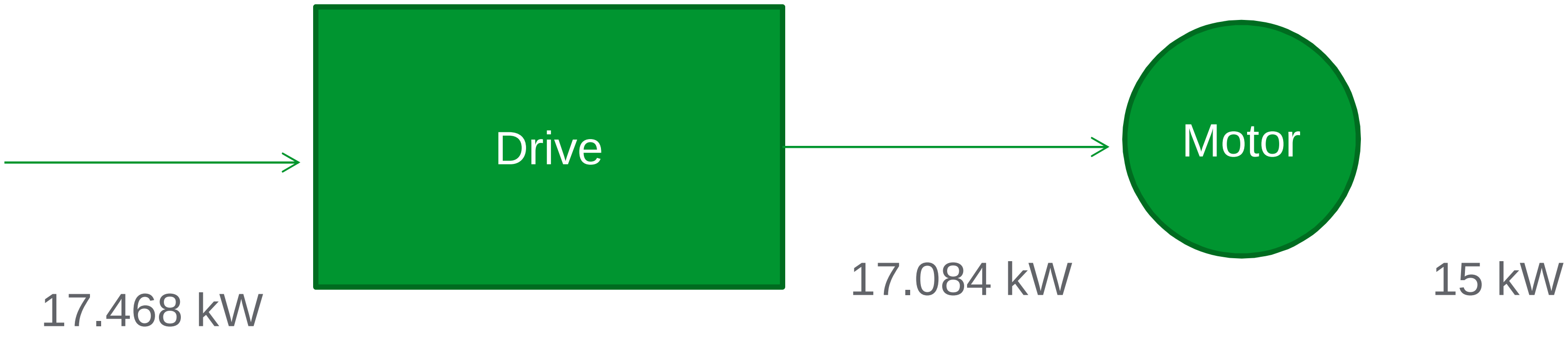
Electrical Power to the motor

- Voltage(line to line) * Current * Power Factor * sqrt(3) => Power
- 380 V * 32.85 A * 0.79 * 1.732 = 17.084 kW
- Motor Efficiency = 15 / 17.084 = 87.8%



Power to the Drive

- Voltage * Current * Power Factor * sqrt(3) => Power
- 400 V * 26.54 A * 0.95 * 1.732 = 17.468 kW
- Efficiency = 17.084 / 17.468 = 97.8%



Comparison of NEMA to IEC

- Even though the output current is allowed to be higher than needed for the 460 V motors, you can see that the power through the drive matches for both environments.

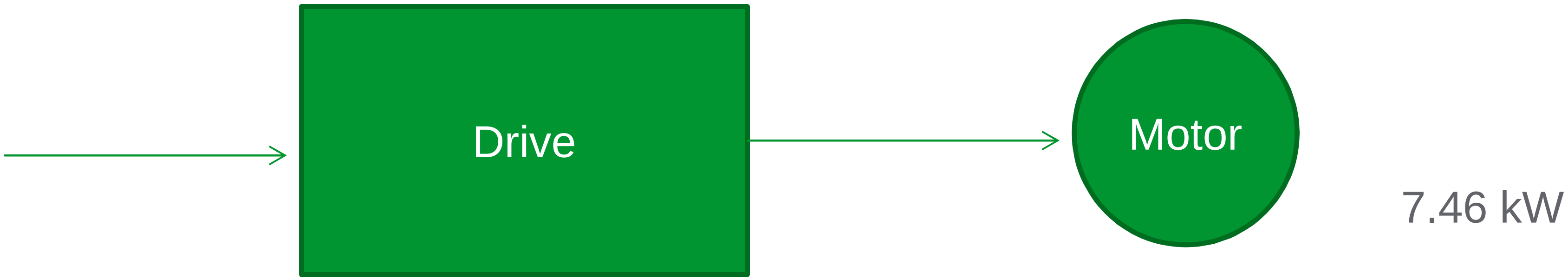
- You can't use the higher output current to go to the next higher power motor, because the input current and the nameplate HP ratings will be exceeded.

	Input	Output	Mechanical
NEMA, UL	17.375 kW	16.994 kW	14.92 kW
IEC	17.468 kW	17.084 kW	15 kW

Let’s run at 30 Hz,
half of the normal speed
Full Torque

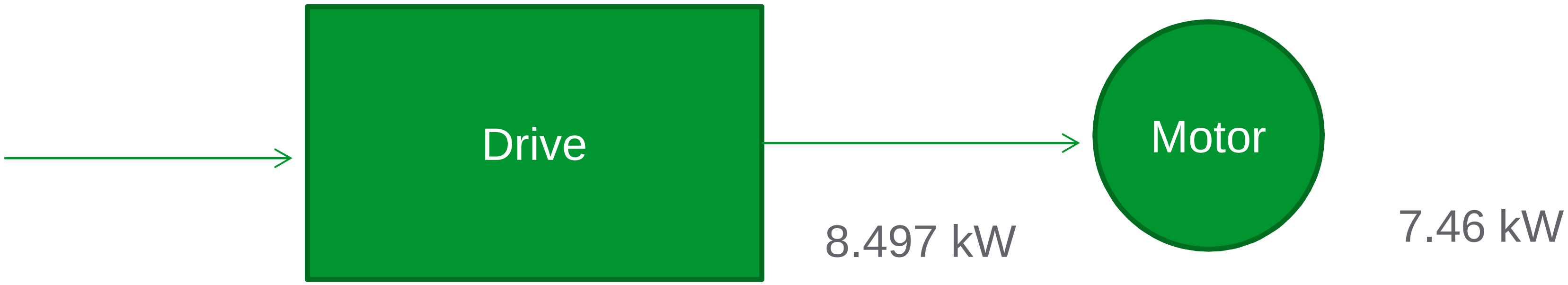
Mechanical Power at half speed

- 875 RPM * 60 lbf•ft / 5250 = 10 HP
- Note: Half speed at full torque is half power
- 10 HP * .746 = 7.46 kW



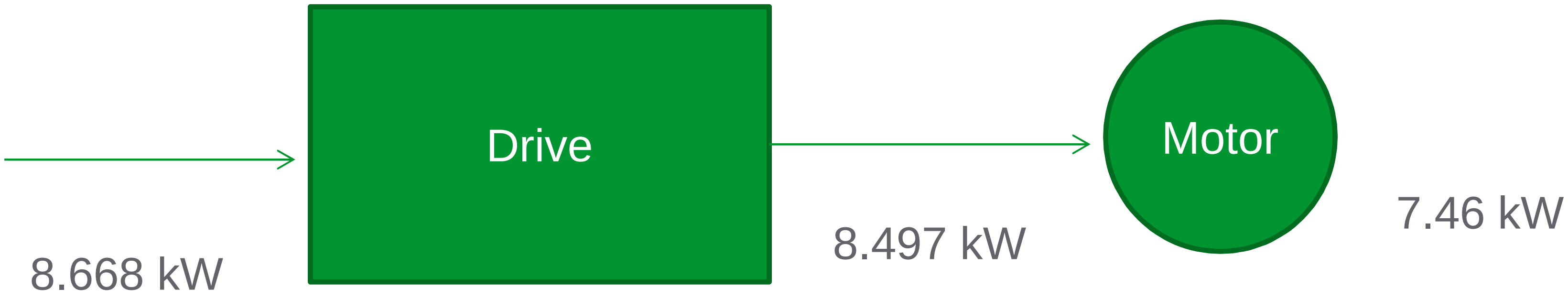
Electrical Power to the motor, half speed

- Voltage(line to line) * Current * Power Factor * sqrt(3) => Power
- 230 V * 27 A * 0.79 * 1.732 = 8.497 kW // Voltage is half at 30 Hz
- Motor Efficiency = 14.92 / 8.497 = 87.8%



Power to the Drive, half speed

- Voltage * Current * Power Factor * sqrt(3) => Power
- 480 V * 11 A * 0.95 * 1.732 = 8.688 kW
- Efficiency = 8.497 / 8.688= 97.8%



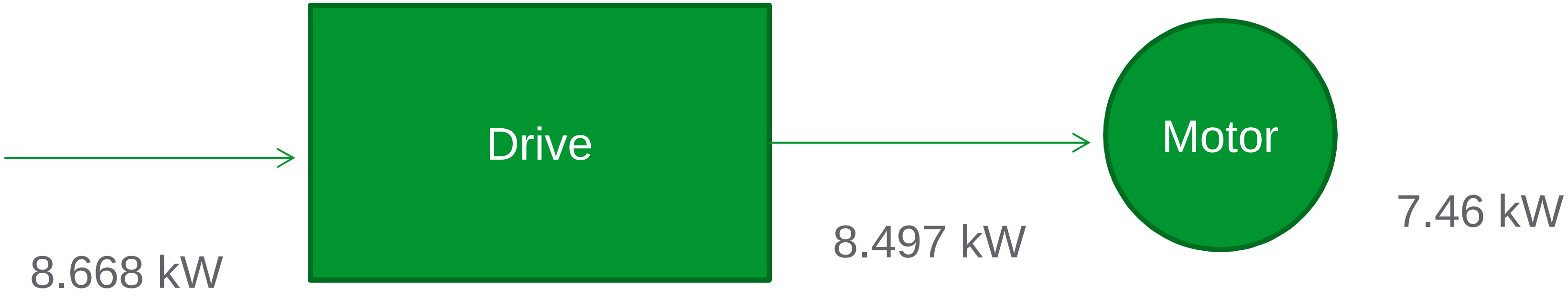
Note: The input current is less than half of the output current. The drive is like an **electronic transformer**: the voltage is cut in half and the current is doubled.

Principle: UL evaluates drives by Voltage and HP

- Nameplate shows Voltage, HP/kW and Current
- The UL file shows Voltage, Maximum Power and Current
- All three limits must be followed. Do not size only by output current.

Power to the Drive, Short Summary

- Convert motor HP to Watts by multiplying by 746 [W/HP]
- Divide by motor efficiency to get the electrical power to the motor.
- Divide by the drive efficiency (~ 0.95 or better at full load) to get input power.
- Divide input power by ($V_{line\ to\ line}$ * sqrt(3)) the get the **fundamental** input current. We can use PF=1 for this estimate. (Actual current will be higher due to harmonics.)



Usage: Power Flow Analysis

- You can use this Power Flow Analysis to make sure that you aren't expecting to create power out of thin air, or make a perpetual motion machine.
- You can use this method to estimate the input and output currents for speeds and loads other than the normal Full Load point.