Transformer Sizing

Line voltage and low voltage power installations.

Industrial electric actuators powered by line voltage (120vac or 230vac) are effectively the standard power option chosen. Wire size, loads, and wire runs can all be readily addressed by installers. Typically, to comply with electrical codes and probably local norms as well, most wiring installations feature either 14ga or 12ga wire providing the electrical interconnect between the actuator and the breaker feed panel (Figure 1).

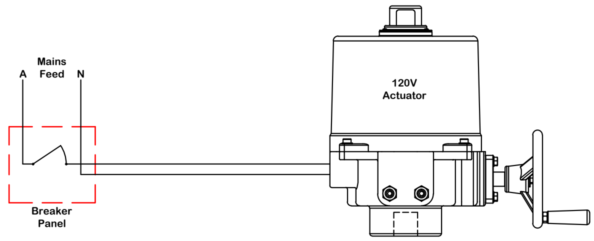

Figure 1
Line voltage actuator electrical installation

Low voltage systems (Figure 2) are a contrast in that they use lower voltage and higher current draws to power similar equipment. Improvements in solar power supplies make using a low voltage system a good option. The higher duty cycle of the low voltage motors is another consideration.

While 24V low voltage devices can be a great solution, the installation will have some important differences from that of a 120vac device -- differences that can be problematic if not addressed properly. This article summarizes a recent training session at ProMation Engineering which addresses these concerns.

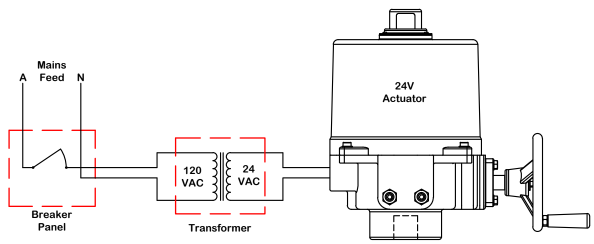

Figure 2
Low voltage actuator electrical installation

What do you use to change voltages between source (Mains) and load (Device)?

A **transformer** (Figure 3) uses a primary electromagnetic field to induce current flow in a secondary electromagnetic field. The result of this process is that the (power) output of the secondary field is transformed to the desired voltage level. In the case of the transformer for a typical laptop computer, the incoming power of 120vac 2A is transformed to 19vDC 6.32A.

A transformer powering an industrial actuator will be a bit more robust, for example, a 500VA rated 24V transformer. This will transform line voltage 120vac, approximately 4.2A into 24V and approximately 20A. VA is Volts x Amps and is the standard rating for transformers. Comparing the laptop computer transformer to the industrial transformer looks like this:

19V x 6.32A = 120VA   **120VA/19V = 6.32A**

24V x 20.83A = 500VA   **500VA/24V = 20.83A**

Figure 3
E300E Industrial Control Transformer

When low voltage actuators are required or specified, several different factors need to be considered that are normally taken for granted in line voltage applications. It is critically important to provide a properly sized transformer to avoid an unwanted drop in voltage, a situation that can cause overheating, stalled motors, and damage to equipment.

A "Properly Sized" transformer: The ability of the power source to provide all the necessary demand of the actuator(s) to overcome the starting current for all connected actuator(s) without "clipping" the output voltage. This includes the efficiency of the device to perform the conversion from line to low voltage.

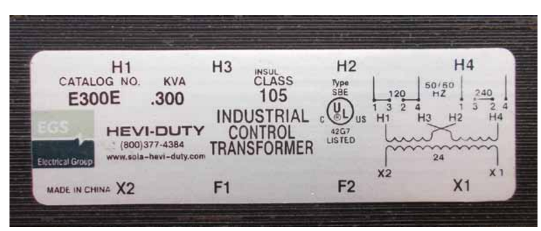

Figure 4
120vac or 230vac input to 24vac output.

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Low voltage considerations for proper transformer sizing:

1. **Inrush (starting current) to get the actuator motor moving at load.**
2. **Running Current, which is typically 5-10 times that of line voltage (120vac) units of the same torque ability.**
3. **Length of wire run (lost due to resistance is more pronounced in low voltage installations).**
4. **VA sizing of Transformers**
5. **How many actuators are going to be connected to a single source?**
6. **Low voltage does NOT necessarily mean you do not need to install wiring runs in conduit.**

Explaining each consideration individually:

1.Inrush (starting current): Increased current draw needed to get the Actuator Motor moving, at load, for EVERY start.

Example 1

For a P5-120N4 actuator from Table 1,the Inrush current (starting current) is 3.8A, and the Running current is 2.0A

Inrush: 120V ,3.8A
Running: 120V, 2.0A

For a similar P5-24N4-AC/DC actuator from Table 2, the Inrush current is 9.0A and the Running current is 7.5A.

Inrush: 24V, 9.0A
Running: 24V, 7.5A

Simply comparing the Inrush (starting) current values you can see the 24V unit draws more than 2x that of the 120vac unit when starting. This increased current load will need larger wire to work properly.

Even though inrush current lasts only a very short span of time, our experience has shown that having an undersized power supply can and will cause issues such as brownouts, motor overheating, slow motor movement, wire heating, and possible permanent motor damage.

2. Running Current: Should always be a lower current draw than the Inrush current. It is worthy of note because the 24v Running current is much larger than that of the 120vac line voltage load. In the example above, the 24v unit draws 4x the current as the 120vac unit when running.

Avoid the mistake of calculating the size of the transformer based on the sum of the running current loads because it can cause a high current situation very quickly.

3. Length of wire run: Every wire has an inherent resistance to the flow of electricity. It is based in part on the diameter of the wire and its length and the electricity will be lost in the form of heat. Common reference tables (Table 3) show voltage drop in copper wire to be approximately 1 ohm per 1000 feet when using 10 gauge wire. The voltage drop per 100 feet of wire is a function of the current load and wire gauge as shown in **equation 1**:

$$V_D = .2 \times I_L \times 1.26^{(AWG-10)}$$

V_D = Voltage drop (Volts per 100 feet)
I_L = Current load (Amps)
AWG = Wire gauge

We have used a similar equation to determine voltage drop by wire gauge to develop our Wire Sizing Charts (Tables 4-7). These charts show the maximum suggested wire run which keeps the voltage loss

Actuator Specifications	P4		P5		P6	
Torque "lb/Nm	3500"lbs/400Nm		4400"lbs/500Nm		5750"lbs/650Nm	
Supply Voltage	120vac	230vac	120vac	230vac	120vac	230vac
Max Inrush Current	3.8A	2.0A	3.8A	2.0A	3.8A	2.0A
Running Current	1.9A	1.1A	2.0A	1.1A	2.1A	1.1A
Motor	Split Phase Capacitor					
Runtime (90°@60Hz/vdc)	16 sec		22 sec		28 sec	
Runtime (90°@50Hz)	18 sec		25 sec		31 sec	
Duty Cycle	25%					
Motor Starts	1200 per hour					
Weight	47lbs/22kg					

Table 1

Actuator Specifications	P4		P5		P6	
Torque "lb/Nm	3500"lbs/400Nm		4400"lbs/500Nm		5750"lbs/650Nm	
Supply Voltage	12vac/vdc	24vac/vdc	12vac/vdc	24vac/vdc	12vac/vdc	24vac/vdc
Max Inrush Current	16.1A	9.2A	13.5A	9.0A	12.5A	8.5A
Running Current	16.1A	8.5A	14.1A	7.5A	12.3A	7.0A
Motor	DC Brush Type					
Runtime (90°@60Hz/vdc)	16 sec		22 sec		28 sec	
Runtime (90°@50Hz)	16 sec		22 sec		28 sec	
Duty Cycle	75%					
Motor Starts	1200 per hour					
Weight	47lbs/22kg					

Table 2

AWG gauge	Conductor Diameter Inches	Ohms per 1000 ft.	Maximum amps for chassis wiring	Maximum amps for Power Transmission
OOOO	0.46	0.049	380	302
OOO	0.4096	0.0618	328	239
OO	0.3648	0.0779	283	190
0	0.3249	0.0983	245	150
1	0.2893	0.1239	211	119
2	0.2576	0.1563	181	94
3	0.2294	0.197	158	75
4	0.2043	0.2485	135	60
5	0.1819	0.3133	118	47
6	0.162	0.3951	101	37
7	0.1443	0.4982	89	30
8	0.1285	0.6282	73	24
9	0.1144	0.7921	64	19
10	0.1019	0.9989	55	15
11	0.0907	1.26	47	12
12	0.0808	1.588	41	9.3
13	0.072	2.003	35	7.4
14	0.0641	2.525	32	5.9
15	0.0571	3.184	28	4.7
16	0.0508	4.016	22	3.7

Table 3

Wire resistance (Ohms/1000ft) as a function of Wire Gauge

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at or below 10%. The wire run tables published in our literature use typical resistance tables for calculating wire run lengths.

The typical Wire Sizing Chart shows the supply voltage by product (columns) as related to the wire gage. Generally the larger the wire, the longer the run can be. (Note: 8ga wire has a larger diameter than 10ga wire.) Using smaller wire than listed is not recommended. Using larger wire is usually an option but consider the terminal lug sizes for your installation and the added cost of the additional copper wire.

Example 2

If using a 120vac P5 actuator(table 4), reading from the wire sizing tables you conclude that you can run roughly 552 feet with 14ga THHN copper wire, and up to 844 feet if using 12 ga wire of the same type. The wire run tables published in our literature use typical resistance tables for calculating wire run lengths.

But if using a 24vac P5 actuator(table 5), reading from the product specification tables you conclude that you can run only 181 feet with 8ga THHN copper wire, and only 121 feet using 10 ga wire of the same type.

Example 3

If you installed a 120v actuator and wired it using 14ga wire(table 6), you could reliably operate the actuator up to 552' away from the breaker panel.

But if you decided to change that same actuator to a 24V unit(table 7), and you did NOT change the interconnect wire gage, you could only run 47 feet away from the power source!! (less than 10% of the original distance).

4. VA sizing of Transformers: Next, consider the sizing of the transformer or power supply. The 24V P5 used in Example 3 requires 9.0A inrush, and 7.5A to run the actuator. Reminder, this is power required AT the actuator, at the END of the wire length.

The easy part of the math is to multiply the actuator Starting current requirement by the actuator voltage rating.

Inrush: 24V x 9.0A = 216VA
Running: 24V x 7.5A = 180VA

Most transformer manufacturers make standard sizes, and you'd most likely use a 250VA transformer. Working backwards, the 250VA transformer will provide up to 10.4A @ 24vac. Looks like a good solution.

5. Number of actuators (load): The load is every device connected to the secondary of the power supply. Every load attached to the transformer must be calculated V x A and added together, using the starting current value for A.

Using the 24V P5 used in Example 3, which requires 9.0A inrush, and 7.5A to run the actuator, how big of a transformer is required to power 2 of the same actuators?

Inrush: 24V x 9.0A = 216VA
216VA x 2 = 452VA

As you consider using a larger transformer always remember to consider whether the line voltage protection (relays, breakers, etc.) can supply the required amperage.

Wire Sizing Chart

Actuator	P4		P5		P6	
	MAX distance between Actuator and Supply (feet)					
Voltage	120VAC	230VAC	120VAC	230VAC	120VAC	230VAC
Wire Gage / Amps	3.8A	2.0A	3.8A	2.0A	3.8A	2.0A
16	342	1245	342	1245	342	1245
14	552	2010	552	2010	552	2010
12	844	3075	844	3075	844	3075
10	1435	5227	1435	5227	1435	5227
8	2142	7802	2142	7802	2142	7802

Table 4

Wire Sizing Chart

Actuator	P4		P5		P6	
	MAX distance between Actuator and Supply (feet)					
Voltage	12VAC/VDC	24VAC/VDC	12VAC/VDC	24VAC/VDC	12VAC/VDC	24VAC/VDC
Wire Gage / Amps	16.1A	9.2A	13.5A	9.0A	12.5A	8.5A
16	-	28	-	29	-	31
14	-	46	16	47	17	49
12	20	70	24	71	26	75
10	34	119	40	121	44	128
8	51	177	60	181	65	192

Table 5

Wire Sizing Chart

Actuator	P4		P5		P6	
	MAX distance between Actuator and Supply (feet)					
Voltage	120VAC	230VAC	120VAC	230VAC	120VAC	230VAC
Wire Gage / Amps	3.8A	2.0A	3.8A	2.0A	3.8A	2.0A
16	342	1245	342	1245	342	1245
14	552	2010	552	2010	552	2010
12	844	3075	844	3075	844	3075
10	1435	5227	1435	5227	1435	5227
8	2142	7802	2142	7802	2142	7802

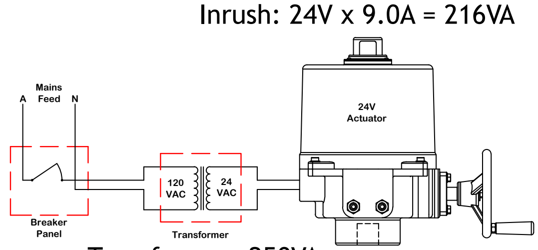
Table 6

Wire Sizing Chart

Actuator	P4		P5		P6	
	MAX distance between Actuator and Supply (feet)					
Voltage	12VAC/VDC	24VAC/VDC	12VAC/VDC	24VAC/VDC	12VAC/VDC	24VAC/VDC
Wire Gage / Amps	16.1A	9.2A	13.5A	9.0A	12.5A	8.5A
16	-	28	-	29	-	31
14	-	46	16	47	17	49
12	20	70	24	71	26	75
10	34	119	40	121	44	128
8	51	177	60	181	65	192

Table 7

Inrush: 24V x 9.0A = 216VA



Transformer: 250VA

Figure 5
Transformer Sizing based on Inrush current and wire size and length of run

Continued on Page 4

6. Low Voltage Conduit: Low voltage wires are susceptible to heat just like line voltage wires.

Wires can get hot if a component draws too much amperage. Placing wires in conduit as a precaution against fire is an insurance policy.
Using the tables we've amassed so far, you can run the calculations very easily to check if everything will work as designed.

Example 4

Assess this proposed installation:
Model: A single P5-24V on/off actuator, 9.0A inrush, 7.5A running current, 100' 10ga wire, using a 250VA 24V transformer.

250VA/24V = 10.42A

Transformer provides up to 10.4A at a full 24vac, required is 9.0A inrush, so the transformer is sized correctly.

Interconnect is 10ga copper wire 100' long. Using equation 1 (Page 2), the voltage drop at the END of the 100' 10ga (during the START sequence).

$$V_D = .2 \times I_L \times 1.26^{(AWG-10)}$$
$$V_D = .2 \times 9.0A \times 1.26^{(10-10)}$$
$$V_D = .2 \times 9.0A \times 1 = 1.8vac$$

So AT the actuator, you will get 22.2VAC.

24vac - 1.8vac = 22.2vac

The actuator is rated for 24vac +/-10%, so it can drop down to (24vac * 90%) = 21.6V.

The 10ga wire will work correctly at 100' and the actuator will provide the full rated torque.

Transformer, actuator, wire gage and length, will all perform as designed.

This example is all based on a SINGLE actuator connected to the transformer.

Key Takeaways for using / sizing transformers.....

- Use INRUSH current for sizing instead of RUNNING current.
- Separate actuator power supplies from non-inductive load devices (sensors, PLC, etc).
- Carefully consider wire gage as a function of installed CONDUIT wire run length.
- Be cognizant of the dangers of parallel wiring of on/off actuators, regardless of actuator voltage.
- Conduit may not be required by code but can be useful as a safety precaution.

Quiz/Discussion:

- Can you swap out a 120vac actuator and replace it with a 24vac?
- Can you swap out a 24vac actuator and replace it with a 120vac?
- What happens when you connect multiple actuators or devices to the same transformer?

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