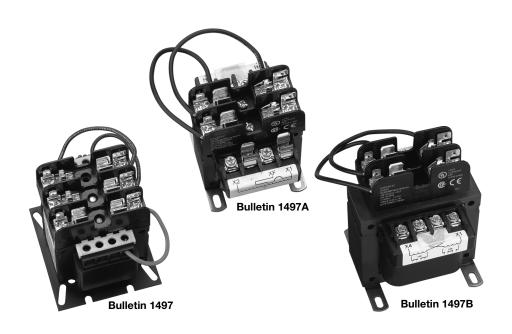


# PROPER SELECTION OF CONTROL CIRCUIT TRANSFORMERS

# **BULLETIN 1497, 1497A, AND 1497B CONTROL CIRCUIT TRANSFORMERS**

The proper selection of the control circuit transformers is important for suitable operation and proper function of electromagnetic devices. This paper outlines the importance of proper selection of control circuit transformers. It discusses both the key considerations and two methods of selecting transformers.





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# What is a Control Circuit Transformer?

# Inrush Volt-Ampere and Sealed Volt-Ampere Considerations

A control circuit transformer is a device designed to provide a reduced control voltage for energizing the coils of electromagnetic devices such as motor starters, contactors, relays, and timers. These devices make up the majority of the loads supplied by the control circuit transformer. Control circuit transformers are also referred to as Industrial Control Transformers, Machine Tool Transformers, and Control Power Transformers.

The proper size, or the VA rating, of the control circuit transformer is important. It will be a determining factor in the life of the transformer, which ultimately will reflect on the proper operation of control devices that it supplies. The methods of selecting transformer VA ratings addressed in this technical paper are applicable to 50...3000 VA control circuit transformers.

The transformers used in this application fall into the dry type insulation category. Typical primary voltages in the United States are 600, 480, 240, and 208. Transformers can also be manufactured with special primary and secondary voltage combinations.

There are two VA values to be considered when selecting a transformer. Energizing electromagnetic components creates a large momentary surge current, commonly referred to as inrush VA. This is the first VA value to be considered. The inrush VA will last approximately 5...20 milliseconds and can have a value as high as ten times the transformer's nameplate rating. Thus, the inrush VA will be high in value and short in duration. A properly selected control circuit transformer is designed to handle the momentary inrush VA and at the same time maintain a secondary voltage within a set range.

The second value to be considered is the sealed VA, the amount of volt-amperes required to maintain the energized state of an electromagnetic device. This VA requirement will be 5...10 times less than the inrush VA.

In the United States, compliance with NEMA Standard ICS 2-110 is another important consideration. The NEMA Standard requires the alternating current contactor to successfully close at 85% of its coil rated voltage. For example, an alternating current contactor with 120 volt rated coil must be able to successfully close at 102 volts which is 85% of its rated voltage.

When a transformer is used with a contactor or starter, the contactor or starter must successfully pick-up at 90% of the rated line voltage of the transformer. The purpose of this NEMA Standard requirement is to:

- **1.** Establish a standard or policy for the operation of the control device.
- **2.** Coordinate values for the control device and the control circuit transformer.
- **3.** Set known limits to address the inherent transformer voltage drop due to the inrush current from an unsealed alternating current electromagnet.

For example, a transformer with a rated line voltage of 480 volts, a rated secondary voltage of 120 volts, and an operating voltage at 90% of the line voltage would have 432 volts on the primary of the transformer. This would result in a theoretical 108 volts on the secondary, based on the turns-ratio, assuming no voltage drop through the transformer. Properly selected transformers must limit the voltage drop under inrush conditions such that 95% of the rated secondary voltage occurs with 100% of the rated line voltage applied. Combining these two conditions result in a secondary voltage of approximately 102 volts which meets the contactor pick-up requirement.

# Secondary Voltage Considerations

The secondary voltage that is present when a light load or no load is attached to the transformer should also be considered. Open circuit secondary voltages (no load) can be 10% higher than nominal with nominal input voltages applied. This means that a 480...120 volt transformer with full 480 volts applied to the primary, can have 132 volts available at the secondary terminals. When you add the effect of high line input condition (528 volts) to this output, the secondary can reach over 145 volts. This is a worst case condition, but not out of the question. This makes it even more important to size the transformer correctly for the application and understand that the secondary voltage is designed to be nominal rated voltage when loaded to the nameplate VA. Oversizing the transformer only serves to make this condition worse.

# 600V Primary Device Considerations

The Allen-Bradley Bulletin 1497, 1497A, and 1497B transformer product line includes primary voltage ratings that span from 115...600V AC. Special design attention has been applied to the 575...600V AC designs to address the potential failure of 600V units when exposed to line aberrations or events such as surges and spikes frequently caused by switched capacitor banks or the connection of certain types of electrical equipment, such as welders and plating equipment, to the circuit.

In general, standard transformer construction for a 600V AC primary design tends to be more susceptible to these problems than lower primary designs. Allen-Bradley Bulletin 1497, 1497A, and 1497B 600V units have been strengthened in terms of insulating materials and winding separation to provide a robust product capable of withstanding all but the most severe of these frequently encountered line conditions.

# Long Wire Runs Considerations

Another consideration in the selection of the transformer is long wire runs. These occur if the control devices requiring power are located away from the transformer. When a long wire run is present, the resistance and capacitance cause a voltage drop to the control device. If the voltage drop is severe enough, the control device may not pick-up. To address this, the transformer must be selected taking this voltage drop into account. An interposing relay may also be required. Voltage drop calculators are available from numerous internet sites.

# Control Circuit Transformer Selection Methods

# Method I: Short and Conservative Means of Selecting Control Circuit Transformers

Method 1 provides a short and conservative means that will yield a sufficiently sized transformer. Assuming that all control devices, including the transformer, are located within the same unit, the steps are as follows:

- 1. Calculate the total sealed volt-ampere burdens of all the devices that could be sealed at any one time;
- **2.** Multiply the value from Step 1 by 1.25;
- 3. Calculate the maximum inrush volt-amperes of the closing device or devices;
- **4.** Add the maximum inrush volt-amperes of closing device or devices calculated in Step 3 to the required sealed VA calculated in Step 2;
- **5.** Divide the maximum VA calculated in Step 4 by 4.

Using the larger of the two values calculated in Steps 2 and 5, select a transformer whose VA rating is:

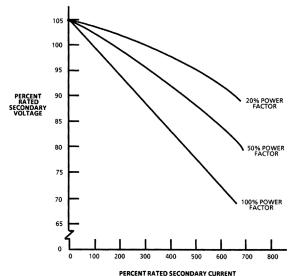
- Closest to, but not lower than, the larger calculated value; and
- Greater than the total sealed VA requirement

The above method of selecting a transformer is only applicable to Allen-Bradley Bulletin 1497, 1497A, and 1497B control circuit transformers. Many standard transformers from other manufacturers are built to different manufacturing standards and have higher losses (lower output voltage) and thus, would require larger VA ratings than calculated by this method.

# Method II: Detailed Procedure of Selecting Control Circuit Transformers

Method 2 is a detailed procedure of selecting a control circuit transformer for a single relay or contactor and is important when other considerations are required, such as, high operating temperatures and long wire runs. When using this method of selection, technical data such as load operating temperature, frequency, impedance, reactance and resistance may be needed for load devices. However, this type of data is proprietary for many manufacturers. The specific transformer application will determine the data actually needed for proper selection of a control circuit transformer.

Transformer regulation curves are required for proper selection of transformers. Each transformer has a regulation curve for different power factors. The complete family of transformer regulation curves, which are available from the manufacturer, may be necessary to select the proper transformer. Examples of transformer regulation curves are shown in Figure 1.



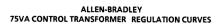
**Figure 1. Transformer Regulation Curves** 

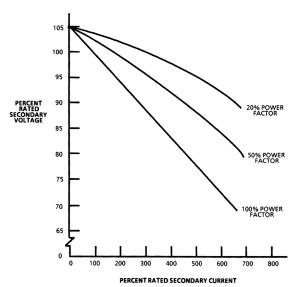
In order to determine if the size or VA rating of a particular transformer is acceptable, an inrush impedance load line for the load must be calculated and then plotted on the transformer regulation curves. The power factor of the load must also be determined. The point where the load's power factor curve intersects the impedance load line is needed to determine if the percent rated secondary voltage of the particular transformer is acceptable. If not, the procedure is repeated using the regulation curves of a different VA rated transformer.

Allen-Bradley Bulletin 1497, 1497A and 1497B transformers properly applied will provide the 85% minimum secondary voltage per NEMA standards with 90% of the rated voltage on the primary. As discussed earlier, this condition is met if under inrush conditions the secondary voltage is not allowed to drop below 95% of its rating with 100% of the rated voltage on the primary.

The following example (Figure 2) uses the Allen-Bradley Bulletin 1497 75VA transformer regulation curves.

Figure 2. Allen-Bradley Bulletin 1497 75VA Transformer Regulation Curves





Given: Load = Allen-Bradley Bulletin 509 Size 1 starter

Assume: Cold coil resistance =  $53.4\Omega$  @  $20^{\circ}$ C Inrush VA = 192

Coil rated voltage = 120V @ 60 Hz

### Calculations:

Starter inrush current @ 100% secondary voltage (II):

$$I_{I} = VA_{Inrush} \div V_{Sec}$$
$$= 192 \div 120$$
$$= 1.6A$$

Impedance of load @ 20°C (Z):

$$Z = V_{Sec} \div I_{I}$$
$$= 120 \div 1.6$$
$$= 75\Omega$$

Reactance of load @ 20°C (X):

$$X = (Z^{2} - R^{2})^{1/2}$$

$$= ((75)^{2} - (53.4)^{2})^{1/2}$$

$$= 52.67\Omega$$

Percent power factor of load @ 20°C (PF):

$$PF = (R \div Z) \times 100$$
  
= (53.4 \div 75) \times 100  
= 71.2%

The impedance load line, to be calculated, must intersect the 75VA transformer regulation curve at the calculated power factor of 71.2%, and at 95% of rated secondary voltage in order to be acceptable. Two points are calculated to establish the impedance load line.

Rated secondary current (I<sub>Sec</sub>):

$$I_{Sec} = VA \div V_{Sec}$$
  
= 75 ÷ 120  
= 0.625 A

Percent rated secondary current @ 100% secondary voltage (%I<sub>Sec</sub>):

$$\%|_{Sec} = (|_{1} \div |_{Sec}) \times 100$$
  
= 1.6 ÷ 0.625 × 100  
= 256%

At 100% rated secondary voltage the percent rated secondary current is equal to 256%. This data locates the upper point of the impedance load line.

Starter inrush current @ 70% secondary voltage (II1):

$$I_{11} = I_1 \times .7$$
  
= 1.6 × .7  
= 1.12 A

Percent rated secondary current @ 70% secondary voltage (%I<sub>Sec1</sub>):

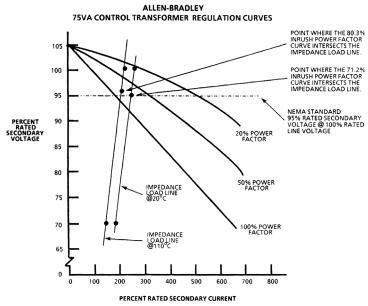
$$I_{Sec1} = (I_{11} \div I_{Sec}) \times 100$$
  
=  $(1.12 \div 0.625) \times 100$   
=  $179.2\%$ 

At 70% rated secondary voltage the percent rated secondary current is equal to 179.2%. This data locates the lower point of the impedance load line.

Draw the load line between these points.

Referring to Figure 3, locate the 71.2% inrush power factor on the load line, by interpolating between the regulation curves. This point can be read on the vertical axis, as the transformer's rated secondary voltage (in %) occurring during inrush. It should be 95% or higher. In this example, it is approximately 95.5 percent, and the application is acceptable.

Figure 3.



However, if this starter was operated after its coil had reached operating temperature or was operated in a jogging or plugging application, the calculations would have to take into consideration the elevated coil temperature.

Using the data from the previous example and the additional data following, the calculations would be as follows:

Assume: Hot coil operating temperature = 110°C

Calculations:

Coil resistance at 110°C (R):

R = 
$$((234.5 + T_2) \div (234.5 + T_1)) \times R_{@20^{\circ}C}$$
  
=  $(344.5 \div 259.5) \times 53.4$   
=  $70.9$ Ω

Reactance of load @ 110°C (X):

$$X = X_{@20^{\circ}C}$$
$$= 52.67\Omega$$

Impedance of load @ 110°C (Z):

$$Z = (X^2 + R^2)^{1/2}$$
  
=  $((52.67)^2 + (70.9)^2)^{1/2}$   
=  $88.3\Omega$ 

Starter inrush current @ 100% secondary voltage @ 110°C (I<sub>12</sub>):

$$I_{12} = V_{Sec} \div Z$$
  
= 120 \div 88.3  
= 1.36A

Percent power factor of load @ 110°C (PF):

PF = 
$$(R \div Z) \times 100$$
  
=  $(70.9 \div 88.3) \times 100$   
=  $80.3\%$ 

The impedance load line, to be calculated, must intersect the 75VA transformer regulation curve at the calculated power factor of 80.3% and at 95% of the rated secondary voltage in order to be acceptable. Two points are calculated to establish the impedance load line.

Percent rated secondary current @ 100% secondary voltage @ 110°C (%I<sub>Sec2</sub>):

$$\%I_{Sec2} = (I_{12} \div I_{Sec}) \times 100$$
  
= 1.36 \div .625 \times 100  
= 217.6%

At 100% rated secondary voltage, the percent rated secondary current is equal to 217.6%. This data locates the upper point of the impedance load line.

Starter inrush current @ 70% secondary voltage @ 110°C (II3):

$$I_{13} = I_{12} \times .7$$
  
= 1.36 × .7  
= 0.95A

Percent rated secondary current @ 70% secondary voltage @  $110^{\circ}$ C (% $I_{Sec3}$ ):

$$\%I_{Sec3} = (I_{13} \div I_{Sec}) \times 100$$
  
= .95 ÷ .625 × 100  
= 152%

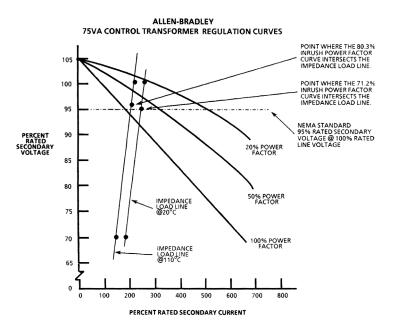
At 70% rated secondary voltage at 110°C, the percent rated secondary current is equal to 152%.

This data locates the lower point of the impedance load line.

Draw the load line between these points.

Referring to Figure 4, locate the 80.3% inrush power factor on the load line by interpolating between the regulation curves. This point can be read on the vertical axis as the transformer's rated secondary voltage (in %) occurring during inrush. It should be 95% or higher. Note that in this application the percent rated secondary voltage is approximately 96%, taking into account the power factor shift and increase in operating temperature. Again, this application, using the 75VA control transformer, is acceptable.

Figure 4.



# European Common Market Considerations

The requirements for industrial control circuit transformers to be used in the European Common Market are identified by the International Electrotechnical Commission (IEC) and specified under EN61558, non-short-circuit-proof isolating transformers, under the Low Voltage Directive 73/23/EEC. Manufacturers of control circuit transformers indicate compliance with these requirements by placing a CE mark on the product. The EN61558-2 standard replaces the previous EN60742 standard. The EN60742 standard expired December 31, 2003. However, some manufacturers still carry the CE mark based on the expired EN60742 standard. Thus, care should be taken when purchasing control circuit transformers that will be used in the European Common Market.

Furthermore, many manufacturers place the CE mark on the control circuit transformers based on Self-Certification. In such instances, before drawing up the EC Declaration of Conformity, the manufacturer must ensure that certain technical documentation is available for inspection purposes. In accordance with the European Union, this

documentation is called a "Technical File," and it is a principle means of accessing product conformity. For specific details regarding the contents of a Technical File, refer to the European Union Guidelines on the Application of Directive 73/23/EEC.



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Fortunately, one sure way of knowing that control circuit transformer comply with the most current EN61558-2 standard is that in addition to the CE mark, the product will contain a third party certification (e.g., TÜV Rheinland mark). The TÜV Reinland mark certifies that the control circuit transformer has been third-party tested by TÜV Rheinland to standards accepted by the European Common Market. TÜV is a Notified Body that may make a report in accordance with the provisions of Article 8 or give an opinion in accordance with the provisions of Article 9 of Directive 73/23/EEC. Refer to the European Union LVD Notified Bodies under 73/23/EEC for a listing of Notified Bodies.

# **Summary**

This paper has outlined the importance of properly selecting control circuit transformers. The considerations for selecting transformers are inrush VA, sealed VA, compliance with NEMA standards, and the effect of long wire runs. Two methods of selecting transformers were presented. First, a conservative method, applicable to the Allen-Bradley Bulletin 1497, 1497A, and 1497B control circuit transformers used in conjunction with multiple loads, was discussed. Second, a more detailed and precise method used only in conjunction with a single relay or contactor, requiring technical application information and transformer regulation curves, was discussed. Finally, this paper discussed key considerations for utilizing control circuit transformers in the European Common Market.

The proper selection of the control circuit transformers is important for suitable operation and proper function of electromagnetic devices.

Notes:

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