PQTN APPLICATION

Power Quality Testing Network

Powering Industrial Equipment
Utilization Voltage Matching
Voltage Regulation

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Using Buck-Boost Transformers to Match Equipment Voltage and Increase Sag Tolerance

Application

Versatile and affordable, the buck-boost transformer has many applications in the typical industrial environment. As shown in Figure 1, a typical buck-boost transformer has dual primary and dual secondary windings. The two identical primary windings are available in 120-, 240-, and 480-volt ratings. The two identical secondary windings are available in low voltages such as 12-, 16-, 24-, and 48-volt ratings.

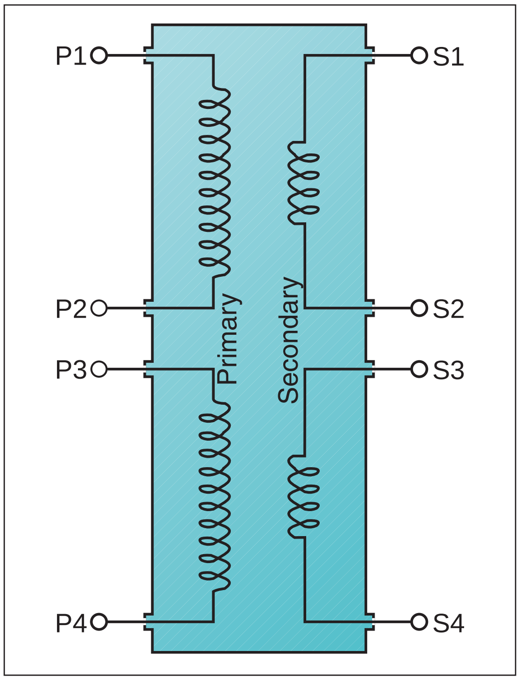

Figure 1. Typical Buck-Boost Transformer with Two Primary Windings, Two Secondary Windings, and Eight Terminals

Buck-boost transformers are versatile because their terminals may be field-connected in many ways to meet the voltage requirements of industrial equipment, including connection as a standard fully isolated transformer. As shown in Figure 2 (page 2), a buck-boost transformer can also be field-connected as an auto transformer, which can either decrease (buck) or increase (boost) the supply voltage from five to twenty percent, depending on the way the primary and secondary windings are connected. Because only the secondary windings carry load current in an autotransformer configuration, a buck-boost transformer can supply a load rated as much as ten times higher than the kVA rating on the transformer nameplate. And although buck-boost transformers are single-phase, they can be applied to most three-phase equipment by matching three single-phase transformers.

As an autotransformer, the buck-boost transformer has two principal applications in an industrial environment. First, it can be used to match an existing utilization voltage to equipment voltage. For example, consider overseas equipment requiring a utilization voltage that is not available at the point of use. Because a buck-boost can be configured as an autotransformer, it can match this load to an existing power supply. Such a transformer would be smaller and therefore considerably less expensive than a step-up or step-down isolation transformer.

Second, a buck-boost transformer can be used to boost voltage to certain equipment to mitigate the effects of minor voltage sags. The ability of sensitive equipment to ride through even minor voltage sags is greatly compromised when the voltage at the equipment terminals is near the low end of the nominal voltage range in ANSI Standard C84.1 (see Table 1). Increasing the utilization voltage to the upper end of the ANSI standard may be an inexpensive way to increase equipment sag tolerance.

Table 1. Ranges for U.S. Utilization Voltages (Taken from ANSI Standard C84.1)

Nominal Utilization Voltage (Vrms)	*Voltage Range (Vrms)*		
	Maximum	*Minimum*	*Minimum**
115	126	110	108
200	218	191	187
230	252	220	216
460	504	440	432
575	630	550	540

*Non-Lighting Circuit

Utilization voltages can also be adjusted via no-load tap changers on existing step-down service transformers. However, changing these taps interrupts the power to *all* transformer loads. Therefore, entire processes within a facility must be shut down during tap changes. Additionally, changing the taps of the service transformers will affect terminal voltages throughout the plant, potentially increasing voltages at equipment that do not require a higher voltage. Finally, such a wholesale increase in utilization voltage may make loads that are not vulnerable to voltage sags vulnerable to overvoltages, possibly resulting in insulation stress, overheating, and component failure.

This PQTN Application describes ways to properly match the rated voltage of equipment to the available supply voltage and to increase the sag tolerance of equipment. By applying a buck-boost transformer as an autotransformer, an industrial facility can treat only those loads that need it.

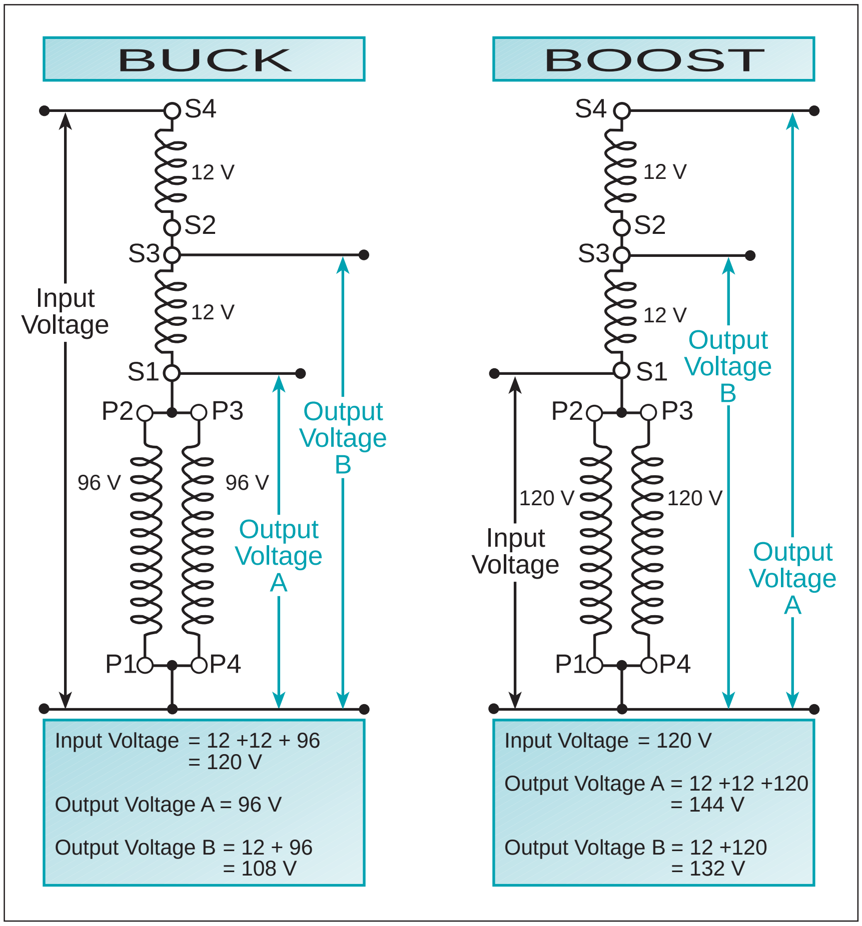

Figure 2. A buck-boost transformer with two twelve-volt windings can be used to buck 120 volts down to 96 volts or 108 volts. The same transformer can be used to boost 120 volts up to 144 volts or 132 volts.

WHAT TO LOOK FOR

Consider using a buck-boost transformer when one of the following symptoms exists:

- Equipment nameplate voltage does not match a supply voltage available at the point of use. For example, a 230-volt motor is connected to a 208-volt supply.
- Equipment such as high-intensity discharge (HID) lighting, motor contactors, and other process controllers drop out during minor voltage sags while other equipment and devices ride through the sags.
- Equipment that is powered by long cables shut down during voltage sags.
- The utilization voltage at equipment is near the low end of the ANSI C84.1 range. For example, the voltage at the terminals of a 120-volt motor-control center is measured at 108 volts.

HOW TO SELECT A BUCK-BOOST TRANSFORMER

To Match Available Voltage to Equipment

Select a buck-boost transformer to match the available voltage to the equipment voltage rating by following these six steps:

Step 1 Measure the voltage available at the equipment terminals.

Step 2 Read the nameplate data to determine the rated voltage and current of the equipment.

Step 3 To determine a buck-boost value, subtract the available voltage from the equipment voltage rating.

Step 4 Select a voltage rating for the transformer secondary windings that are as close as possible to the buck-boost value in Step 3. For example, some programmable logic controllers sold from overseas markets are rated at 100 volts. The difference between the available utilization voltage (120 volts) and the equipment voltage is –20 volts. Therefore, you would select a buck-boost transformer with two 120-volt primary windings and two 16-volt secondary windings (field-connected in parallel) to buck the voltage down to about 104 volts.

Caution: The load current of a buck-boost transformer should not exceed the rating of the secondary windings. If the windings are connected in series, then the current rating of the secondary windings is equal to the rating of a single secondary winding. If they are connected in parallel, then the rated current is doubled.

Step 5 Determine the current rating of the buck-boost transformer by referring to *Sizing a Buck-Boost Transformer* on page 4.

Step 6 If the remainder from Step 3 is positive, then install the buck-boost transformer in a boost configuration according to the manufacturer's instructions. If the remainder is negative, then install the transformer in a buck configuration according to the manufacturer's instructions.

Caution: Before electing to boost equipment voltage to the upper end of the ANSI C84.1 range, consider the sensitivity of the equipment to overvoltages. For example, an adjustable-speed drive usually has a high sensitivity to voltage swells and capacitor-switching transients, which will upset a drive more frequently when the utilization voltage is boosted to the upper limit of the ANSI voltage range. However, boosting the voltage to the upper limit does not increase equipment sensitivity to other types of transient overvoltages.

Specifying a Buck-Boost Transformer to Increase Sag Tolerance

To select a buck-boost transformer to increase the sag tolerance of equipment, follow these four steps and refer to Table 2 for an example:

Step 1 Install a voltage monitor at the point of utilization to record the voltage during normal operation, including during any voltage sags that cause the equipment to drop out or malfunction.

Step 2 Determine the amount of voltage boost to achieve a utilization voltage at or slightly above the rated voltage of equipment but lower than the maximum utilization voltage in Table 1. Consider the following example. HID lighting designed to operate at 208 volts (200 volts utilization) in a process facility is known to be sensitive to voltage sags that do not upset other facility equipment. The voltage measured at the HID lighting panel is 195 volts during normal conditions and 172 volts during the start-up of a large compressor motor, which causes the lights to go out. The voltage at the panel can be increased by 16 volts and still be within the ANSI C84.1 range for a 208-volt circuit. This voltage boost will prevent the lights from going out during the start-up of the motor.

Step 3 From equipment nameplates, determine the voltage and current ratings of all loads to be connected to the transformer. If such data cannot be gathered, measure the current of all loads to be connected to the transformer. Add the current ratings or current measurements together, then calculate the load kVA by multiplying the nominal load voltage by the load current.

SIZING AND INSTALLATION CAUTIONS

Caution: You may need to re-size overcurrent-protective devices after using a buck-boost transformer to increase the equipment utilization voltage. Always follow Section 450-4 of the *National Electrical Code* when sizing protective devices.

Caution: During a facility shutdown such as during nights, weekends, and holidays, the utilization voltage at the equipment terminals may increase. The voltage at the equipment terminals should never exceed the maximum utilization voltage in Table 1. Therefore, consider wiring buck-boost transformers so that they can be bypassed or turned off during facility shutdowns or low production.

Caution: Always follow the installation instructions and connection diagram provided by the manufacturer.

Caution: Always check the output voltage and phase rotation of a transformer after any electrical modification.

Caution: Because the kVA rating of a buck-boost transformer will not match the kVA rating of its load, electrical drawings and panel boards should clearly indicate any modification involving a buck-boost transformer.

Table 2: Example of Specifying a Buck-Boost Transformer for Increased Sag Tolerance

Step No.	*Measurements and Calculations*
1	Voltage During Normal Conditions: 100 Volts Voltage During Sag: 75 to 82 Volts
2	Minimum Utilization Voltage (Table 1): 110 Volts Maximum Utilization Voltage (Table 1): 126 Volts Required Boost Voltage: 24 Volts Connections: "BOOST," Output Voltage A in Fig. 2 Primary Windings: Two Parallel 120-Volt Secondary Windings: Two Series 12-Volt Boosted Voltage (Normal Conditions): 124 Volts Boosted Voltage (Sag Conditions): 99 to 106 Volts
3	Nominal Voltage: 120 Volts Load Current (Measured): 50 Amps Calculated Load kVA: 6 kVA
4	Transformer Current Rating: $\Delta = \frac{124 - 100}{100} = 0.24$ $C_T = 50\ (0.24 + 1) = 62$ amps Transformer kVA: 24 Volts x 62 Amps ≈ 1.5 kVA

Step 4 Determine the current rating of the buck-boost transformer by referring to *Determining the Current Rating of a Buck-Boost Transformer* below. Then, multiply the current rating by the required buck or boost voltage in Step 2 to calculate the transformer kVA. Note that in the example in Table 2, the kVA requirement of the transformer load in Step 3 is much larger than the calculated kVA rating of the transformer.

Determining the Current Rating of a Buck-Boost Transformer

When the voltage at equipment terminals changes, the current drawn by the equipment will also change. Whether the current increases or decreases depends upon the type of equipment. For example, induction motors and power supplies will draw less current as the voltage increases. The converse is true for most lighting loads.

If you are certain that the current drawn by equipment will decrease when you correct a utilization voltage (buck or boost it), then use either the measured current or the current rating on the equipment's nameplate as the current rating of the transformer. If you are uncertain, then use the load nameplate data or follow the procedure below to size a buck-boost transformer using measured voltage and current.

Calculate Transformer Current from Measurements

First determine the amount of voltage change by using the following formula:

$$\Delta = \frac{V_B - V_M}{V_M}$$

where V_M is the measured utilization voltage and V_B is the corrected utilization voltage. If the amount of voltage change is within plus or minus five percent, then use the measured current as the current rating of the buck-boost transformer. If the amount of voltage change is not within plus or minus five percent, then use the following formula to calculate the current rating of the transformer:

$$C_T = C_M (|\Delta| + 1)$$

where C_T is the estimate for the transformer current rating, C_M is the measured current, and $|\Delta|$ is the absolute voltage change with no sign.

For example, if we decide to boost a 100-volt utilization voltage by 24 volts, then V_M would be 100 volts and V_B would be 124 volts. If the measured current at the equipment is 50 amps, then C_M is 50 amps. First, determine the amount of voltage change:

$$\Delta = \frac{124 - 100}{100} = 0.24$$

Because the amount of change is greater than five percent, we must use the current formula to determine the current rating of the buck-boost transformer:

$$C_T = 50\,(0.24 + 1) = 62 \text{ Amps}$$

BENEFITS

- Prevent costly process and equipment shutdowns.
- Increase equipment reliability.
- Save money by treating only the equipment that needs voltage matching or enhanced sag tolerance instead of treating an entire facility.
- Save space by using a transformer that is typically smaller than an equivalently sized isolation transformer.

WHERE TO FIND HELP

- Manufacturers and dealers of buck-boost transformers
- Your local electric utility

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