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Application Note

Connection and Characteristics of BE1-32 Power Relays

General Principles

The BE1-32 operates on the principle of a Watt transducer. The various available models combine 1 to 3 measuring elements to accommodate the traditional instrument transformer configurations. Each element measures the V.I. cos θ product of the voltage and current connected to its input terminals, where θ is the load angle. (Some connections introduce a 30° phase shift which is compensated by the relay circuit). The V-I phasor diagram in Fig. 1 shows an angle θ which may include the 30° phase shift.

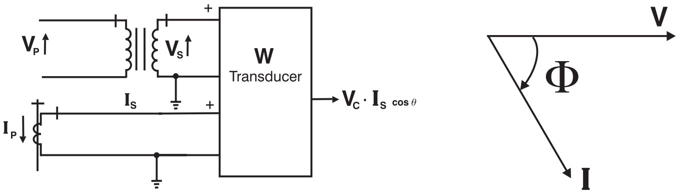


Figure 1 - BE1-32 Measuring Principle

The calibration of the relay is in 3 phase secondary Watts, except for the single element relay (Type A sensing) where it is in single phase Watts.

For sensing types B & V, the relay internally compensates for the phase shift introduced through the connection.

Conventions

In 1948, the AIEE adopted the convention that lagging reactive power shall be positive when flowing in the reference-positive direction.

The first aspect of this convention is that a reference positive current flow direction must be established before any power measurement can be displayed and interpreted. The following directions have been adopted.

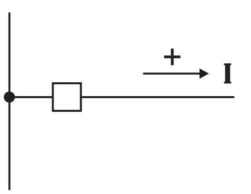


Figure 2a - Bus; current is positive when flowing away from the bus.

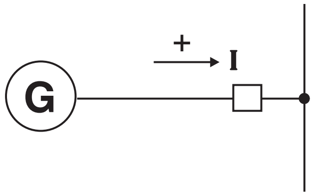


Figure 2b - Generator; current is positive when flowing away from the generator.

When the instrument transformers are added, the convention must be carried to the secondary and onto the relay. Polarity marks on the relays and CT assure that the direction is respected. This is shown in figures 3a & b.

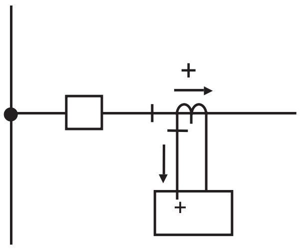


Figure 3a - Conventional current flow at a Bus, with CT

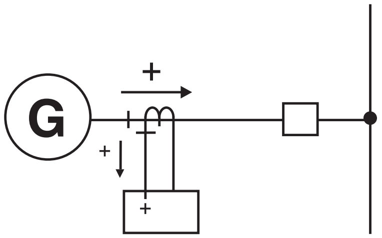


Figure 3b - Corresponding Conventional current flow at a generator, with CT

The second aspect of this convention affects the phasor and scalar diagrams used to represent the voltages, currents and power in a particular circuit. Figures 4a & 4b show that in order to comply with the convention and to maintain the traditional sign directions on the cartesian coordinates, it was necessary to introduce the conjugate current phasor: V is multiplied by I at the opposite load angle.

The apparent power S for a load angle θ is thus :

$$S = P + jQ = V.I.\cos(\theta) + jV.I.\sin(-\theta)$$

Or $S = V.I.\cos(\theta) - jV.I.\sin(\theta)$

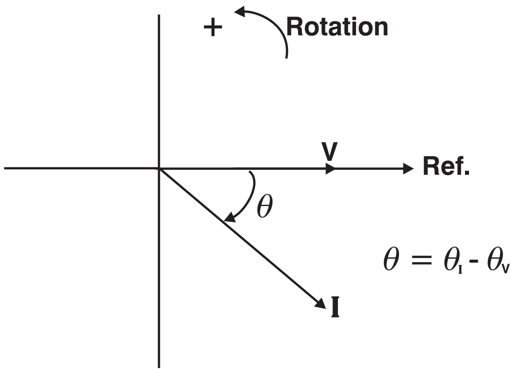


Figure 4a - Conventional V-I phasor diagram

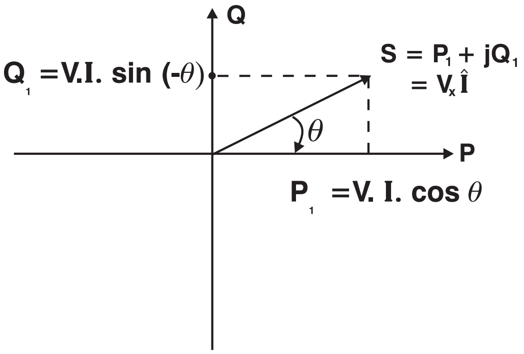


Figure 4b - Conventional P-Q scalar diagram

Note that in Fig. 4a the power angle is defined as $\theta_I - \theta_V$. This convention yields a negative sign for lagging I with V as reference. It is also coherent with the definition of reactive power using the conjugate of the current phasor, shown in Fig. 4b, which requires that a lagging current (or lagging power factor) will result in a positive Var flow.

An alternate convention uses $\theta_V - \theta_I$ as the load angle and avoids using the conjugate of the current when computing the reactive power. The objective is the same: the sign of a lagging power angle must be positive in the equation $Q = V.I.\sin(\theta)$.

This information is useful to help analyze and predict the expected signs of power flow from given phase angle readings.

Characteristics

For simplicity, the following discussion and diagrams will pertain to a single phase BE1-32, type A relay. Details on 3 phase connections and settings will be found in the Instruction Manual.

Over/Underpower Relay (32O/U)

Connections

The connections for generator and bus applications are shown in Fig. 5. Note that the trip direction and conventional power flow directions are the same.

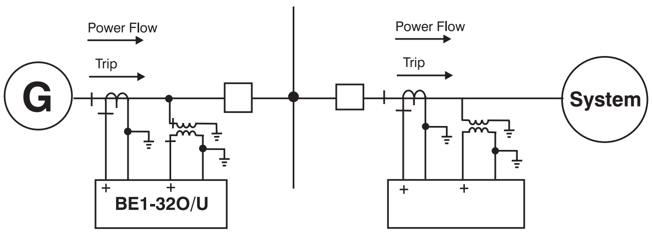


Figure 5 - BE1-32O/U connections

Characteristic

The relay closes on output contact when the measured power magnitude exceeds (Over) or falls below (Under) the set positive threshold. The operating characteristic of the relay is, therefore, a half plane as shown in Fig. 6.

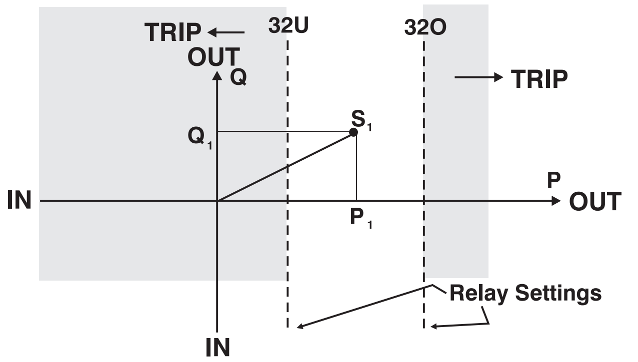


Figure 6 - BE1-32O/U characteristic

Reverse Power (32R)

Connections

The connections for generator and bus reverse power detection applications are shown in Fig. 7. Note that the trip direction and conventional power flow directions are opposite. The CT secondary connection to the relay follows the trip direction: when the primary current flows in the trip direction, the secondary current must enter the polarity mark on the relay.

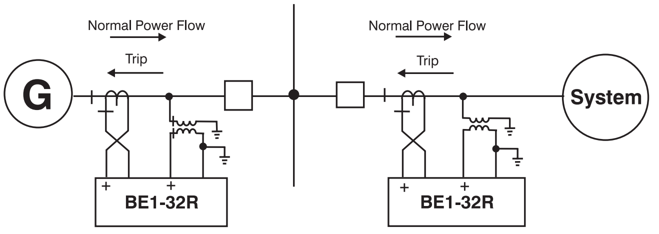


Figure 7 - BE1-32R (Reverse Power) connections

Characteristic
The operating characteristic for a generator is shown in Fig. 8. The operating modes indicated in Fig. 8 are based on the normal power flow indicated in Fig. 7.

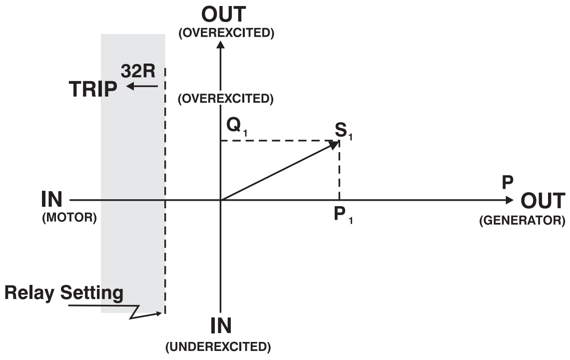


Figure 8 - BE1-32 characteristic for generator

VAR Sensing

Since the operating characteristic of the relay is a half plane determined by the phase angle between the voltage and current connected to the measuring element, it is possible to measure VARs by shifting the reference voltage by 90°. This is done by selecting a voltage which is in quadrature phase with the appropriate line to neutral voltage.

The following diagrams illustrate how the characteristic operating half plane can be shifted on the phasor diagram to detect different system conditions. These diagrams combine the power (P,Q) and phasor (V,I) diagrams into one for easy reference.

Figure 9 shows the relay polarities corresponding to the desired trip direction. The voltage connection determines if the relay trips for watts or vars.

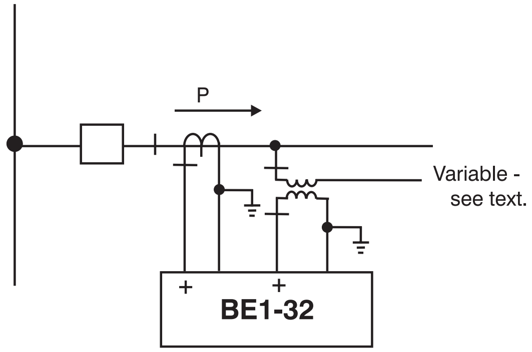


Figure 9 - BE1-32 connection

Fig. 10 shows the normal 32 connection using Vb & Ib. The relay trips when the V.I.cos(θ) product is positive and exceeds the tap setting Ps.To reverse the trip direction (32R), simply cross the current connections at the relay.

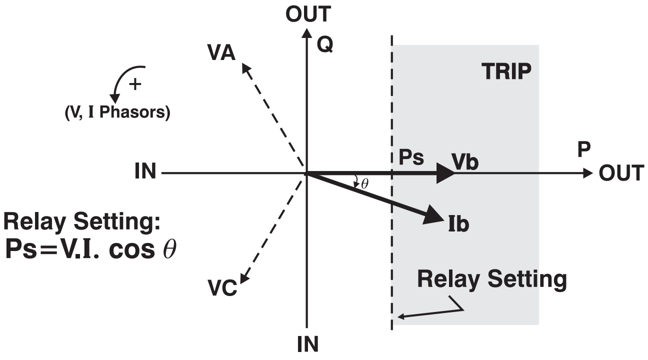
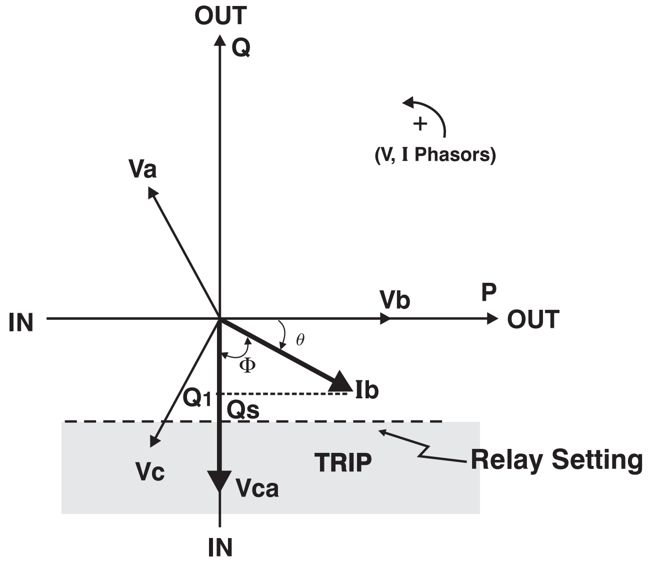


Figure 10 - WATTS OUT Trip connection. Current shown is normal, lagging PF load.

The BE1-32 relay measures V.I.cos(F), where F is not necessarily the load angle. The voltage and current connections determine if this quantity is real or reactive power. By shifting the voltage 90°, using Vca as the reference voltage, a VAR IN characteristic can be obtained. Since the relay closes its output contact when this product is positive and exceeds the tap setting, the location of the boundary of the half plane characteristic for this connection determines the Vars characteristic, shown in Fig. 11. This connection is sometimes used to detect the loss of excitation in a generator, although it does not follow the generator capability and minimum excitation limiter curves as closely as the preferred BE1-40Q relay.



Relay measures: $V_{ca} \cdot I_b \cdot \cos\Phi$ (Type A sensing)

$= V_{ca} \cdot I_b \cdot \sin\theta$

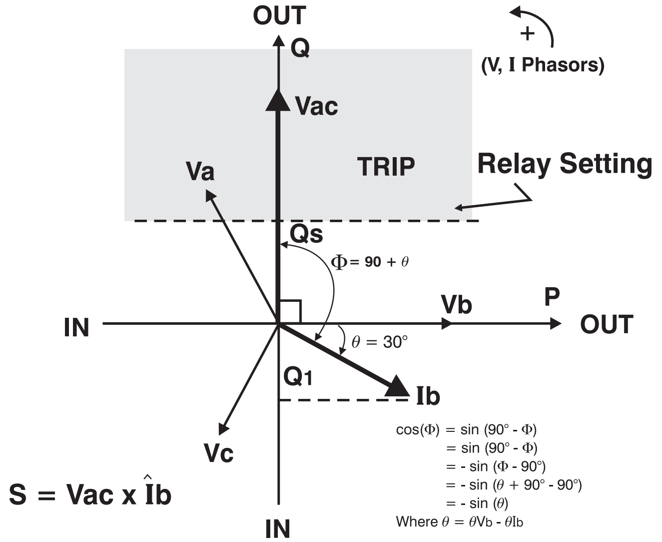
$= \sqrt{3} \cdot V_b \cdot I_b \cdot \sin\theta = \sqrt{3} \cdot$ (single phase Vars)

Since the relay setting (Tap) is in single phase power, and the phase to phase connection increases the power seen by the relay by √3, the tap setting for a desired single phase threshold Qs is

$$\text{Tap} = \frac{Qs}{\sqrt{3}}$$

Figure 11 - VARs IN Trip connection. Current shown is normal, lagging PF load.

Fig. 12 shows the characteristic to detect an excessive VARs OUT condition, obtained by reversing the voltage connection, thus using Vac as the reference. The relay trips for Vars OUT exceeding the setting. Note that the phase angle calculations shown on Fig.12 adopt a positive sign for a lagging load angle, to reflect the relay design which uses the voltage as the reference.



$S = V_{ac} \times \hat{I}_b$

$$\begin{aligned}\cos(\Phi) &= \sin(90° - \Phi)\\ &= \sin(90° - \Phi)\\ &= -\sin(\Phi - 90°)\\ &= -\sin(\theta + 90° - 90°)\\ &= -\sin(\theta)\end{aligned}$$

Where $\theta = \theta V_b - \theta I_b$

Relay measures: $V_{ac} \cdot I_b \cdot \cos\Phi$ (Type A sensing)

$= V_{ac} \cdot I_b \cdot \sin\theta$

$= \sqrt{3} \cdot V_b \cdot I_b \cdot \sin\theta = \sqrt{3} \cdot$ (single phase Vars)

$$\text{Tap} = \frac{Qs}{\sqrt{3}}$$

Figure 12 - VARs OUT Trip connection. Current shown is normal, lagging PF load.

For More Information

For further assistance with product orders or questions, contact Basler Electric Technical Support at 618-654-2341.

For additional information, including more application notes, product bulletins, and instruction manuals, visit www.basler.com, contact your Application Engineer, or contact Technical Support at 618-654-2341.

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