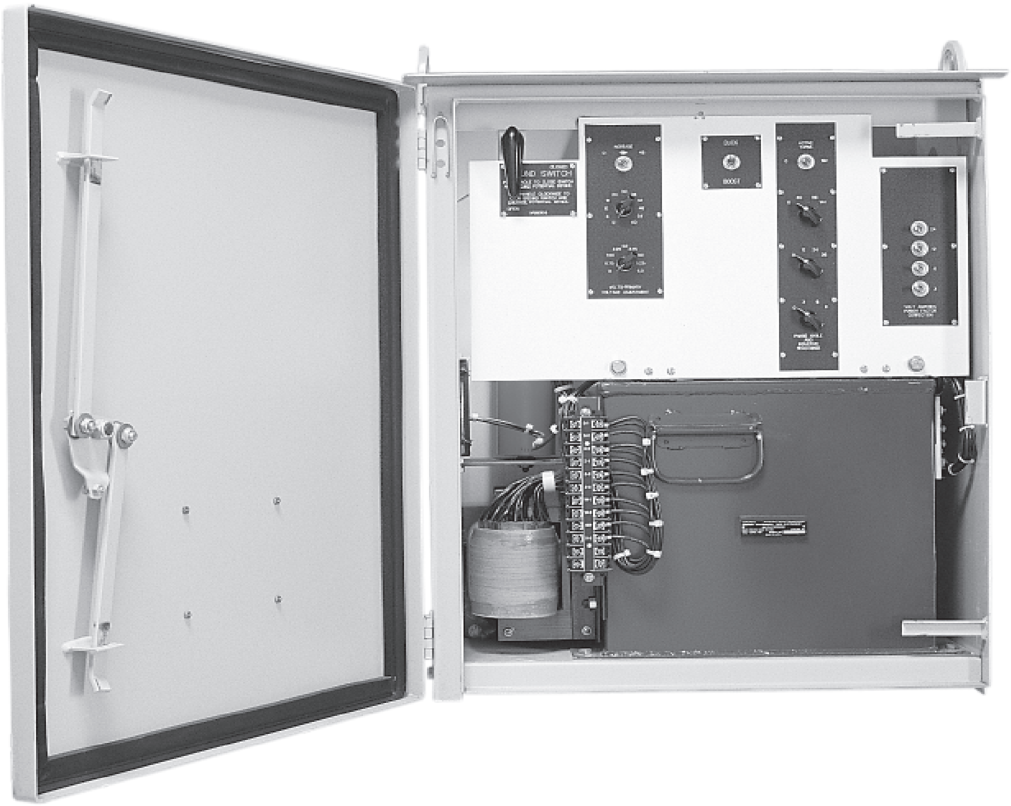
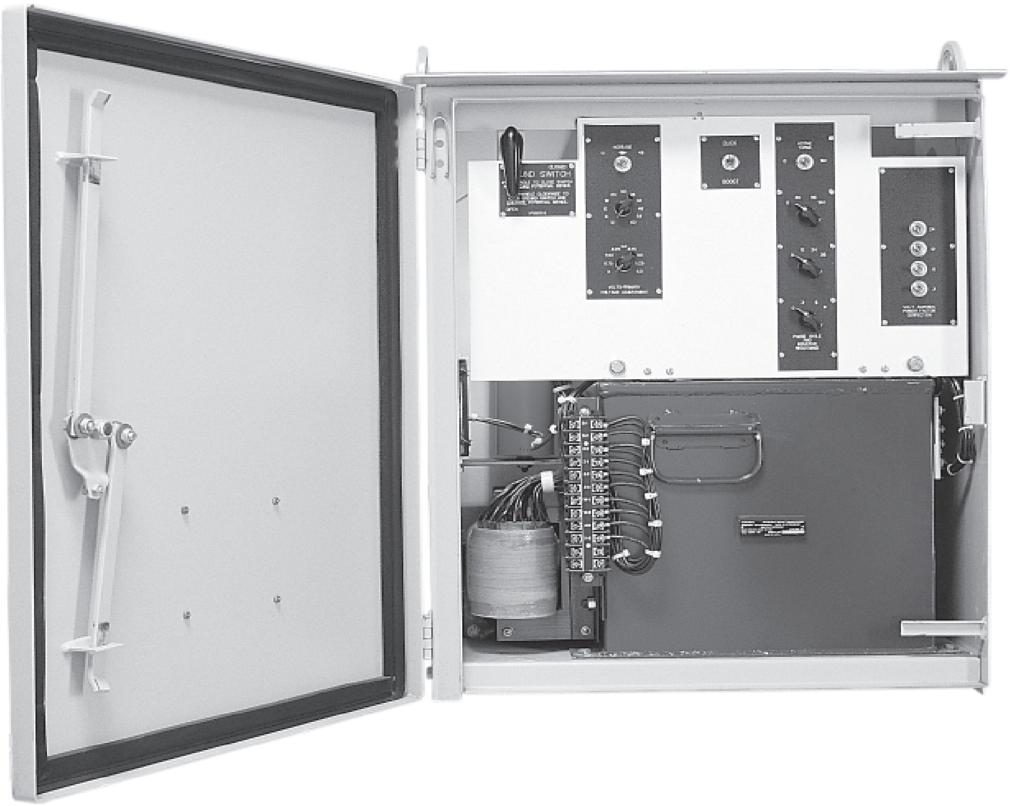
Bushing Potential Device, Type PBA2

PTAE-APD903
IZUA 7711-210

Instructions for Installation and Maintenance





All possible contingencies which may arise during installation, operation, or maintenance, and all details and variations of this equipment do not purport to be covered by these instructions. If further information is desired by purchaser regarding his particular installation, operation or maintenance of his equipment, the local ABB Inc representative should be contacted.

Description

Application

The condenser bushing potential device is a means for securing small amounts of 60 hertz power at 115 volts and 66.4 volts from high voltage lines through the medium of the condenser bushing. For 115kV and higher voltages this device is the most economical means of securing such small amounts of power.

These devices provide a 115 and 66.4 volt output which is substantially proportional to the system line-to-ground voltage and in phase with it. This output is commonly used to energize synchroscopes, voltmeters, and voltage responsive relays. The device accuracy is not adequate for use with metering instruments where revenue is involved.

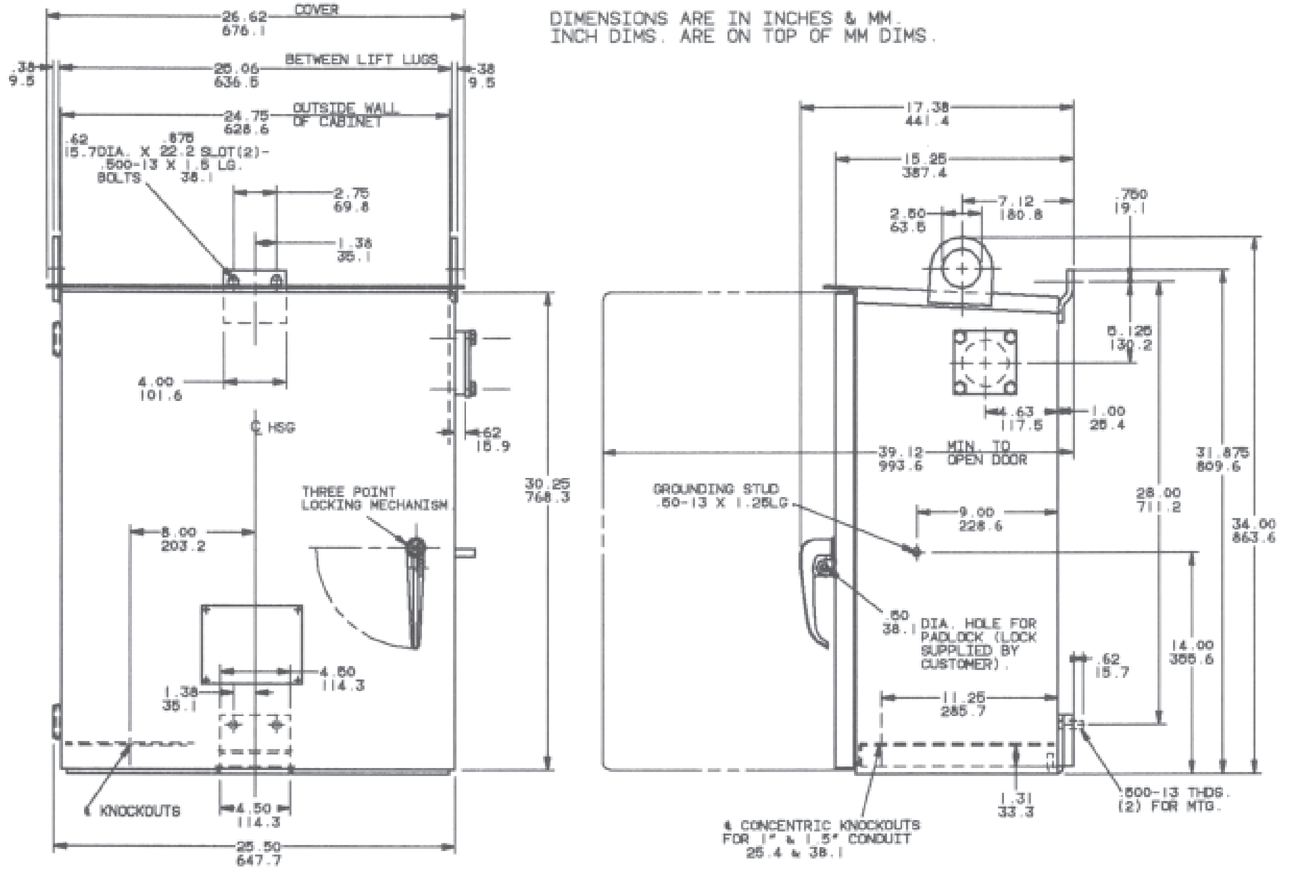
Construction

The potential device is built in an outdoor, weatherproof, steel housing arranged for mounting on the side of an oil circuit breaker or transformer in the vicinity of one of the condenser bushings. A special cable assembly of weatherproof construction, and with a grounded external shield, connects the potential device to one of the metallic layers of the condenser bushing.

The device network (see Fig. 6) consists of a main transformer having adjustable reactance, an auxiliary transformer of adjustable ratio, a tapped capacitor to correct burden power factor, a protective spark gap, and a dead-front adjusting panel.

A grounding switch permits de-energizing the device, and a heater (to be energized from an external voltage source) prevents internal sweating of the housing.

Standardized mounting dimensions permit the interchangeability with most standard ABB or Westinghouse units sold since the middle of 1934. The standard device is electrically usable for most bushings having capacitance taps per IEEE C57.19.01-2000 Type A: Normally Grounded having the tap on the second metallic layer above ground potential. This includes substantially all Westinghouse bushings manufactured since the middle of 1935 and having a voltage rating of 115kV or higher. Cable lengths (see Fig. 2) are also standard for circuit breakers, but special lengths are general for transformers. End fittings of cables are common for all.



DIMENSIONS ARE IN INCHES & MM.
INCH DIMS. ARE ON TOP OF MM DIMS.

Figure 1: Outline and Mounting

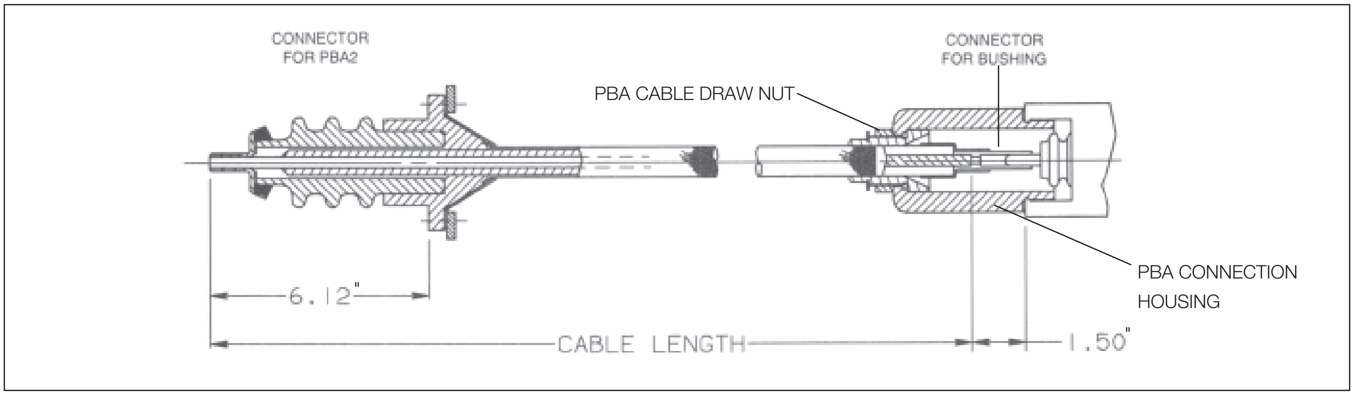


Figure 2: Cable Lead-in Assembly

Rating

Each device has output voltages of 115 and 66.4 for the main burden (terminals S1, S2, S3) and an auxiliary winding provides the same voltages (terminals Z1, Z2, Z3) for use when broken-delta connections are required.

The burden ratings of the standard devices, when used with standard bushings in each case, are shown in Table 1.

Table 1

System Voltage Line-To-Line	System Voltage Line-To-Ground	Max. Watts* Total Burden	Device Style** ***
115 kV	66.4 kV	25	3D69822G01
138 kV	79.7 kV	35	3D69822G01
161 kV	93.0 kV	45	3D69822G02
230 kV	133 kV	80	....
287 kV	166 kV	100	....
330-345 kV	191-199 kV	150	....

*** In no case shall the burden on the auxiliary winding (Z1, Z2, Z3) exceed 75 watts.**

**** Styles do not include lead-in cable, see Table 2.**

***** These designs are for ABB or Westinghouse bushings. Bushings by other vendors require special PBA configuration.**

Table 2. Cables with Type A Connectors

Cable Length*	Style#
96"	3D69768G01
120"	3D69768G02
144"	3D69768G03
168"	3D69768G04
192"	3D69768G05
216"	3D69768G06
240"	3D69768G07
*Cable lengths other than those listed can be ordered if necessary	

Since the device rating is a function both of the system voltage and of the particular bushing capacitance values, it is obvious that special bushings, or standard bushings used at non-standard voltages may have burden ratings which are at variance with the foregoing tabulation. In this connection it is to be noted that the auxiliary capacitance built into each device varies according to the device application. See page 10 “Calculation of Approximate Adjustment.”

Performance

The Type PBA2 Potential Device is a Class”“A” device as defined by AIEE Standard # 31 and NEMA Standards SG4-1968. The regulation characteristics with respect to varying line voltage and varying burden meet the limits established by these standards.

Since this type of device is basically a series-tuned device it is sensitive to the system frequency. For small frequency deviations there is practically no ratio effect, but there is a slight phase shift. For example, a deviation of one hertz in 60 will produce a phase shift up to 2 degrees, depending on the particular bushing device and system voltage. The greatest phase shift is experienced when the potential device is loaded to its rating, and when the normal system voltage is low relative to the bushing rating.

When high-speed directional relays are energized from this device, it is recommended that the basic burden be power factor corrected to 100%, or slightly leading, and that the device be loaded to its rating in watts (as shown on the nameplate), by adding parallel resistance if necessary. The purpose of this is to reduce to a minimum the possibility of incorrect relay operation, which might result from device output transients following a system short circuit extremely close to a device.

Erection

The potential device may be lifted from its crate or pallet and handled by means of the two lifting lugs on the side of its roof to mount it on the circuit breaker or the transformer.

Depending on the particular breaker or transformer bracket provided for the lower edge of the potential device, proceed as follows (see Fig. 1):*

a. If the lower device support on the transformer or breaker carries two tapped holes then bolt the J bracket, which is shipped loose with the potential device, to this pad using the two countersunk head bolts provided. There is a notch in the center of the rear lower flange of the device, which will fit into the hook provided by this J bracket. Rest the weight of the potential device into this bracket and place the two bolts into the two slots of the upper device support, and secure these in place.

b. If the transformer or breaker carries a lower device support consisting of a bent steel bar, and with two notches cut into its edge instead of two tapped holes, then the J bracket may be scrapped and the potential device rested directly on the notched bar. The upper end is bolted into place with the two bolts.

c. In either case, the paint shall be scraped away from the upper pad where it is bolted against the corresponding pad on the breaker or transformer in order to assure a good ground connection at this point.

d. The primary connection is made by installing the high voltage cable assembly of Fig. 2. This is done with the bushing grounded. The cable is installed by removing the mounting flange cover from the side of the potential device housing and removing the cover from the tap receptacle on the bushing flange. The tap receptacle on the bushings of recent manufacture may be found filled with approximately one pint of transformer oil, which will drain out when the cover is removed. Discharge the bushing tap layer by touching the socket contact with a grounded wire.

1. If the bushing is ABB O plus C or other type that permits addition of transformer oil to the test tap with the tap cover in place, you may choose to fill the PBA connector housing with transformer oil. In this case, do not add the petrolatum to the PBA connector housing.
2. Otherwise, pack the inside of the PBA connector housing with the petrolatum provided, taking care to leave no air pockets.

e. Push the bushing connector into the tap, then thread the PBA connector housing into the threaded portion of the bushings tap. Tighten by hand, approximately 1/4 turn after the gasket is in contact with both the tap and the connector housing. Lubricate the gasket with a thin application of transformer oil or petrolatum whichever is being used.

f. Turn the PBA cable draw nut clockwise, until tight.

g. If you have chosen to fill the PBA connector housing with transformer oil, do so now. Please see the bushing's application literature for filling instructions and oil expansions space requirements.

h. Place the porcelain end of the cable assembly into the hole in the side of the potential device housing. Bolt the two flanges in place using the hardware provided. The composition flange at the cable end is also the gasket. Draw up the bolts progressively around the cable so that there is not excessive pressure at any point. Tighten up the bolts only sufficient to create a slight bulge all around the edge of the composition.

i. Connect the internal jumper connection in line with diagram of Fig. 6 by opening the PBA'S door and partially dropping the front panel assembly.

It is suggested that when a device is installed and connected that its voltage adjustment be set to a minimum (and the ground switch opened) until such time as the normal burden is connected and the device adjusted.

*** If the device is to be mounted on equipment that is not manufactured by ABB, the mounting arrangement may be slightly different than described here.**

Adjusting

General

The Type PBA2 is a ‘resonant’ or ‘in-phase’ device having Class’“A” performance, and hence it must be adjusted or tuned to match a specific bushing and a specific burden. A reference voltage of known value and phase angle position is required to make this initial adjustment. This reference voltage is usually supplied from the secondary voltage of a potential transformer of the desired ratio, which is connected line-to-ground to the same phase of the transmission line as the bushing to which the potential device is mounted.

However, the reference voltage may be taken from another potential device which has been previously adjusted, or it may be taken from the low voltage secondary of the power transformer provided it is known that voltage is in phase with the line-to-ground voltage of the transmission line. The object is to have a reference voltage for comparison, this reference voltage to be approximately 115 volts (or this value divided by 1.73) as may be decided upon for the device output, and this voltage to be in phase with the transmission line-to-ground voltage.

There are three adjustments provided on the device adjusting panel; these are power factor correction of the burden, phase angle adjustment of the transformer to series tune the bushing reactance, and voltage adjustment to control the burden voltage. The phase angle adjustment shows its effect by shifting the phase angle of the secondary or output voltage. The controls on the adjusting panel are marked power-factor correction, volt-amperes, phase-angle, and inductive reactance, and voltage adjustment.

The numbers on the respective adjustments are in terms of volt-amperes of power factor correction; active turns of reactance winding and volts-primary of the ratio transformer. The values are useful in making the device adjustment.

It is desirable to adjust the device with the final burden in place. If this is not possible then a synthetic burden shall be used having the identical volt-ampere and power factor characteristics of the actual burden.

The adjustment procedure requires a voltmeter of fairly high impedance to check the magnitude of the output voltage, whether 115 volts or 66.4 volts (note that the ratio of these two voltages in the output is fixed so that only one of them need be adjusted and checked). To check the phase angle of the output voltage requires either a phase angle meter having two voltage coils, a low voltage voltmeter, or an oscilloscope. The oscilloscope is probably the most satisfactory for phase angle adjustment.

If the reference voltage being used is the exact magnitude desired then the entire adjustment can be made by using two voltmeters (one reading about 150 volts, and the other about 5 volts) by connecting the ground of the reference and the ground of the device output together and then checking voltage between the line terminals, first with the 150 scale voltmeter and finally with the 5 scale voltmeter. The device will be correctly adjusted when the voltage between line terminals is a minimum (less than 1 volt).

Procedure

Power Factor Correction

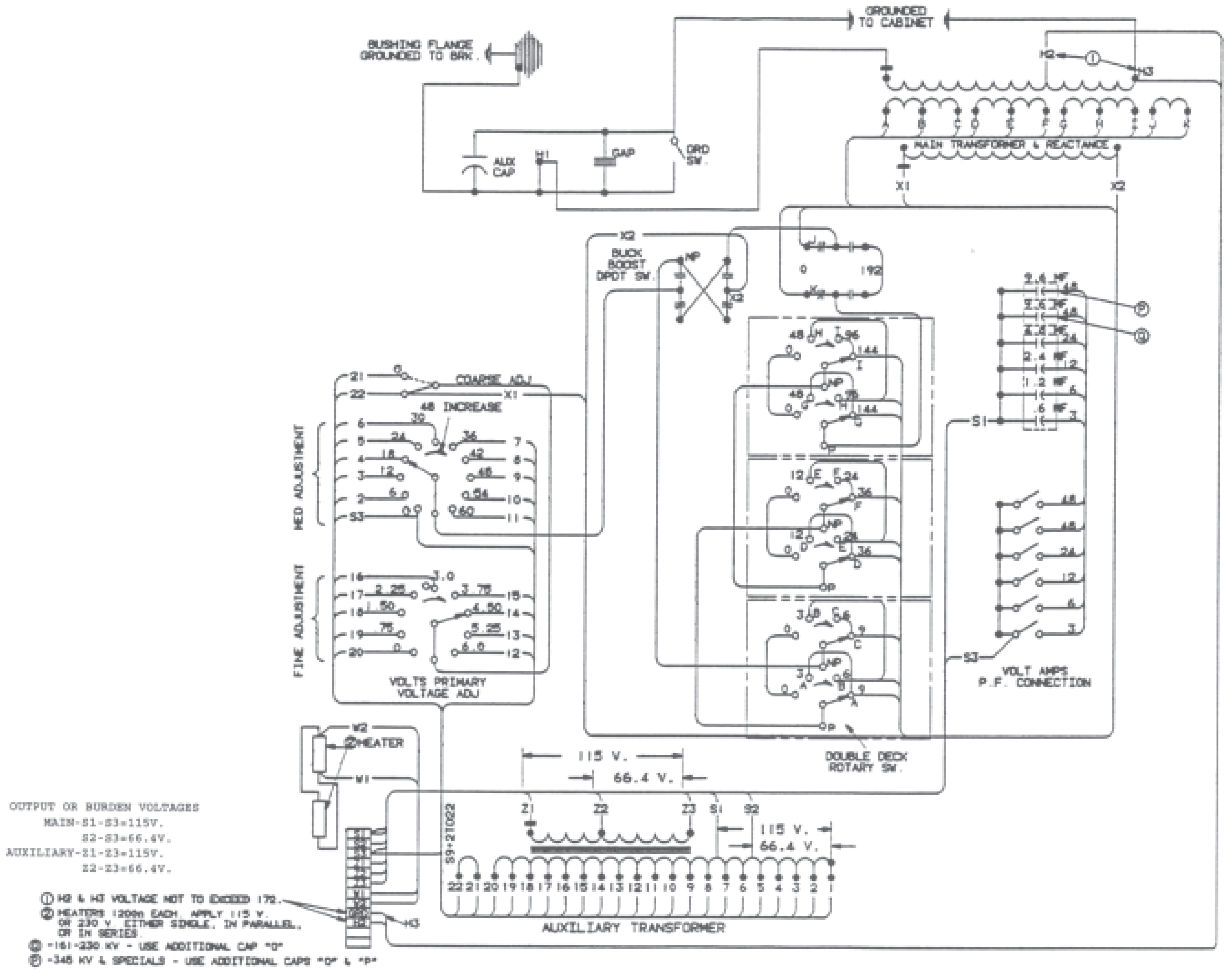
Correct the power factor of the burden to unity, or to a slightly leading angle. This is the first step and may be done by switching in an amount of capacitive volt-amperes, to match the reactive volt-amperes of the burden. In the case of delta-connected burdens operating from a bank of three potential devices, it may be simplest to excite the total burden from a separate voltage source and to adjust the capacitors to secure unit power-factor in each phase. This can be done by grounding terminal S3 (Fig. 3) of each device and applying the three-phase test voltage to the three S1 terminals, or the three S2 terminals, depending on the voltage. The primary shall be de-energized for this test and the ground switch open.

If in this test the protective gap flashes over this may be stopped by making a radical change in the phase angle setting, such as by reversing the BUCK-BOOST switch, or by changing large sections of turns in the tapping arrangement.

As an alternative, the reactive volt-amperes can be calculated and the corresponding capacitive volt-amperes set on each device.

Phase Angle and Voltage Adjustment

There is some interdependence between the phase angle and voltage adjustment and so these will be considered together. These are the final adjustments and are best made with the final burden (power factor corrected) connected in its final form to the potential device. The device adjustment is basically a single-phase procedure, even when connected into a 3 phase group.



OUTPUT OR BURDEN VOLTAGES
MAIN-S1-S3=115V.
S2-S3=66.4V.
AUXILIARY-Z1-Z3=115V.
Z2-Z3=66.4V.

① H2 & H3 VOLTAGE NOT TO EXCEED 172.
② HEATERS 1200Ω EACH. APPLY 115 V. OR 230 V. EITHER SINGLE, IN PARALLEL, OR IN SERIES.
Ⓞ -161-230 KV - USE ADDITIONAL CAP "O"
Ⓟ -345 KV & SPECIALS - USE ADDITIONAL CAPS "O" & "P"

Figure 3: Connection Diagram

For this adjustment the device must be connected to its final condenser bushing, with normal line-to-ground voltage on the bushing stud, and with a reference voltage available for comparison. See also ADJUSTING-GENERAL above.

The ratio or output voltage adjustment is a matter of voltage magnitude only, and this is checked by voltmeter reading. The phase angle of the output voltage may be checked by low reading voltmeter, by phase angle meter or by oscilloscope, as previously mentioned.

Fig. 4 is the circuit diagram for checking the phase angle and ratio using the oscilloscope with vertical and horizontal sweeps each energized at 115 volts 60 hertz. The oscilloscope shall be adjusted so that the total deflection in each the vertical and the horizontal directions is roughly the same. The reference and the output voltages are in phase when the trace on the oscilloscope is the nearest possible to a single straight line. Some variation in the wave form of the two voltages may prevent the trace from ever becoming a perfect straight line. When the voltages are out of phase, the trace tends to be an ellipse; it would be a circle with the two voltages 90 degrees out of phase. The oscilloscope as used here will not distinguish in-phase from 180° out-of-phase.

Make up the circuit of Fig. 4 with the ground switch of the device in the closed position, which de-energizes the device. Place all of the rotary switches and the toggle switch of the phase angle adjustment in the zero position and set the voltage adjustment dials to maximum (which is primary voltage and hence will give the minimum output voltage). Next open the device ground switch and shift the voltage adjustment dials to obtain approximately 115 volts S1 to S3. Note the oscilloscope trace; it is very probably an approximate ellipse. To determine which direction to proceed from here, switch in 24 or 48 turns of the phase angle adjustment and then note the position of the buck-boost switch which gives the nearest to a straight line trace on the oscilloscope. This simple check should establish the correct position of the buck-boost switch and then the finer adjustments of the phase angle switches is a straight forward procedure to secure a straight line trace on the oscilloscope. Start by first trying the larger steps (192 turns is the largest step) and if any step is in excess of that required then drop back to the next lower turns in the same switch. For example, with the three rotary switches in the zero position, and if 192 is then found to be excessive then return the toggle switch to zero and try 144 turns on the top rotary switch. If this is still excessive then turn the top rotary switch back down to 96 turns, and so on, until some points is reached which is short of the required amount. Then proceed to the middle and lower rotary switches in order until the closest setting is reached. The total number of turns tapped in is the sum of the settings on the three rotary switches and the 0 to 192 toggle switch. Reference to figure 5 will give an idea of the effect of the various number of turns of the reactance winding, both buck and boost.

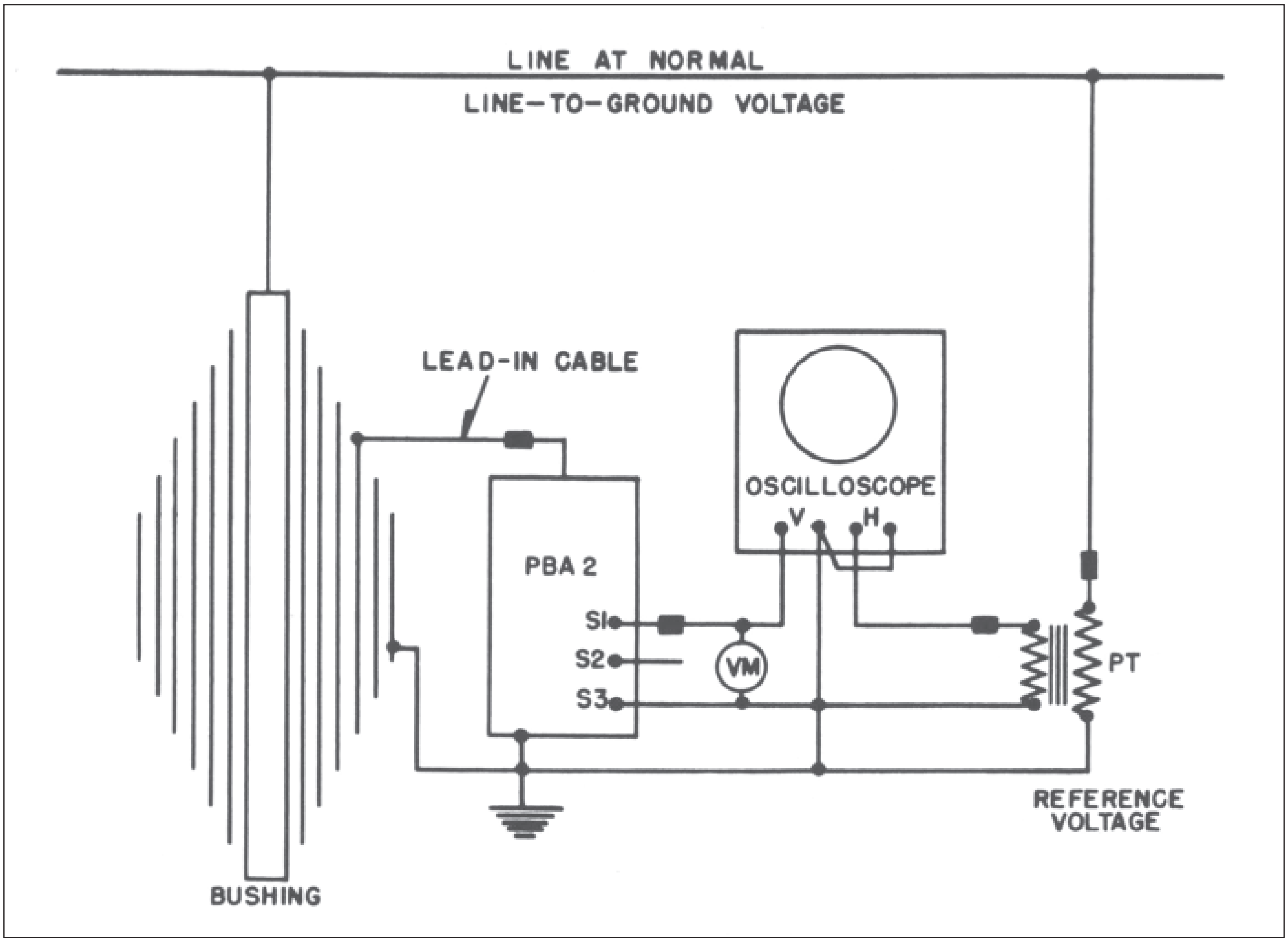


Figure 4: Test Circuit Using Oscilloscope

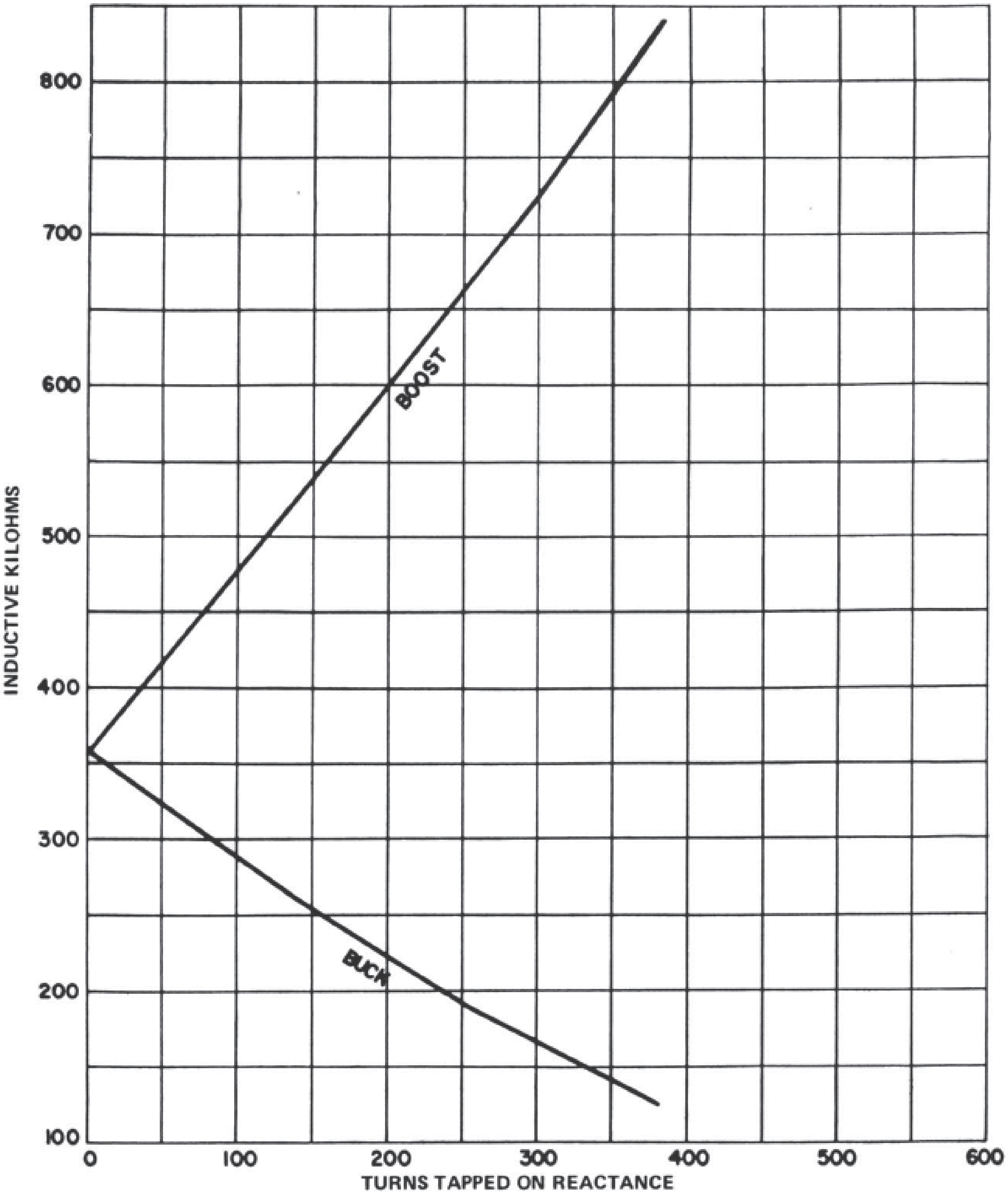


Figure 5: Curve of Ohms versus Turns of Reactance

Excessive transformer reactance (refer to Fig. 5) will result in a lagging voltage at the burden, and vice versa.

When a straight line is being approached on the oscilloscope, the output voltage shall be checked and readjusted to the desired value. The final setting is with the correct output voltage and with the oscilloscope trace the closest possible to a straight line, bearing in mind that differences in wave form of the two voltages will prevent a perfect straight line.

To check for polarity correctness, connect terminal S3 to the ground of the reference voltage and then check the voltage between S1 terminal and the polarity terminal of the reference voltage. With correct polarity this voltage will be zero and with reversed polarity the voltage will be approximately 230.

If an oscilloscope is not available then use two voltmeters, one high scale and one low scale, and with these measure the difference or error voltage and the output voltage. This plan, which uses the difference voltage, pre-supposes that the reference voltage is of the exact magnitude, which is desired for the adjusted device.

In the case of delta-connected three-phase burdens, it is necessary to make preliminary or approximate adjustments of each device first and to then re-check and trim each device one or more times until the three phase voltages to ground are equal and each in phase with its reference voltage.

When final adjustment is accomplished, with the burden connected, check voltage H2-H3. This voltage shall not exceed 172V. Voltage in excess of 172V indicates excess burden connected to the device and excess voltage on the primary of the transformer.

Calculation of Approximate Adjustment

If the capacitance values C1, C2 and C3 of Fig. 6 are known, then it is possible to calculate the approximate adjustment of a device when used with a particular bushing at a specific line voltage. It is assumed that the burden is corrected to substantially unit power factor. For this purpose the nominal values of C3 (in the potential device) are,

Device	C3
S#3D69822G01	2000pF
S#3D69822G02	3000pF
All others	Check the device for value

The values of C1 and C2 shall also be used in picofarads. If C4 is obtained by measuring a bushing mounted in a grounded structure, it will contain appreciable stray capacitance to ground. Since this stray capacitance is not effective in the circuit of the potential device it is more accurate to use 0.85C4.

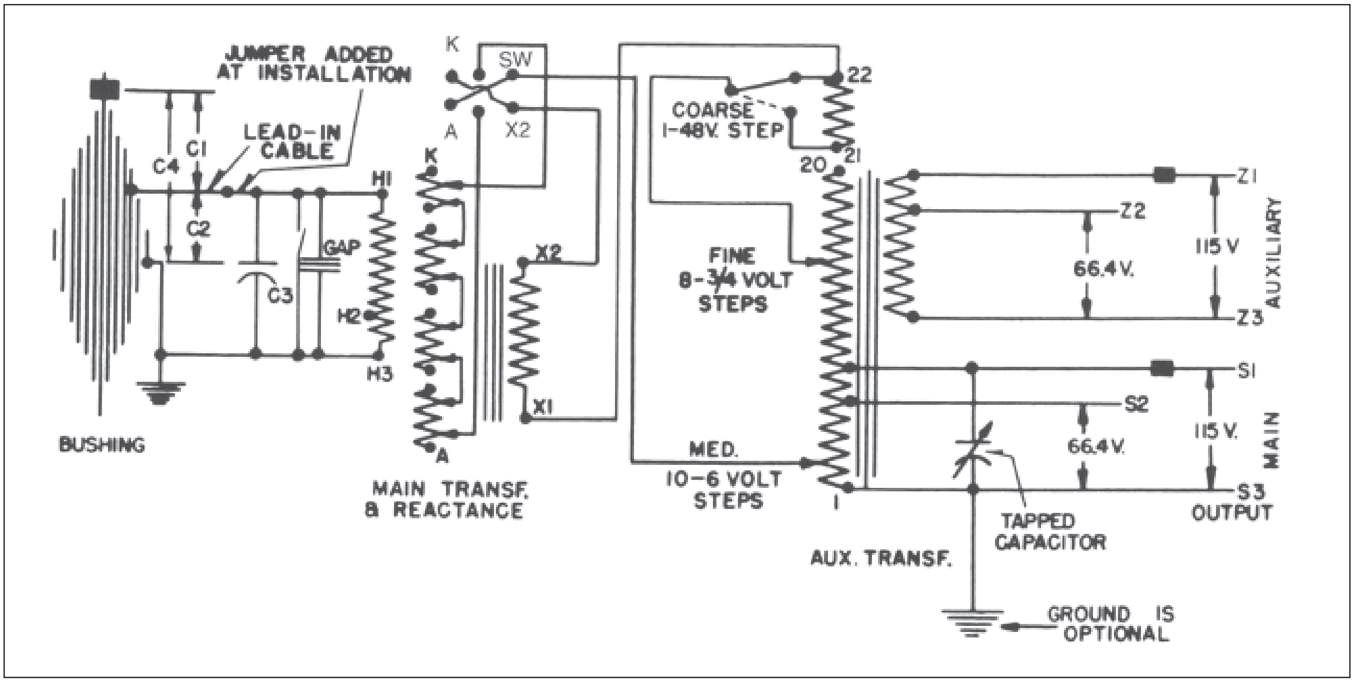


Figure 6: Schematic Diagram

Capacitance C2 similarly measured will contain an insignificant percentage of stray capacitance.

Capacitance C1 is then:

$$C1 = \frac{C2 \times 0.85C4}{C2 - 0.85C4} \qquad (1)$$

Approximate adjustments may be calculated using the nomograph (Fig. 7) and the instructions on the following pages or the equations below.

First calculate the bushing tap voltages as if no potential device burden were present. This is determined from the relation:

$$e = E \frac{C1}{C1 + C2 + C3} \qquad (2)$$

Where e is the open circuit tap voltage in volts and E is the actual system line-to-ground voltage at the condenser bushing.

The dial setting of the voltage adjustment should then total,

$$\text{dial volts} = 173 - \frac{e}{44.1} \qquad (3)$$

For the phase angle adjustment it is necessary to know the capacitive reactance XC which must be series tuned. This value in ohms is, for 60 hertz:

$$XC = \frac{10^{12}}{377^{*}\,(C1+C2+C3)} \qquad (4)$$

*377 = 2 πf, with f = 60 hertz

Using this value of XC refer to curve Fig. 5 and using the same value of reactance determine whether the device reactance switch is to be in the BUCK or BOOST position and further determine the number of turns required in the phase angle adjustment. Now set the rotary switches and toggle switch of the phase angle adjustment so that the total turns are the same as that determined from the curve.

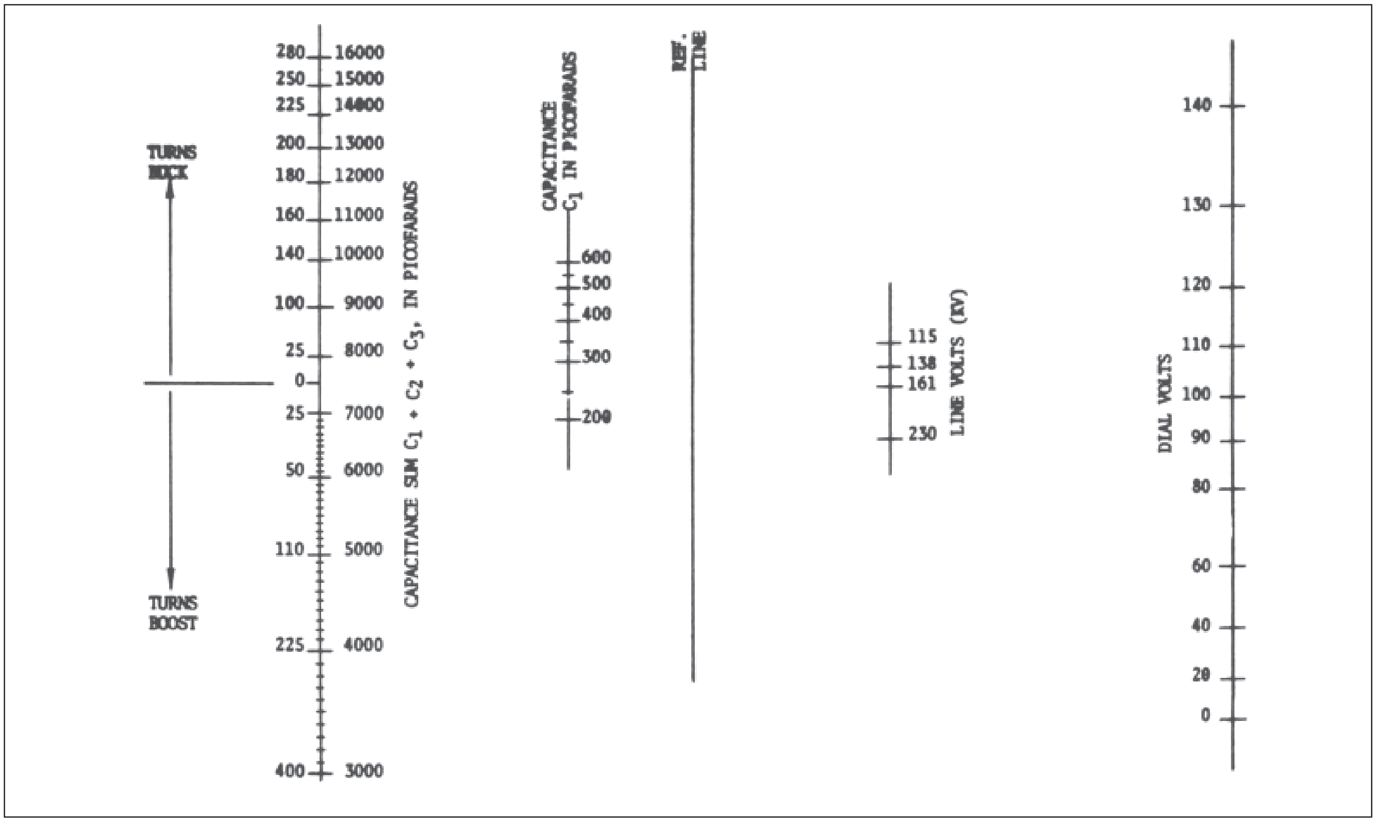


Figure 7: Nomograph for PBA2 Potential Device

Use of nomograph for PBA 2 potential device

1. Calculate the sum of C1 + C2 + C3 using capacitance values of Fig. 3. Mark that value on the first scale on the monograph.

2. Mark C1 on the second scale

3. Draw a straight line through the points on the C1 + C2 + C3 scale and the C1 scale extending to the reference line.

4. Locate the system voltage, which the PBA2 device is measuring on the line volts scale.

5. With a straight line connect the points on the reference line (where the first connecting line intersects the reference line) and the line volts scale, extending to the dial volts scale.

6. Read the correct value for the dial setting of the voltage adjustment on the dial volts scale.

7. Read the number of turns buck or boost to switch in on the furthest left scale opposite the C1 + C2 + C3 point.

Example

C1=300, C2=3000, C3=3000,
Line Volts=138 kV

C1+C2+C3=300+3000+3000=6300 Picofarads

Reading the Scale – Dial Volts=87
Turns Boost=42

Unusual Combinations

Unusual combinations of voltage, bushing, potential device and burden can be checked for workability by calculation. Unit power factor burdens are assumed.

Equation (3) above means that the open circuit tap voltage e will be workable if it lies between 3000 volts and 7600 volts. Of course with e as large as 7600 it would not be possible to carry any burden on the device, since the operating tap voltage rises with added burden, and 7600 is the limiting voltage on the transformer primary.

If the exploration of the paragraph above shows the combination to be workable then its burden carrying ability can be roughly checked by the following:

The reactance XC of equation (4) must be in the range of 125,000 to 800,000 ohms for 60 hertz, or 104,000 to 670,000 ohms for 50 hertz.

Let ex = maximum permissible reactance voltage.

$$\text{then } ex = \sqrt{(7600)^2 - e^2} \qquad (5)$$

$$\text{Max. watts} = \frac{ex}{XC} \times \frac{e}{K} \qquad (6)$$

Constant K from empirical equation K = .95 + .078XC/100,000 but not less than 11.

Application Notes

Heater

Each device contains two vitreous enameled resistors of 1200 ohms each. These are to be energized from an external source for the purpose of preventing the internal sweating of the device. Sweating is objectionable from the point of view of corrosion and also it may temporarily affect some of the high voltage insulation resulting in adjustment unbalance. The resistors may be connected series, parallel or singly and may in any arrangement be energized by either 115 or 230 volts giving a range of 5.5 to 88 watts. The suggested arrangement of the two in parallel at 115 volts gives 22 watts of heating.

Protective Gap

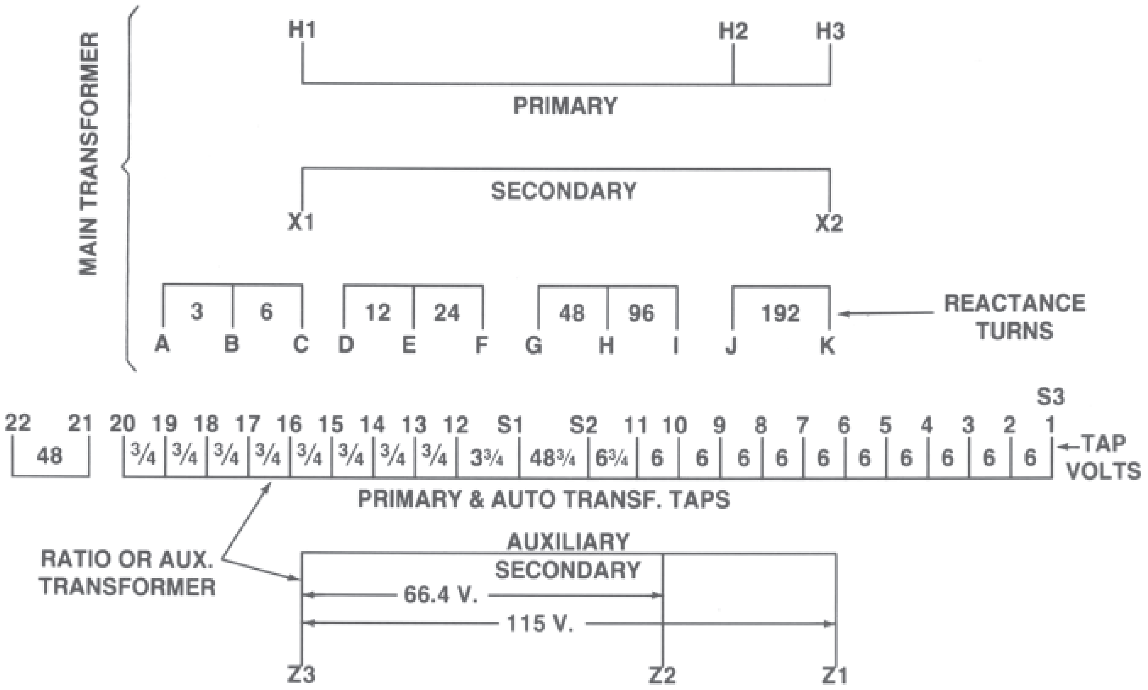
The protective gap across the primary of each device is sealed to prevent modification of its setting by reason of atmospheric changes. It is set to breakdown at 15 to 16 kV 60 hertz, which is sufficiently high to permit operation of the device indefinitely at line-to-line system voltage. The gap will flashover if a short, or overload, is placed on the output of the device, since the primary voltage of the device rises in proportion to the output watts. Continued arcing of the gap will not cause damage for the reason that the current which can flow is limited to a very low value by the impedance of the condenser bushing.

Over voltage Operation

These potential devices may be operated at over voltages up to line-to-line potential for several hours without damage. Over voltages will result if one or two lines of ungrounded system become grounded.

Fusing of Burdens

Inasmuch as the possible output is limited by the protective gap there is no object in attempting to protect burdens by use of fuses.



MAIN TRANSFORMER

PRIMARY — H1-H3 MAX. VOLTS 7600
PRIMARY — H2-H3 MAX. VOLTS 172
PRIMARY — RATIO H1-H3/H2-H3=H1-H3/X1-X2=44.1/1
PRIMARY — REACTANCE 105,000 to 840,000 OHMS APPROX.

RATIO TRANSFORMER

RATIO RANGE, PRIMARY TO S1-S3=173/115 to 59/115
S1-S3 = 115 VOLTS
S2-S3 = 66.4 VOLTS
Z1-Z3 = 115 VOLTS
Z2-Z3 = 66.4 VOLTS

Figure 8: Transformer Tap and Ratio Chart

Operating Tap Voltage

The primary of the device transformer is designed for continuous operation at voltages not in excess of 7600 volts. Therefore, it is necessary to check the voltage H2-H3 after any alteration to be certain this voltage does not exceed 172V.

Adjustment-Need For

The adjustment of a potential device is in effect a “tuning” procedure to affect a “match” between condenser bushing, a potential device and a burden. Therefore, since any one of these is not a perfect duplicate of any other of its own kind, it is necessary to completely re-adjust when any one of the combination is changed.

Auxiliary Winding

The output winding with terminals Z1, Z2 and Z3 is designed for a maximum of 75 watts, and no more than this amount of burden shall be connected to the Z terminals, even though the total rating of the device may be in excess of 75 watts in some cases.

Grounding

Any one terminal of either the “S” winding or the “Z” winding of a device may be grounded (it is not necessary), if desirable for the purposes of the connected burden. The primary of the device transformer is grounded to the device housing and it in turn is grounded to the transformer or breaker tank by the device mounting and by the sheath of the lead-in cable. The current, which flows to ground, is a small fraction of an ampere.

Type of Burden

Burdens having ferro-magnetic cores shall be substantially linear in impedance to 1.73 times normal voltage.

Broken Delta Burdens

The burden connected to the Z terminals, under condition of maximum zero sequence voltage, shall not exceed 50% of the device rating.

Record of Adjustment

A record of the adjustment setting of a given device in a given location will consist of a record of the following:

Volt-amperes of power factor correction, “Buck” or “Boost” of reactance switch, total turns of reactance tapped in, and total volts on primary of voltage adjustment transformer.

Trouble Shooting

Inability to make voltage of phase angle adjustment calls for the following:

1. Recheck the reference voltage for phase angle position.

2. Recheck the circuit being used for adjustment.

3. Check accuracy of voltmeter being used, and also of phase angle meter if one is being used. Note that phase angle meters may not register correctly if coils are not operated at their rated voltage or current.

4. Recheck degree of power factor correction.

5. Calculate the approximate adjustment in line with sections on “Calculation of Approximate Adjustment” and”“Unusual Combinations” to be sure device is applicable to the combination at hand.

6. Check for loose, grounded or open connections within device.

7. Frequency other than 60 hertz on system, such as 25 hertz or 50 hertz.

Variability in performance of device may be due to some loose connections, to electrical leakage to ground at the primary voltage of the transformer, or to shorted turns of transformer primary. The electrical leakage might be in the bushing tap, in the lead-in cable or in the potential device.

Flashing of gap means an overburden on the device, or a ground or short either inside or outside the device, or a defective gap. The gap shall flash over in the region 15 to 20 kV 60 hertz.

A shifting of adjustment with passage of time can be indicative of deterioration of the condenser bushing.

Poor ratio regulation will result from increased losses in the device, and this may result from poor connections or shorted turns in transformers.

Maintenance

The bushing potential device is a piece of static equipment and requires no maintenance other than to see that the heater is energized when it is required, to see that the paint finish is kept in good condition, and to be sure no extraneous objects rest on the lead-in cable. If there is suspicion of change in voltage output then see Trouble Shooting above.

Notes

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