US008570024B1

(12) **United States Patent**
Piesinger

(10) **Patent No.: US 8,570,024 B1**
(45) **Date of Patent: Oct. 29, 2013**

(54) **NON-CONTACT PHASE IDENTIFICATION METHOD AND APPARATUS**

(76) Inventor: **Gregory Hubert Piesinger**, Cave Creek, AZ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 452 days.

(21) Appl. No.: **12/932,241**

(22) Filed: **Feb. 22, 2011**

Related U.S. Application Data

(60) Provisional application No. 61/338,910, filed on Feb. 24, 2010.

(51) **Int. Cl.**
G01R 19/00 (2006.01)

(52) **U.S. Cl.**
USPC **324/67**; 324/66; 324/86; 702/72; 702/188

(58) **Field of Classification Search**
USPC 324/66, 67, 86; 702/72, 188
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

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8,013,592	B2 *	9/2011	Giubbini et al.	324/76.77
2011/0130992	A1 *	6/2011	Kolwalkar et al.	702/72

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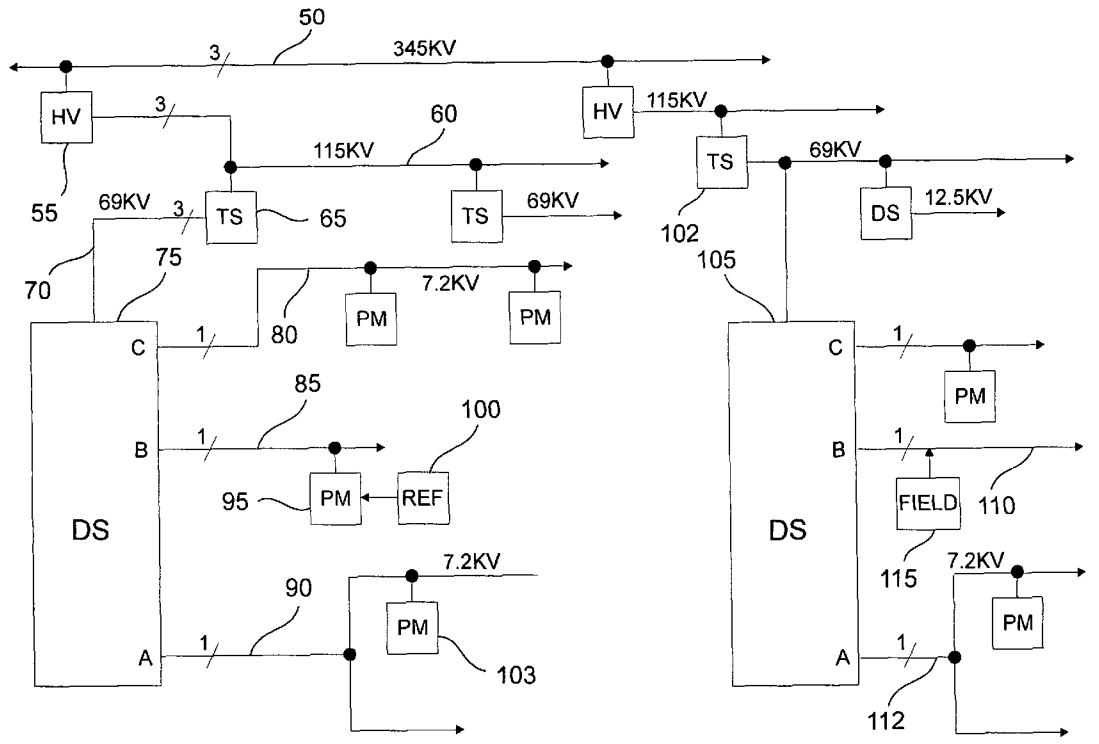
Primary Examiner — Patrick Assouad
Assistant Examiner — Sean Curtis

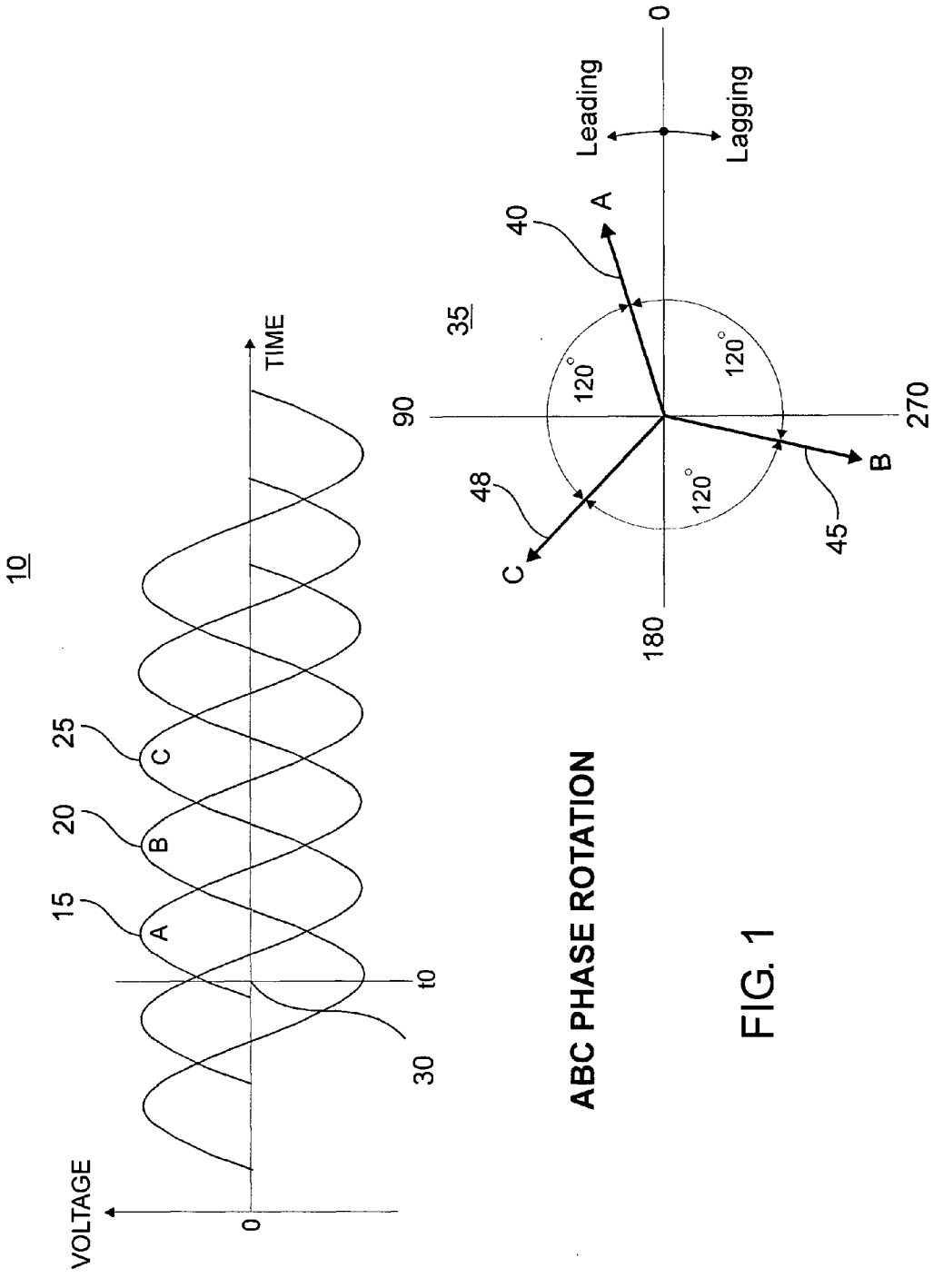
(57) **ABSTRACT**

A phase identification system identifies the unknown phase attribute of any energized conductor within a three-phase power distribution network by comparing remote location non-contact phase identification instrument phase measurements to phase measurements taken at a reference location. The vector sum of three-phase conductor voltages at the remote measurement location are used to determine the near, center, and far conductor phase attributes of the three-phase lines being measured. This allows phase attributes of high overhead conductors to be determined from ground level using a non-contact handheld instrument.

20 Claims, 17 Drawing Sheets



HV = HIGH VOLTAGE SUBSTATION TRANSFORMER
TS = TRANSMISSION SUBSTATION TRANSFORMER
DS = DISTRIBUTION SUBSTATION TRANSFORMER
PM = POLE OR PAD MOUNT TRANSFORMER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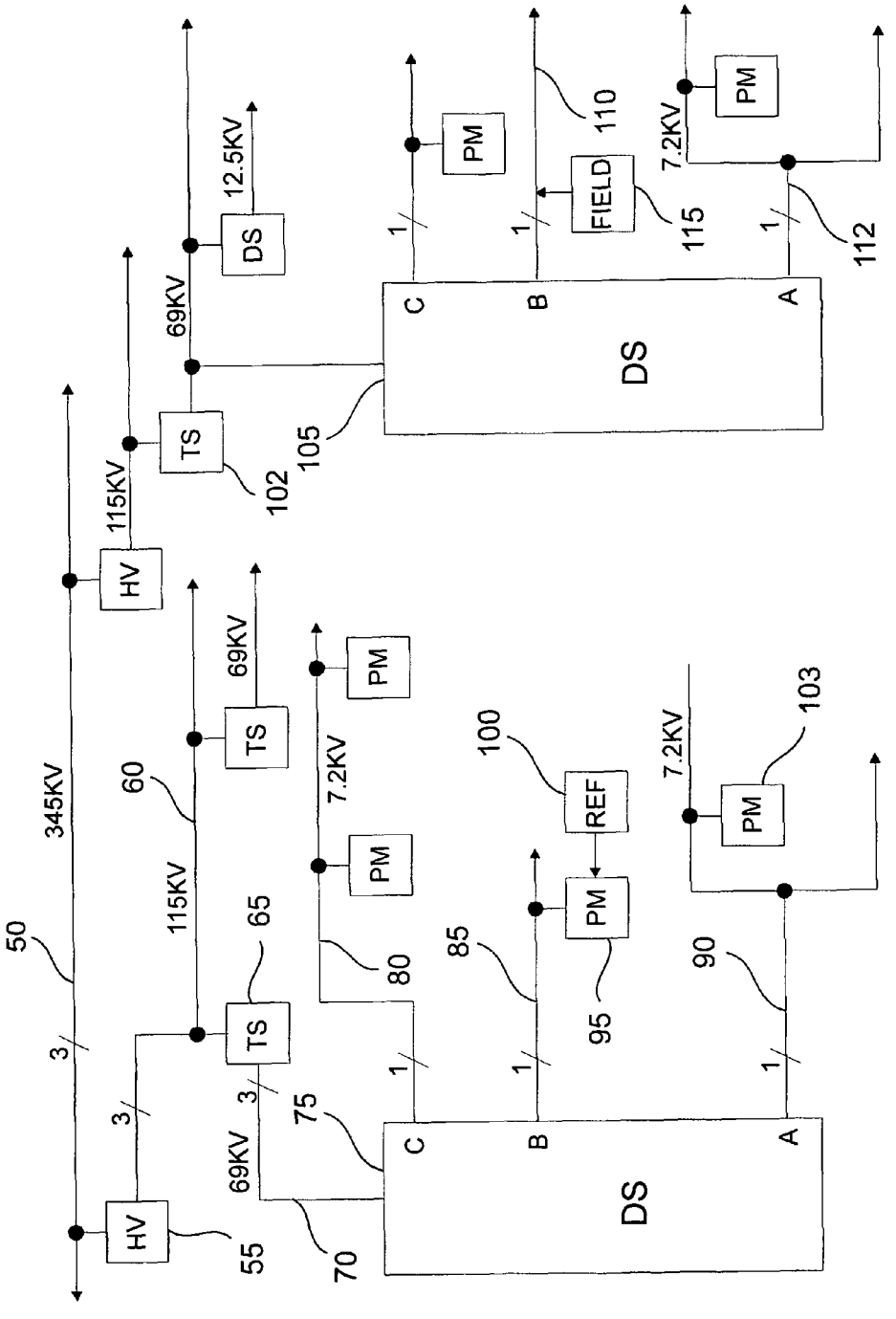
VOLTAGE
TIME
0
t0
15
20
25
30
A
B
C
35
40
45
48
0
90
180
270
Leading
Lagging
120°
120°
120°
ABC PHASE ROTATION

FIG. 1



HV = HIGH VOLTAGE SUBSTATION TRANSFORMER
TS = TRANSMISSION SUBSTATION TRANSFORMER
DS = DISTRIBUTION SUBSTATION TRANSFORMER
PM = POLE OR PAD MOUNT TRANSFORMER

FIG. 2

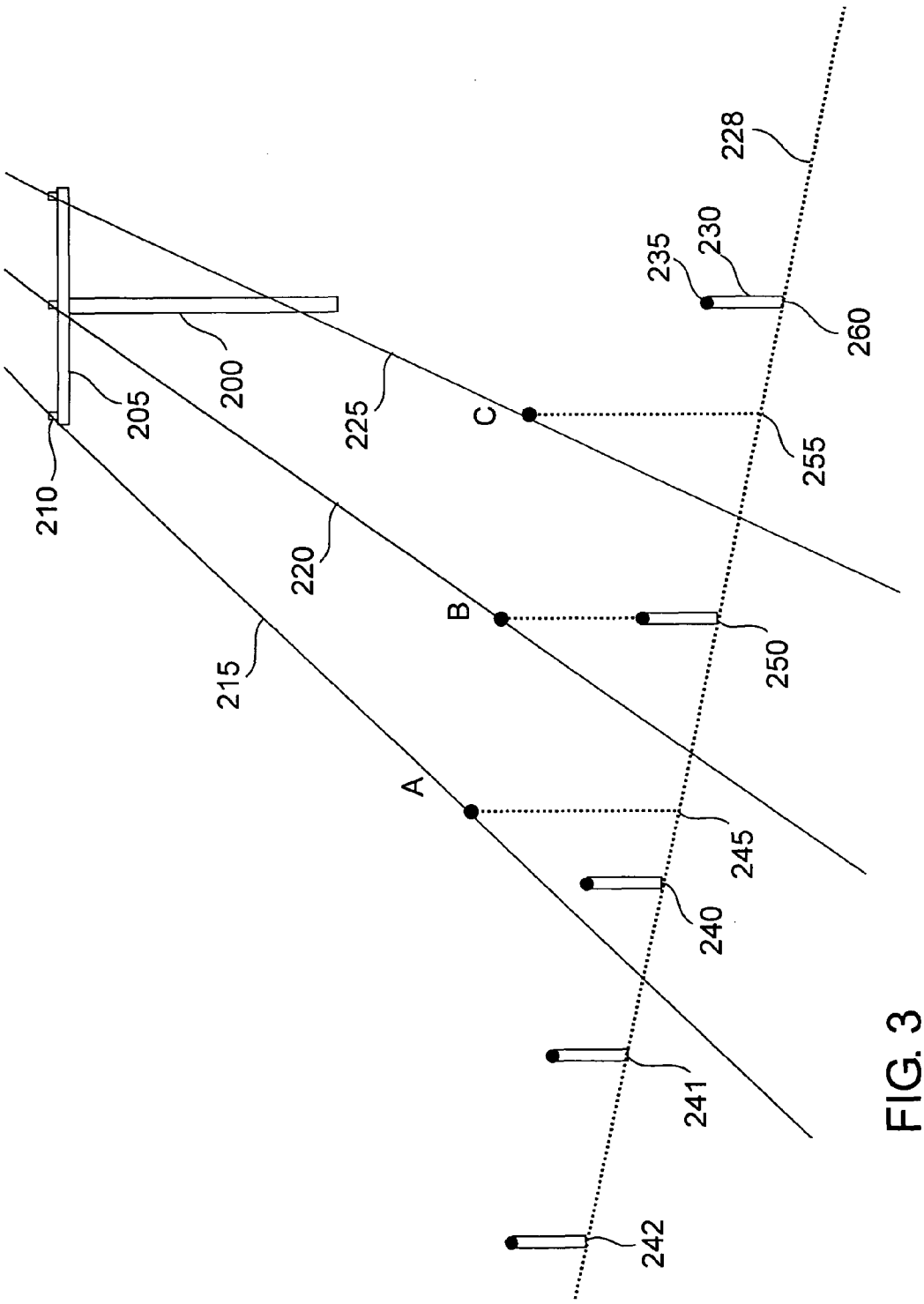

210
205
200
225
220
215
C
B
A
228
235
230
260
255
250
245
240
241
242

FIG. 3

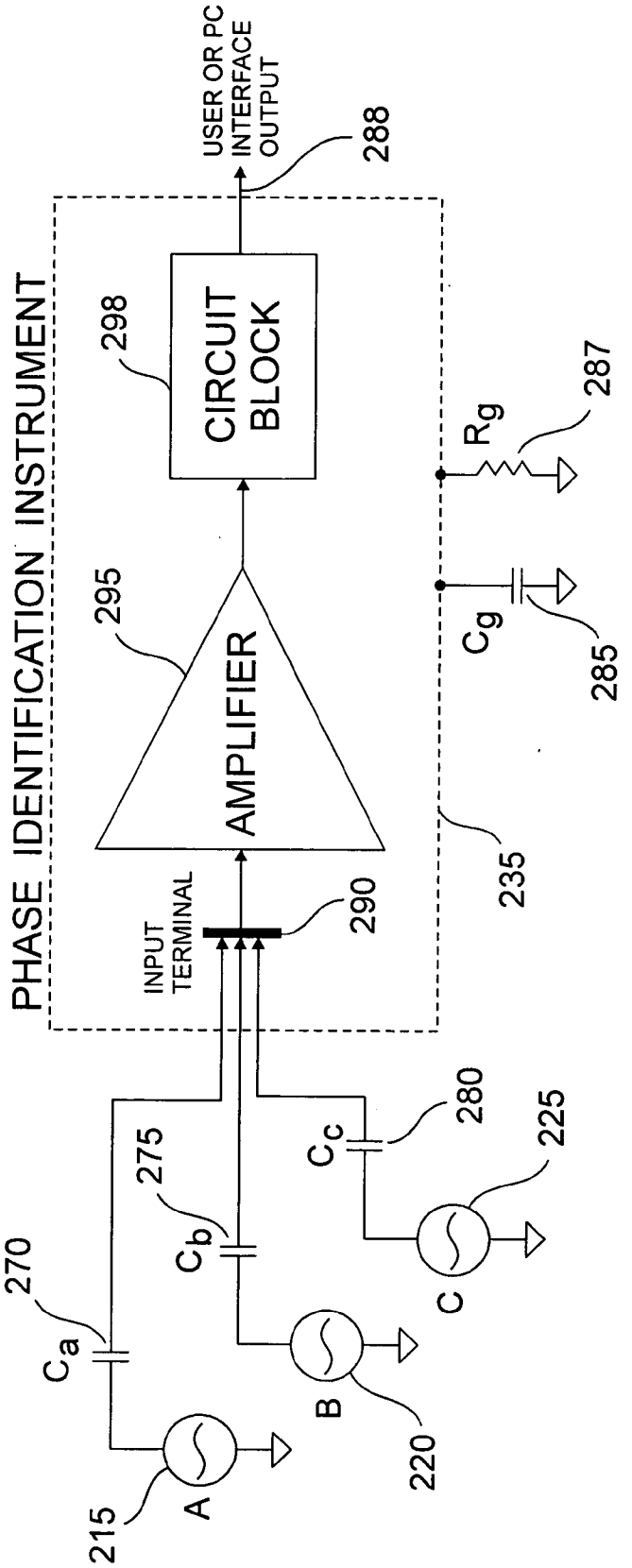

PHASE IDENTIFICATION INSTRUMENT
USER OR PC INTERFACE OUTPUT
288
CIRCUIT BLOCK
298
AMPLIFIER
295
INPUT TERMINAL
290
235
R_g
287
C_g
285
C_a
270
C_b
275
C_c
280
A
215
B
220
C
225

FIG. 4

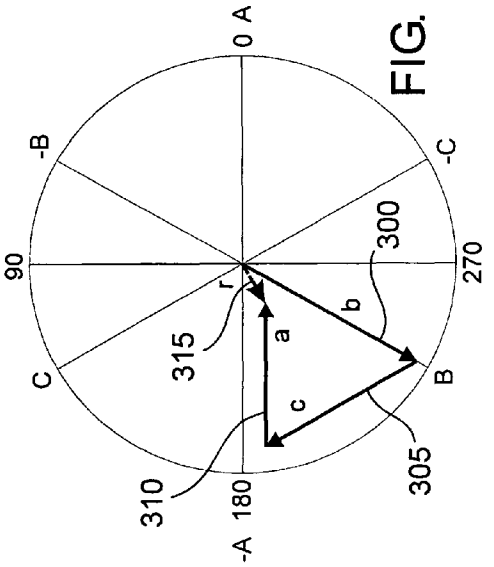


FIG. 6

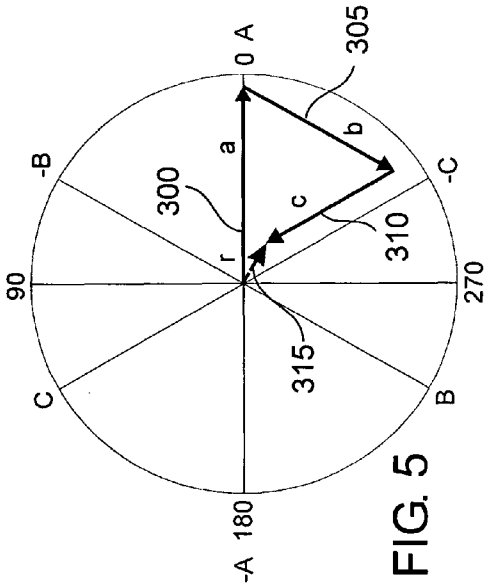
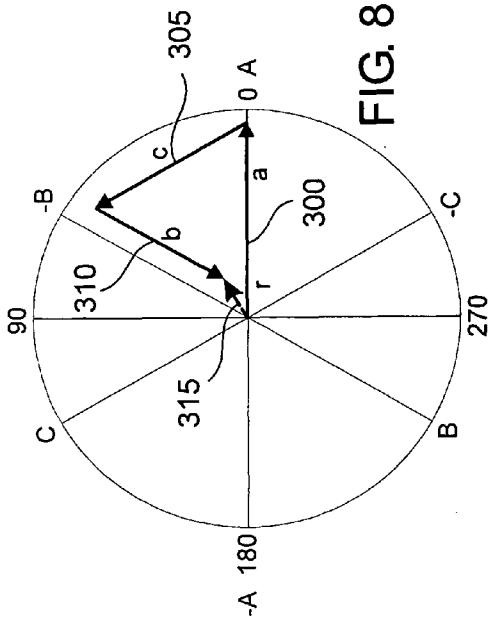


FIG. 5



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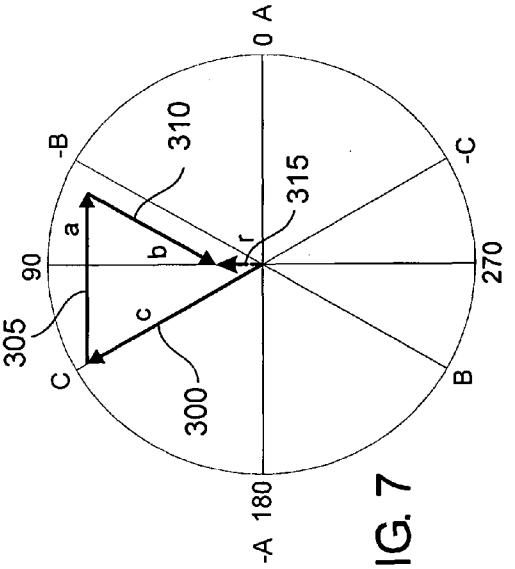

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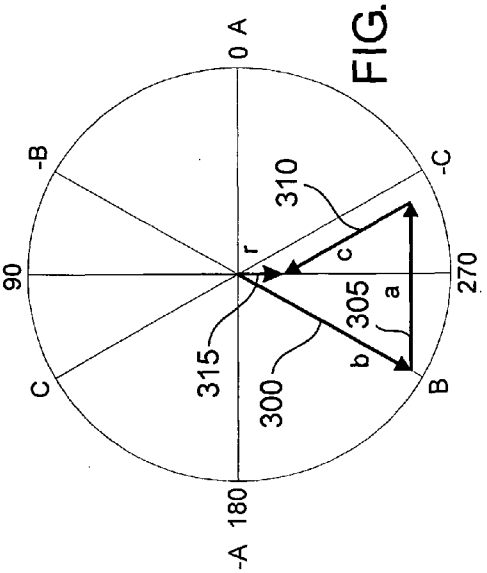

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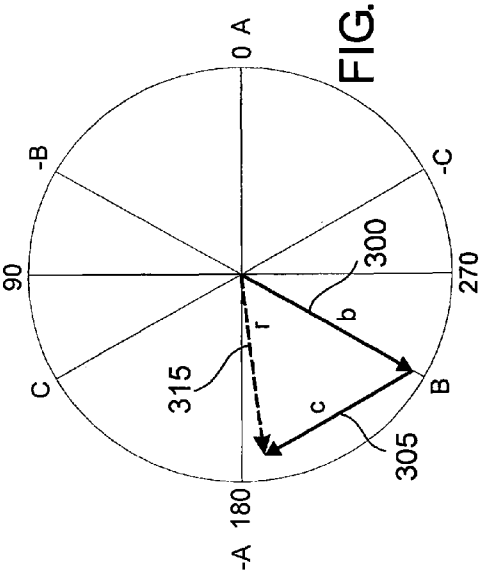
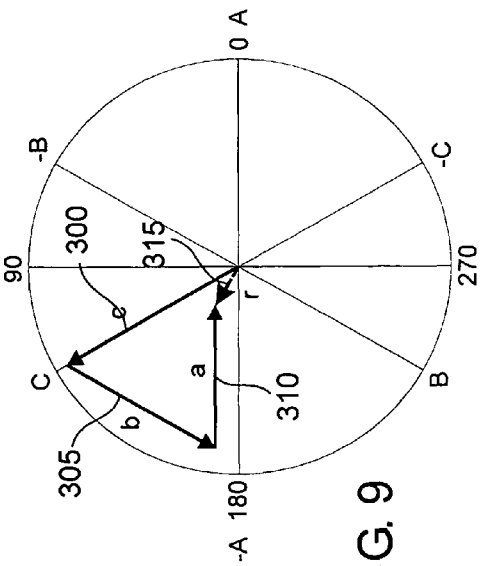


FIG. 12



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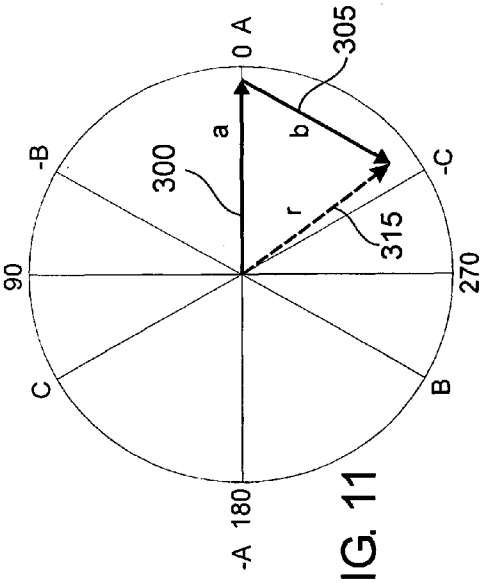

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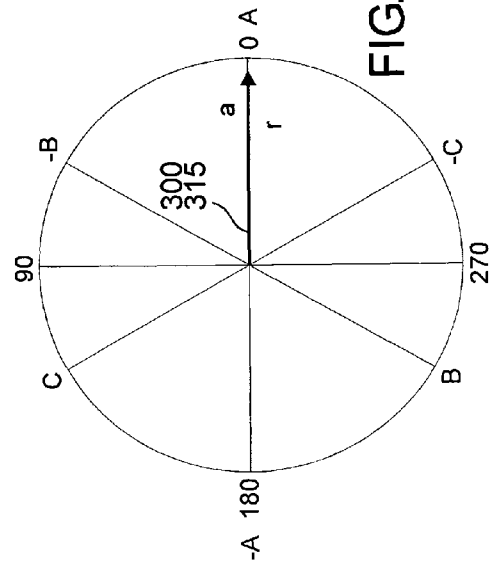

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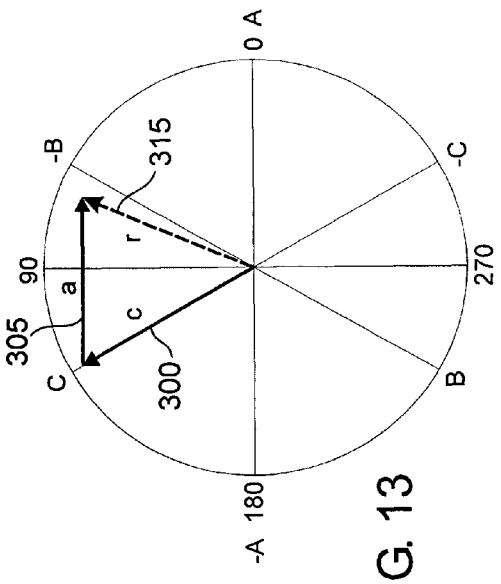

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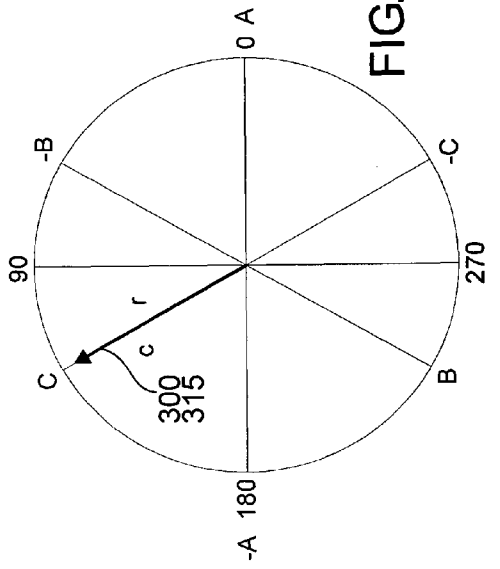

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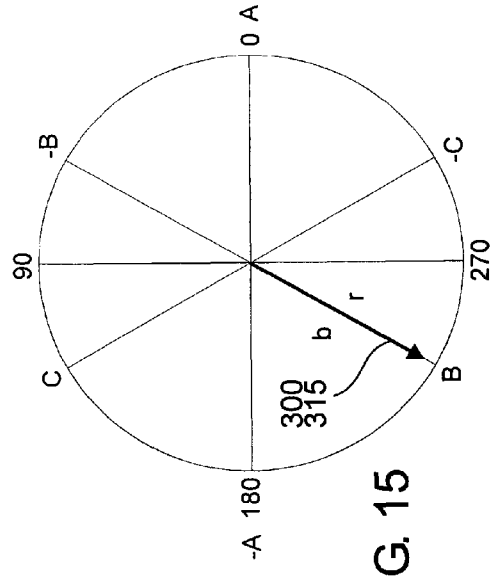

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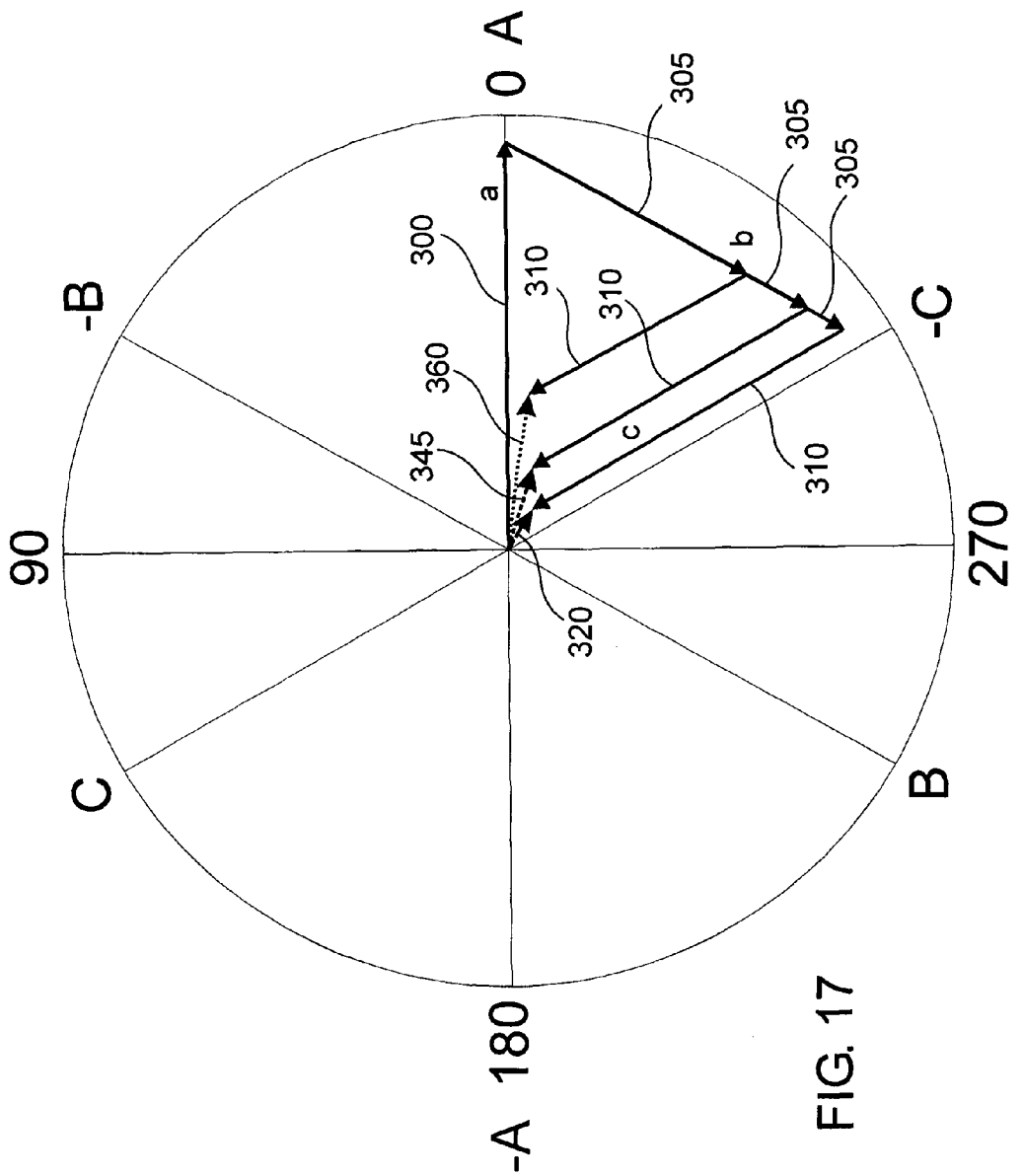

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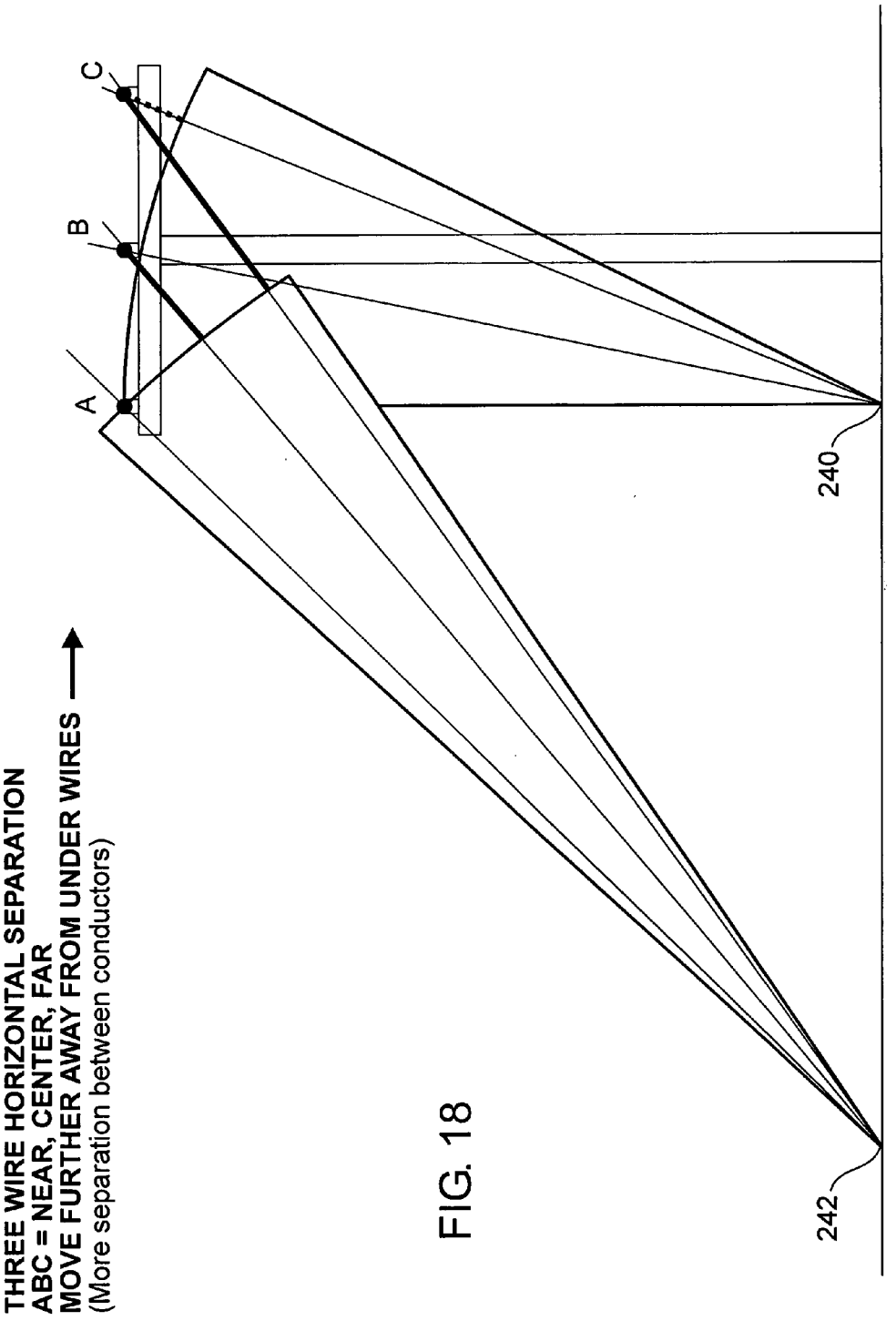
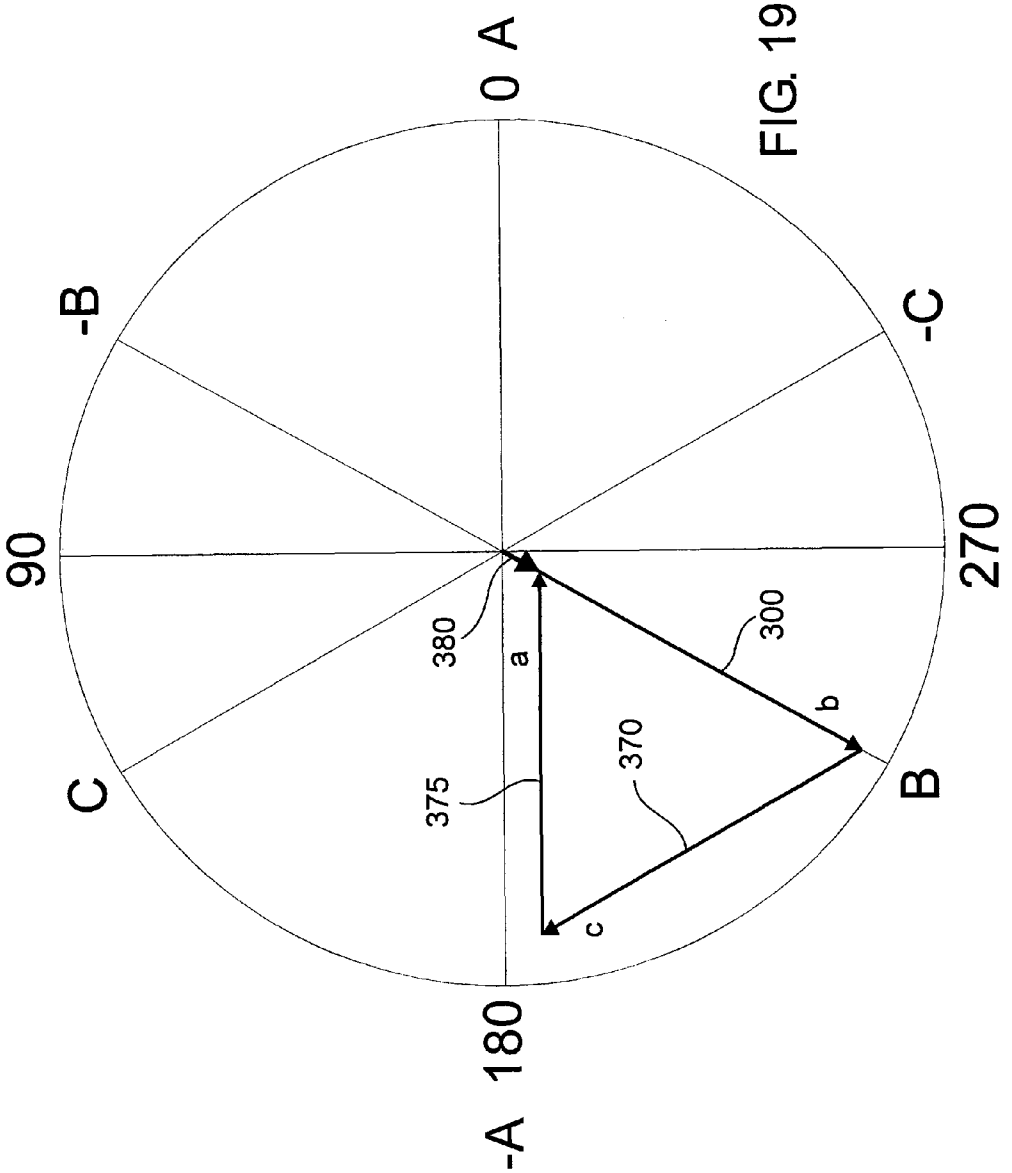

THREE WIRE HORIZONTAL SEPARATION
ABC = NEAR, CENTER, FAR
MOVE FURTHER AWAY FROM UNDER WIRES
(More separation between conductors)
A
B
C
240
242

FIG. 18



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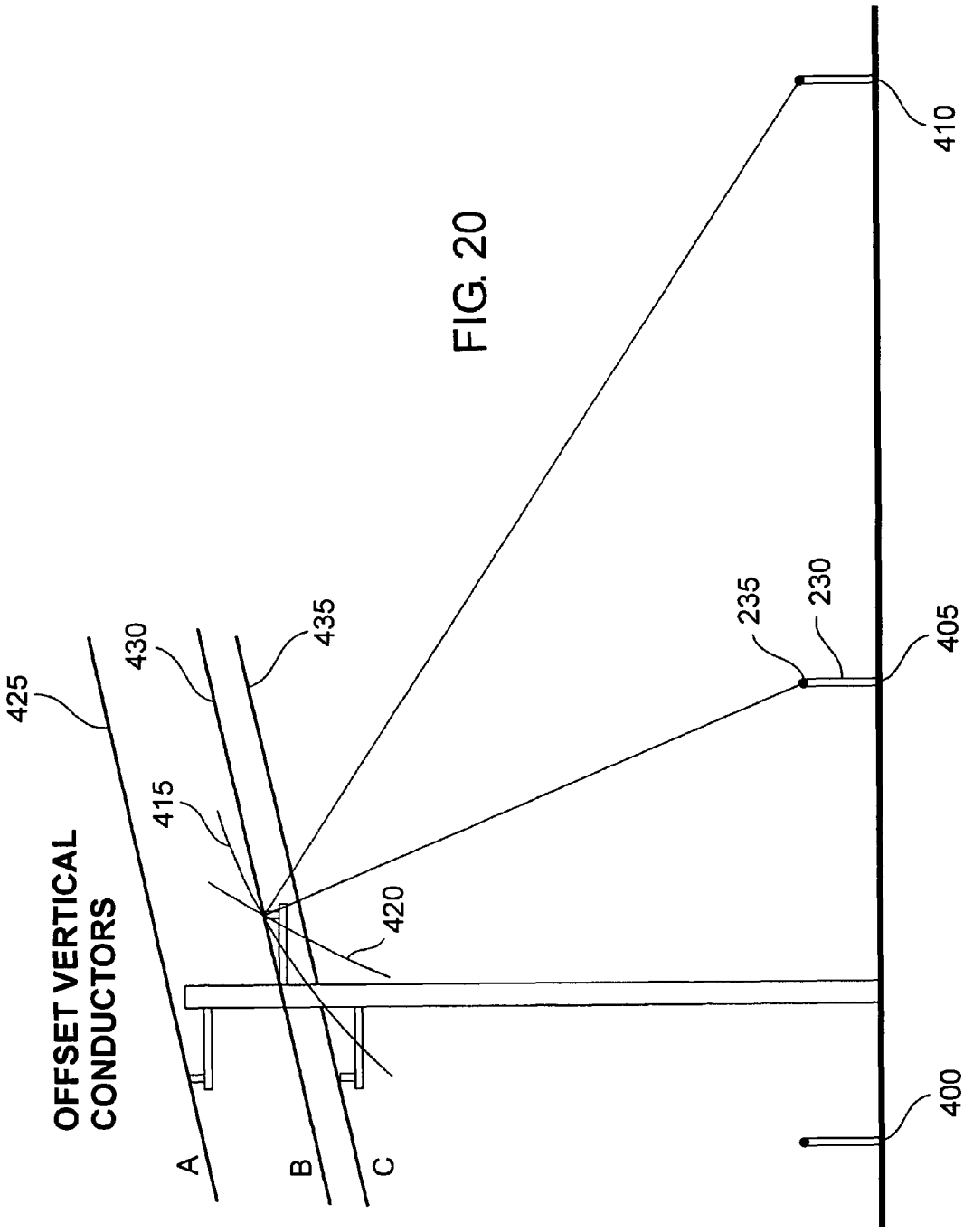

OFFSET VERTICAL CONDUCTORS
A
B
C
425
430
435
415
420
235
230
405
410
400

FIG. 20

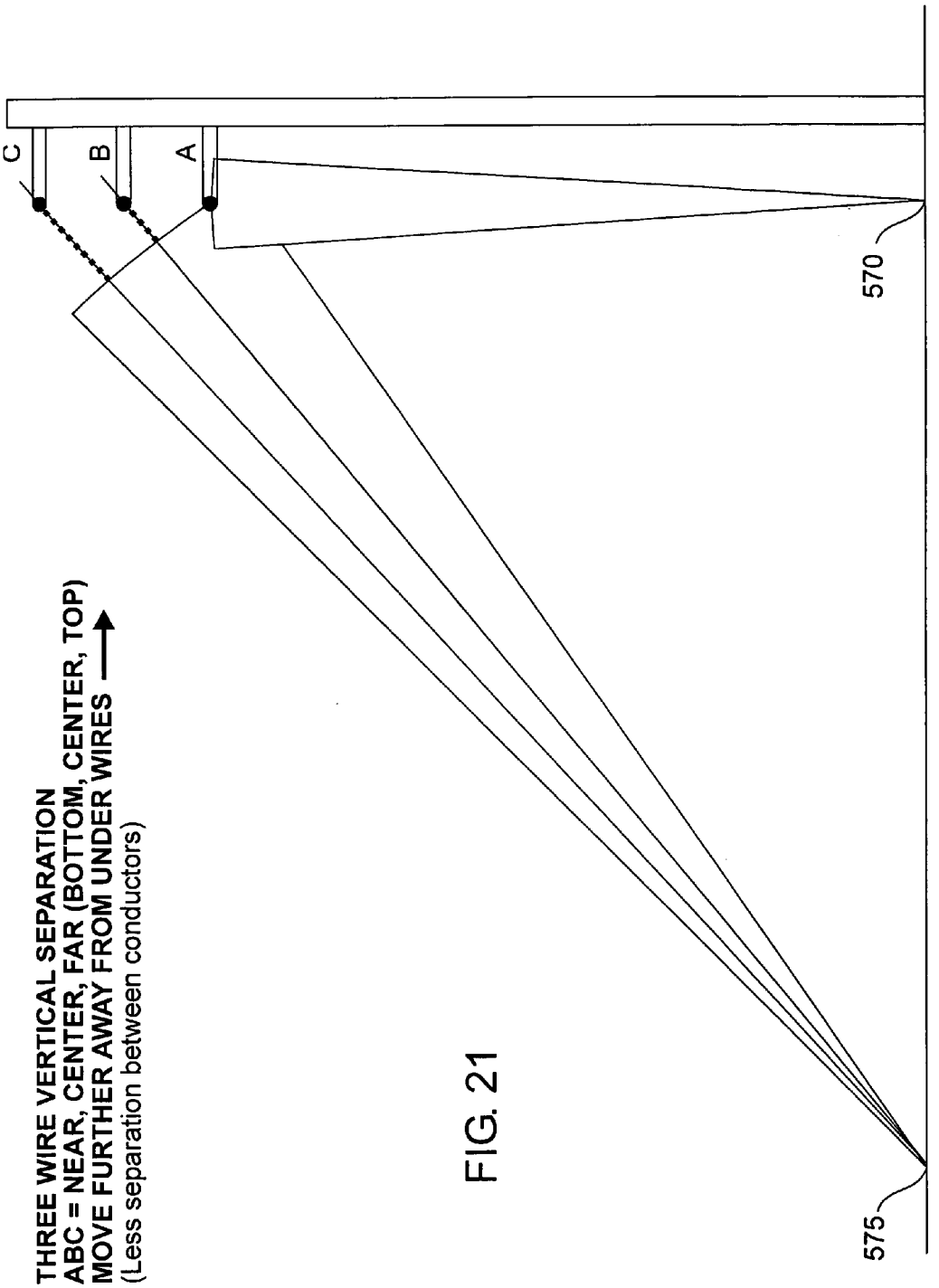

C
B
A
570
575
THREE WIRE VERTICAL SEPARATION
ABC = NEAR, CENTER, FAR (BOTTOM, CENTER, TOP)
MOVE FURTHER AWAY FROM UNDER WIRES
(Less separation between conductors)

FIG. 21

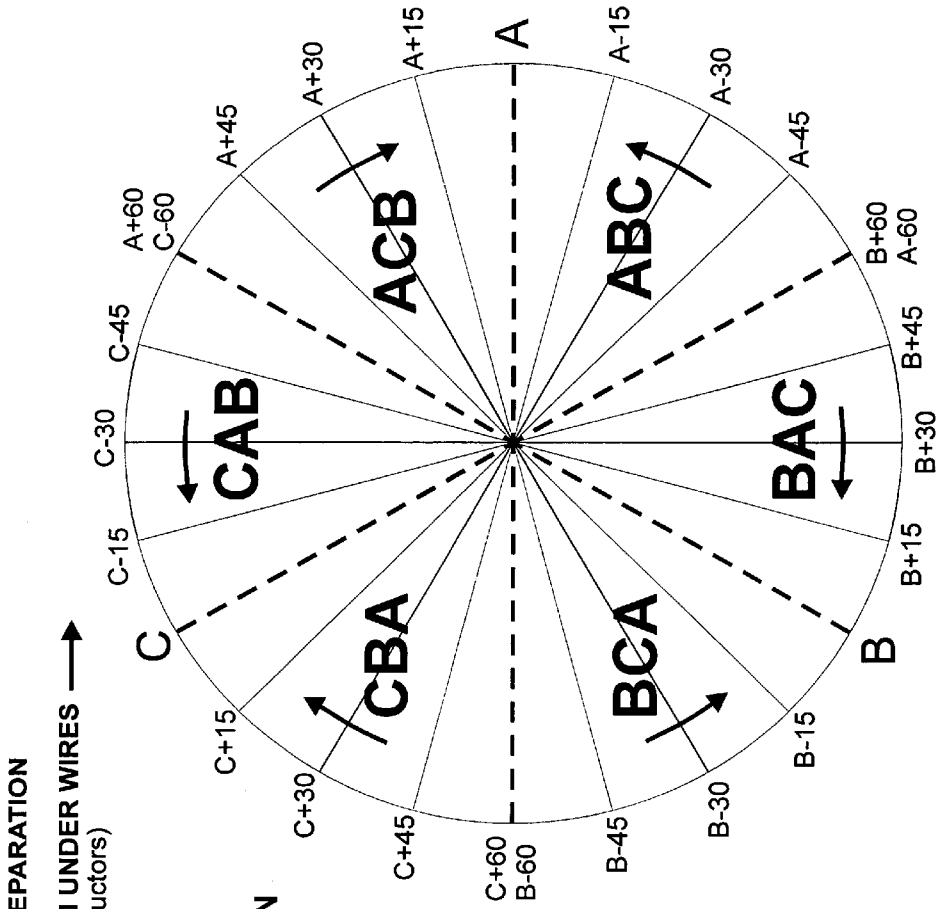

THREE WIRE HORIZONTAL SEPARATION
ABC = NEAR, CENTER, FAR
MOVE FURTHER AWAY FROM UNDER WIRES
(More separation between conductors)
ABC PHASE ROTATION
A
A+15
A+30
A+45
A+60
C-60
C-45
C-30
C-15
C
C+15
C+30
C+45
C+60
B-60
B-45
B-30
B-15
B
B+15
B+30
B+45
B+60
A-60
A-45
A-30
A-15
ACB
ABC
CAB
BAC
CBA
BCA

FIG. 22

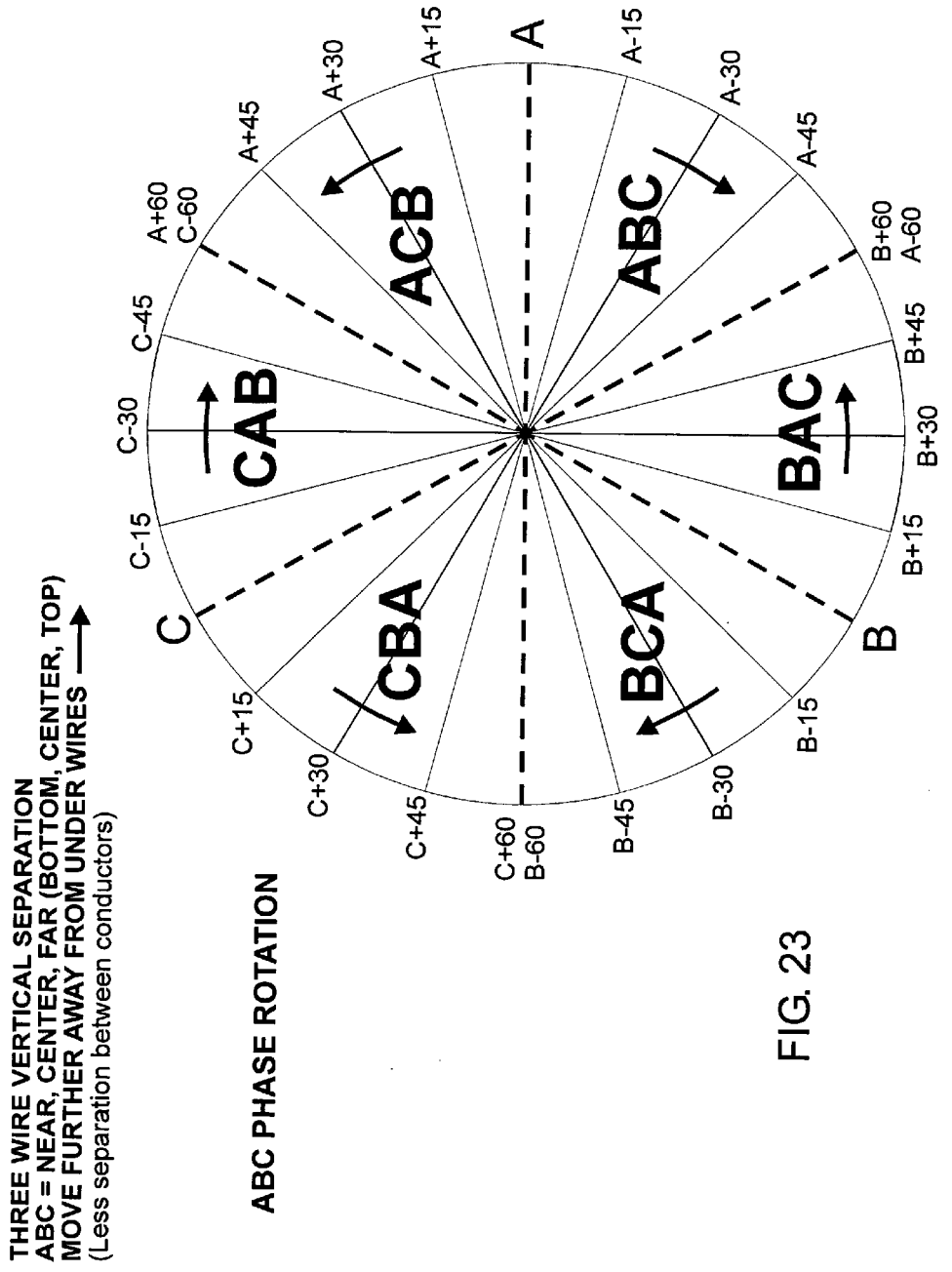

THREE WIRE VERTICAL SEPARATION
ABC = NEAR, CENTER, FAR (BOTTOM, CENTER, TOP)
MOVE FURTHER AWAY FROM UNDER WIRES
(Less separation between conductors)
ABC PHASE ROTATION
A
B
C
ABC
BAC
BCA
CBA
CAB
ACB
A+15
A+30
A+45
A+60
C-60
A-15
A-30
A-45
B+60
A-60
B+45
B+30
B+15
B-15
B-30
B-45
B-60
C+60
C+45
C+30
C+15
C-15
C-30
C-45

FIG. 23

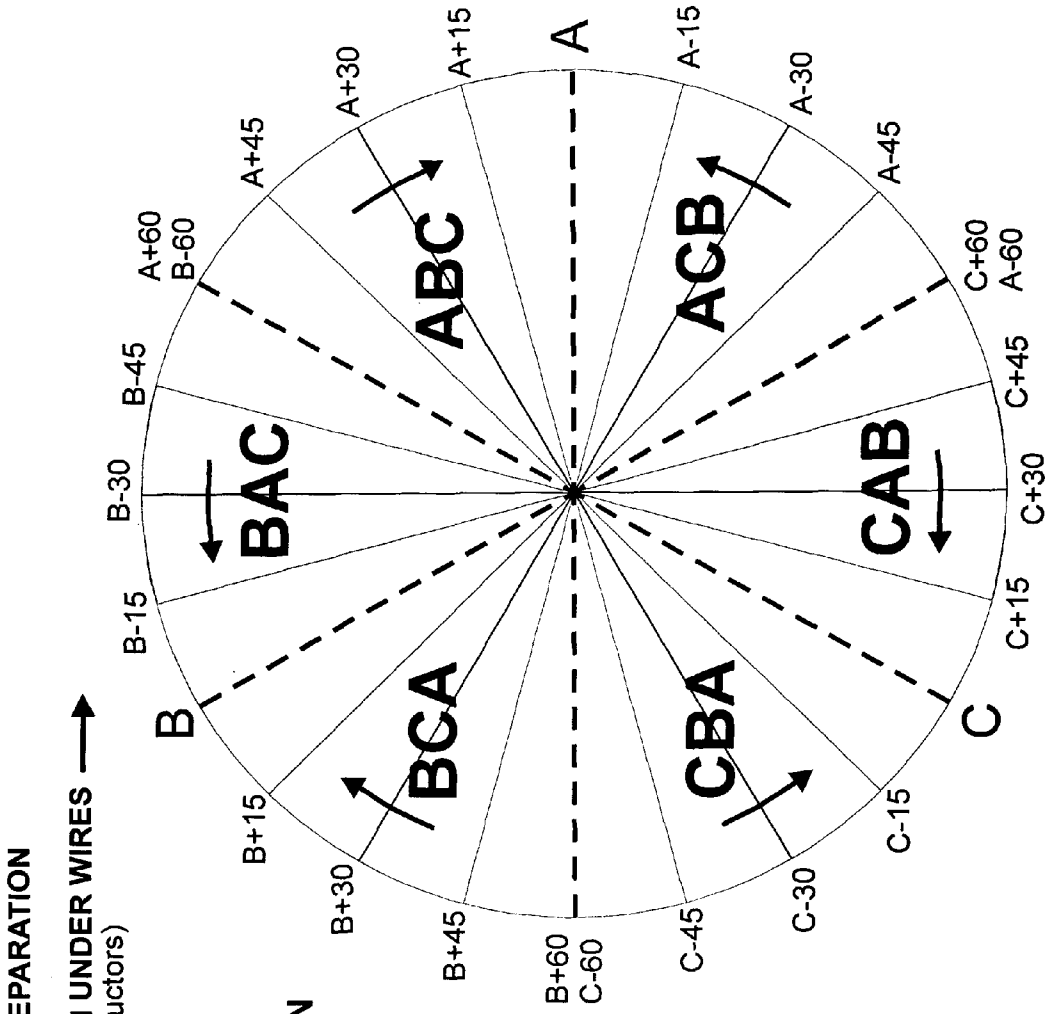
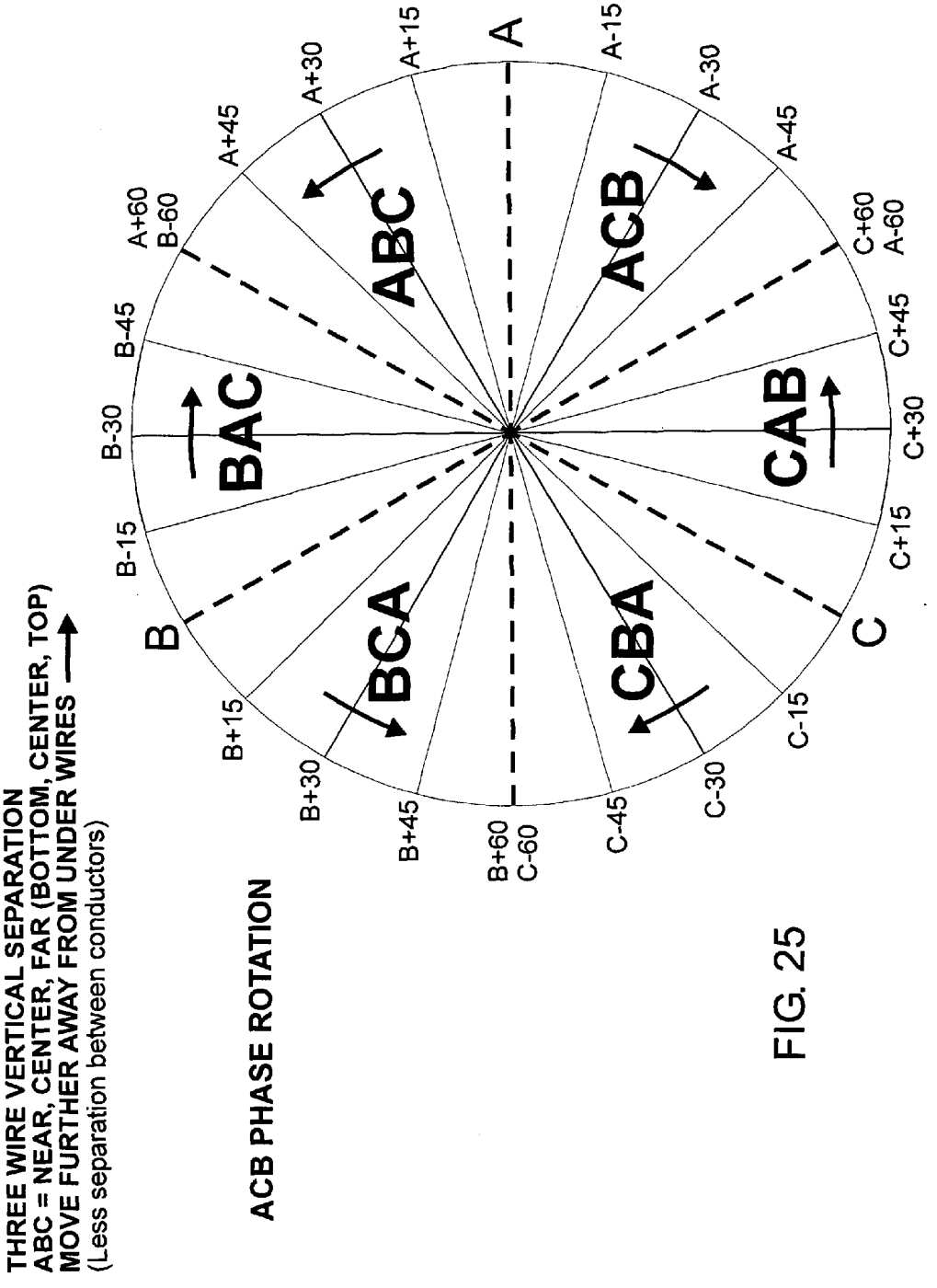

THREE WIRE HORIZONTAL SEPARATION
ABC = NEAR, CENTER, FAR
MOVE FURTHER AWAY FROM UNDER WIRES
(More separation between conductors)
ACB PHASE ROTATION
A
B
C
ABC
ACB
BAC
BCA
CAB
CBA
A+15
A+30
A+45
A+60
B-60
B-45
B-30
B-15
B+15
B+30
B+45
B+60
C-60
C-45
C-30
C-15
C+15
C+30
C+45
C+60
A-60
A-45
A-30
A-15

FIG. 24


THREE WIRE VERTICAL SEPARATION
ABC = NEAR, CENTER, FAR (BOTTOM, CENTER, TOP)
MOVE FURTHER AWAY FROM UNDER WIRES
(Less separation between conductors)
ACB PHASE ROTATION
A
B
C
ABC
ACB
BAC
BCA
CAB
CBA
A+15
A+30
A+45
A+60
B-60
A-15
A-30
A-45
C+60
A-60
B-45
B-30
B-15
C+45
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C-45
C-30
C-15

FIG. 25

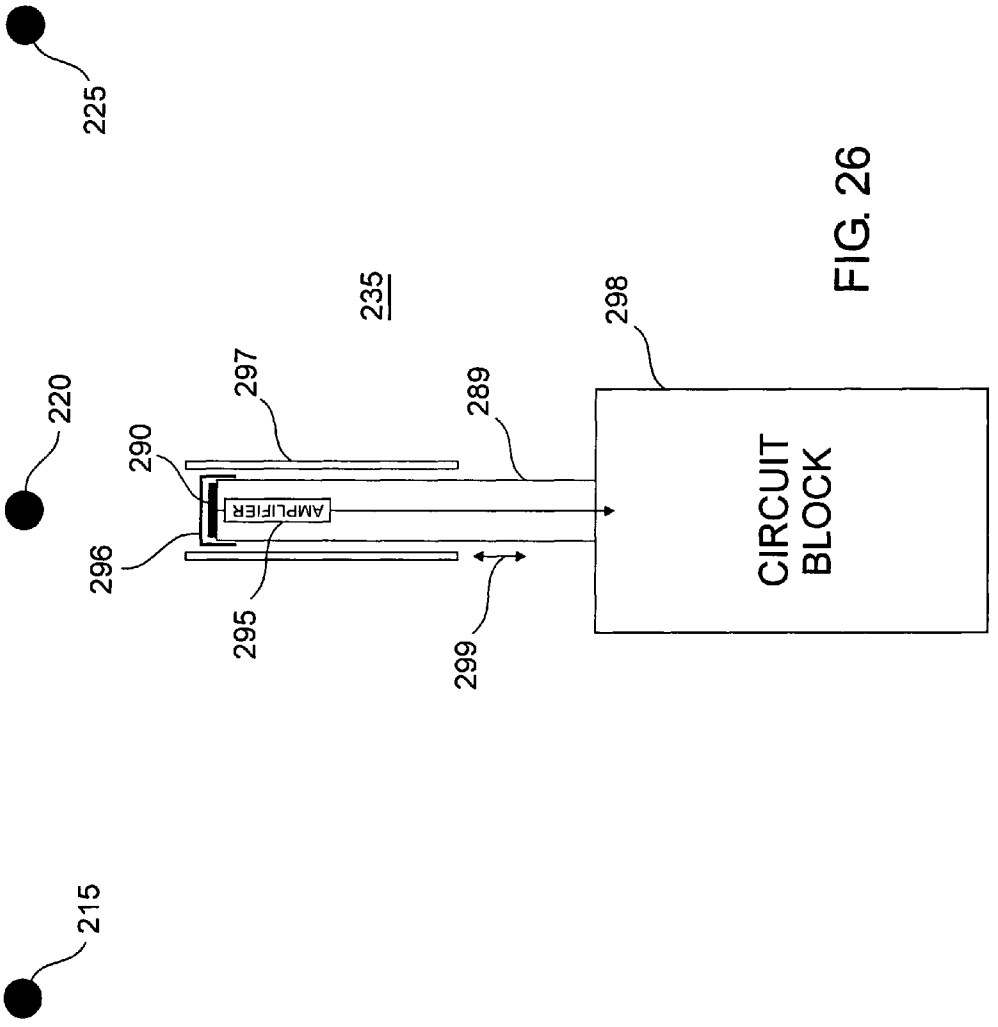
225
220
290
297
235
289
298
AMPLIFIER
CIRCUIT BLOCK
296
295
299
215

FIG. 26

NON-CONTACT PHASE IDENTIFICATION METHOD AND APPARATUS

RELATED INVENTION

The present invention claims priority under 35 U.S.C. §119 (e) to: "Non-Contact Phase Identification Method and Apparatus" Provisional U.S. Patent Application Ser. No. 61/338,910, filed 24 Feb. 2010 which is incorporated by reference herein.

TECHNICAL FIELD OF THE INVENTION

The present invention relates to the field of three-phase power distribution networks. More specifically, the present invention relates to the field of identifying the phase of a conductor in a three-phase power distribution network.

BACKGROUND OF THE INVENTION

Electric power distribution networks are used by the electric utilities to deliver electricity from generating plants to customers. Although the actual distribution voltages will vary from utility to utility, in a typical network, three-phase power at high voltage 345,000 volts phase-to-phase (345 KV) is delivered to multiple high voltage substations at which transformers step this high voltage down to a lower three-phase voltage 115 KV. Multiple transmission substations further lower this voltage to 69 KV. This 69 KV three-phase power then feeds multiple distribution substations whose transformers further step down this voltage to distribution voltage (12,470 volts phase-to-phase) and separate power into three single-phase feeder cables. Typically, these feeder cables operate at 7,200 volts phase-to-ground. Each of these feeder cables branch into multiple circuits to power a plurality of local pole-mounted or pad-mounted transformers which step the voltage down to a final voltage of 120 and 240 volts for delivery to commercial and residential customers.

The instantaneous phases of the three conductors in a three-phase system are separated by 120 degrees. A phase attribute of A, B, or C is typically assigned to each of the three conductors to identify them. The initial assignment of phase attribute to each of the three conductors typically takes place at a transmission or distribution substation and this assignment is somewhat arbitrary. The attributes assigned at the substations become known as the tagging reference phases for that substation because the goal is to consistently tag, mark, or identify each conductor with its proper phase attribute throughout the substation's distribution region.

Utilities have many reasons for accurately identifying the phase of each conductor in their utility. Examples are load balancing to reduce neutral current flow, faster service restoration after outages, and for distribution automation purposes.

Most currently available phase identification instruments use GPS timing signals to obtain instantaneous phase measurements at a reference location and field location at the same instant of time. The phase attribute at the reference location is known which allows the phase attribute at the field location to be determined. For example, if the reference location phase attribute is B and the instantaneous phase measured at both locations are the same, then the field location phase attribute is also B. If the instantaneous field location phase is leading or lagging the instantaneous reference location phase by 120 degrees, then the field location phase attribute is either A or C depending on the utilities known phase rotation.

To identify the field location phase attribute, the instantaneous phases at both locations have to be compared. Current phase identification instruments differ primarily in the method they each use to communicate the instantaneous phase reading between the reference location unit and the field location unit. Most manufacturers implement a real-time communication system using cell phones. Piesinger's, U.S. Pat. Nos. 6,667,610 and 7,031,859 describe a phase identification method that does not require real-time cell phone communication.

To phase identify high voltage transmission and distribution conductors, the phase identification instrument is typically attached to an insulated fiberglass stick. Short sticks are called hot sticks and long telescoping ones are called extendo sticks. The purpose of these sticks is to place the phase identification instrument in close proximity to the conductor being phase identified and to protect the lineman from the high voltage. To reach high overhead transmission and distribution lines, long extendo sticks on the order of 30 to 50 feet may be required.

Maneuvering the phase identification instrument, on the end of a long extendo stick, into position is difficult and time consuming. It is especially difficult in a strong wind because long extendo sticks are not very rigid. Gusting winds can cause the phase identification instrument to sway wildly making it nearly impossible to hold it into position next to a high overhead cable. However, even using short hot sticks is inconvenient because it takes time to attach the phase identification instrument to the stick and hot sticks have to be carefully stored and maintained to remain effective as an insulator.

Accordingly, it is the object of the present invention to provide a new and improved method and apparatus for phase identifying high voltage conductors without the need for hot sticks or extendo sticks.

SUMMARY OF THE INVENTION

Briefly, to achieve the desired objects of the present invention, a high sensitivity handheld phase identification instrument is combined with an optimum measurement procedure to allow a lineman to identify the phase attributes of high overhead transmission and distribution lines while standing on the ground near or underneath the overhead lines.

To achieve the required sensitivity, a high gain front end powerline voltage amplifier or hard limiter is used prior to the phase identification instrument processing circuit. Lineman measurement positions are selected, based on the type of overhead line construction, to ensure that at least one of the lines is closer to the lineman than the remaining lines.

It is a further object of the present invention to implement the front end amplifier so as to minimize the phase shift through the amplifier as a function of signal dynamic range. This allows the same handheld instrument to be used in ground level high voltage cabinets and in substations where close proximity to high voltage conductors result in high signal levels.

It is a further object of the present invention to implement a handheld phase identification instrument that can be used by lower-labor-cost non-linemen personnel by eliminating the need for close or direct phase identification instrument contact with the energized conductor.

These and other embodiments are discussed below.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates voltage phase relationships in a three-phase power network with ABC phase rotation using both voltage-time and phase vector diagrams.

FIG. **2** illustrates a typical three-phase power distribution network.

FIG. **3** illustrates typical horizontal three-phase construction and various phase attribute measurement positions near the lines.

FIG. **4** illustrates a block diagram of the phase identification instrument.

FIG. **5** illustrates the resultant vector due to near, center, far conductor attributes ABC.

FIG. **6** illustrates the resultant vector due to near, center, far conductor attributes BCA.

FIG. **7** illustrates the resultant vector due to near, center, far conductor attributes CAB.

FIG. **8** illustrates the resultant vector due to near, center, far conductor attributes ACB.

FIG. **9** illustrates the resultant vector due to near, center, far conductor attributes CBA.

FIG. **10** illustrates the resultant vector due to near, center, far conductor attributes BAC.

FIG. **11** illustrates the resultant vector due to near, far conductor attributes AB.

FIG. **12** illustrates the resultant vector due to near, far conductor attributes BC.

FIG. **13** illustrates the resultant vector due to near, far conductor attributes CA.

FIG. **14** illustrates the resultant vector due to single conductor attribute A.

FIG. **15** illustrates the resultant vector due to single conductor attribute B.

FIG. **16** illustrates the resultant vector due to single conductor attribute C.

FIG. **17** illustrates the resultant vectors for different differential distances from three-phase conductors whose near, center, far attributes are ABC.

FIG. **18** illustrates conductor distances for different measurement positions on horizontal overhead lines.

FIG. **19** illustrates the resultant vector when standing directly under the center conductor of horizontal overhead lines with attributes ABC.

FIG. **20** illustrates offset vertical overhead line construction.

FIG. **21** illustrates conductor distances for different measurement positions on vertical overhead lines.

FIG. **22** illustrates the expected resultant vector phase angle and its rotation with distance for phase attribute measurements on horizontal overhead lines with ABC phase rotation.

FIG. **23** illustrates the expected resultant vector phase angle and its rotation with distance for phase attribute measurements on vertical overhead lines with ABC phase rotation.

FIG. **24** illustrates the expected resultant vector phase angle and its rotation with distance for phase attribute measurements on horizontal overhead lines with ACB phase rotation.

FIG. **25** illustrates the expected resultant vector phase angle and its rotation with distance for phase attribute measurements on vertical overhead lines with ACB phase rotation.

FIG. **26** illustrates a sketch of the handheld phase identification instrument.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Commonly owned U.S. Pat. No. 6,667,610 issued Dec. 23, 2003 and U.S. Pat. No. 7,031,859 issued Apr. 18, 2006, which are incorporated herein by reference, describe a non-real-time phase identification system. Commonly owned patent application Ser. No. 12/927,767 filed Nov. 23, 2010, which is also incorporated herein by reference, describes a real-time phase identification system.

The basic concept of three-phase powerline voltage with ABC phase rotation is illustrated in FIG. **1**. Voltage-time waveform **10** and rotational vector diagram **35** illustrate voltage-time waveform **10** at instantaneous time t0 **30**. Attribute B voltage **20** and vector **45** lags attribute A voltage **15** and vector **40** by 120 degrees. Likewise, attribute C voltage **25** and vector **48** lags attribute B voltage **20** and vector **45** by 120 degrees.

A typical power distribution network is illustrated in FIG. **2** in which three-phase power cables **50** at 345 KV feed a series of high voltage (HV) transformers **55** spread out over a large geographical area. The 115 KV output **60** of transformers **55** are connected to a series of transmission transformers (TS) **65** also spread out over a large geographical area. The 69 KV output **70** of TS transformers **65** are connected to a series of distribution substation (DS) transformers **75** situated over a smaller geographical area.

The 7.2 KV phase-to-ground (12.5 KV phase-to-phase) phase A feeder **90** of DS transformer **75** powers a local distribution network, which contains a number of pole-mounted or pad-mounted (PM) transformers **103** that are used to provide the final 120/240 volt power to the commercial or residential customers. In the same manner, phase B feeder **85** and phase C feeder **80** also supply power to the same local distribution network.

At some base station reference location **100** in the power distribution network, a PM transformer **95** is used to provide a low-voltage reference phase that can be used to determine the unknown phase of a conductor at any field location **115** in the network.

As described in referenced U.S. Pat. Nos. 6,667,610 and 7,031,859, the instantaneous phase of voltage waveforms at two widely separated points in the power distribution network are measured and compared at the same instant of time using a GPS timing signal. Field location **115** phase measurement and GPS time are encoded into an alphanumeric sequence. At the base station reference location **100**, this sequence is decoded and field location **115** phase measurement, taken by a field probe at the field location, is compared to reference location **100** phase measurement taken by a base station at the same instant of time.

For field location **115** illustrated in FIG. **2**, both instantaneous phase measurements would be the same because both reference location **100** and field location **115** are on phase B. Therefore, conductor **110** would be identified as phase attribute B.

In a typical distribution system, 12.5 KV phase-to-phase voltage is carried by three conductors (**215**, **220**, and **225**) strung between insulators **210** attached to crossarms **205** on wood poles **200** as illustrated in FIG. **3**. In this illustration, phase attributes A, B, and C are carried on conductors **215**, **220**, and **225** respectively. Also illustrated is perpendicular path **228** along the ground under these conductors. Conductors **215**, **220**, and **225** are directly above ground points **245**, **250**, and **255** respectively. A lineman **230** holds phase identification instrument **235** and takes phase measurements at various locations **240**, **250**, and **260**.

FIG. **4** illustrates the capacitive coupling between the conductors and non-contact phase identification instrument **235**. Phase identification instrument **235** functions as the field probe at field location **115** in FIG. **2**. Capacitor **270** represents the coupling between phase A conductor **215** and input ter-

minal **290** of phase identification instrument **235**. Capacitor **275** represents the coupling between phase B conductor **220** and input terminal **290**. Capacitor **280** represents the coupling between phase C conductor **225** and input terminal **290**. The value of each of these capacitors vary as a function of distance between input terminal **290** and each conductor. The impedance of phase identification instrument **235** with respect to ground is represented by its resistance to ground **287** and its capacitance to ground **285**.

The powerline voltage signal on input terminal **290** is amplified using amplifier **295** and processed using circuit block **298**. Circuit block **298** is equivalent to typical industry phase identification meters and in particular to the phase identification meters described in aforementioned commonly owned U.S. Pat. Nos. 6,667,610 and 7,031,859 and patent application Ser. No. 12/927/767. Output **288** represents either phase identification instrument **235** internal display, wired output, or bluetooth communication output to a personal computer (PC).

The magnitude of the powerline voltage signal due to each conductor into amplifier **295** is primarily a function of the distance between conductors **215**, **220**, and **225** and input terminal **290** since the capacitance of capacitors **270**, **275**, and **280** decrease with distance. These powerline voltage signals sum together on input terminal **290** to form a resultant vector.

FIG. **5** illustrates the expected powerline voltage signal phase vectors into amplifier **295** for a lineman standing at position **240** in FIG. **3**. The strongest phase vector **300** is from phase A since phase identification instrument **235** is closest to phase A conductor **215**. The second strongest phase vector **305** is from phase B since phase B conductor **220** is the next closest conductor. The weakest phase vector **310** is from phase C since phase C conductor **225** is the furthest conductor.

If all three conductors were equally distant from phase identification instrument **235**, resultant vector **315** would be zero. That is, the sum of equal magnitude three-phase voltage vectors with 120 degree separation is zero. However, as illustrated in FIG. **5**, the assumed unequal magnitude phase vectors **300**, **305**, and **310** sum to the non-zero resultant vector **315**. Note that for small differences between the magnitudes of phase vectors **300**, **305**, and **310**, the magnitude of resultant vector **315** is small and its phase shift with respect to the phase of the strongest phase vector **300** is between 0 and 60 degrees.

The capacitance between two objects falls off rapidly when the distance between them is small and falls off slowly as the distance between them becomes large. Since the average distance between phase identification instrument **235** and the conductors is large and the differential distance between phase identification instrument **235** at position **240** and each of the conductors is small, the differential difference between phase vectors **300**, **305**, and **310** is also small. Therefore, phase identification instrument **235** indicates phase attribute A for closest conductor **215** since the lagging resultant vector phase shift is less than 60 degrees.

On primary three-phase circuits, a phase error boundary between adjacent phase attributes is 60 degrees. That is, a phase error less than 60 degrees will not cause a phase attribute error. Thus, phase shifts below 60 degrees indicate the correct phase attribute for the closest conductor.

FIG. **6** illustrates resultant vector **315** for the situation where the lineman was again standing at position **240** and conductor **215** was phase B, conductor **220** was phase C, and conductor **225** was phase A. This time the strongest phase vector **300** is phase B and thus phase identification instrument **235** will correctly indicate the phase attribute of closest conductor **215** as phase B.

FIG. **7** illustrates resultant vector **315** for the situation where the lineman was again standing at position **240** and conductor **215** was phase C, conductor **220** was phase A, and conductor **225** was phase B. This time the strongest phase vector **300** is phase C and phase identification instrument **235** will correctly indicate the phase attribute of closest conductor **215** as phase C.

FIG. **8**, FIG. **9**, and FIG. **10** indicate additional results for standing positions and conductor phases where phase vectors **300**, **305**, and **310** represent the near, center, far phase vectors respectively resulting from near, center, far distances between the indicated conductor phases and phase identification instrument **235**.

FIG. **11** illustrates the resultant vector if phase C conductor **225** is missing in FIG. **3** and the lineman is standing at position **240**. In this case, the phase of resultant vector **315** is lagging phase vector **300** by less than 60 degrees. Phase identification instrument **235** would again correctly indicate the phase attribute of the closest conductor as phase A.

FIG. **12** and FIG. **13** illustrate two other conditions in which only 2 phase conductors are implemented. Again, phase identification instrument **235** would correctly indicate the phase attribute of the closest conductor.

FIG. **14**, FIG. **15**, and FIG. **16** illustrate the resultant vectors when only a single phase conductor is present. When only a single phase conductor is present, no phase shift occurs so phase identification instrument **235** correctly indicates the phase attribute of the single conductor.

FIG. **17** illustrates the resultant vectors when the lineman stands at positions **240**, **241**, and **242** in FIG. **3**. FIG. **18** illustrates the near, center, far distances for positions **240** and **242**. For each position, the magnitude of closest phase vector **300** is normalized to the same magnitude for comparative purposes. Resultant vectors **320**, **345**, and **360** represents the lineman standing at positions **240**, **241**, and **242** respectively.

As illustrated in FIG. **18**, the near, center, far distances at position **240** are more equal than at position **242**. Therefore, resultant vector **320** approaches 60 degrees lagging. At position **242**, the near, center, far differential distances are greater so resultant vector **360** approaches 0 degrees lagging.

This resultant vector lagging phase shift reduction with increasing distance from horizontal three-phase lines only takes place at relative close ranges. At very large distances from the conductors, the differential distances from each line to phase identification instrument **235** are nearly equal so capacitance values **270**, **275**, and **280** are nearly equal. Therefore, when phase identification instrument **235** is at very large distances from horizontal lines, the resultant vector phase shift again approaches 60 degrees.

FIG. **19** illustrates the resultant vector when the lineman stands directly under phase B conductor **220** at position **250** in FIG. **3**. Assuming conductors **215** and **225** are equally spaced from conductor **220**, phase vectors **370** and **375** will be equal length. Note that when standing under the center conductor, the resultant vector **380** is in phase with the center conductor phase vector **300**.

FIG. **20** illustrates offset vertical overhead line construction in which two phases are attached on one side of the pole and the third phase is attached between them on the opposite side of the pole. With the lineman standing at position **400**, the phase attribute of bottom conductor **435** can easily be determined since it is the closest conductor. With the lineman standing at position **405** on the center conductor side of the pole, both conductors **430** and **435** are at nearly the same distance as indicated by constant distance arc **415**. However, if the lineman moves further away on the center conductor side of the pole, the phase attribute of center conductor **430**

can easily be determined since it is clearly the closest conductor as indicated by constant distance arc **420**. The phase attribute of top conductor **425** is the attribute not indicated for bottom conductor **435** or center conductor **430**. That is, the A, B, or C attribute not measured which in this example is attribute A.

Another common construction is a vertical arrangement of the conductors as illustrated in FIG. **21** where all three conductors are on the same side of the pole. In this construction, only the bottom conductor can be the closest conductor at any lineman position along ground level. The phase attributes of the middle and top conductors must be determined using the resultant vector phases illustrated in FIGS. **5** through **10** and the rotation of the resultant vector phase at different lineman positions as was illustrated in FIG. **17**.

FIG. **21** illustrates the near, center, far distances when the lineman stands at position **570** directly under three-phase vertical lines and when standing at position **575** left of the vertical lines. The greatest differential distance between the conductors occurs when standing directly under the vertical lines thus giving the resultant vector **360** in FIG. **17**. As the lineman moves to the left, resultants **345** and **320** are obtained respectively as the lineman moves further left. Therefore, the resultant vector phase shift approaches 0 degrees lagging when standing under the vertical lines and approaches 60 degrees lagging as the lineman moves away from the vertical lines.

The phase shift of the resultant vector as the lineman moves away from horizontal and vertical three-phase lines with ABC phase rotation can be summarized in FIG. **22** and FIG. **23** respectively. If the near, center, far horizontal conductors are ABC, FIG. **22** indicates that the resultant phase shift will be lagging and the lagging phase shift will decrease as the lineman moves further from the horizontal lines. If these same lines were vertical, FIG. **23** indicates that the resultant phase shift will be lagging and the lagging phase shift will increase as the lineman moves further from the vertical lines.

FIG. **22** and FIG. **23** illustrate how the near, center, far conductor phase attributes of three-phase lines in horizontal or vertical construction can be determined from the phase shift of the resultant vector. The resultant vector phase for each of the 6 possible different near, center, far conductor phase attributes will fall in one of the 6 illustrated 60 degree phase segments. The middle 30 degrees of each 60 degree segment indicate the most probable phase shift for nominal distances from the three-phase lines.

For example, if phase identification instrument **235** indicated B phase with a −30 degree phase shift, the lineman would know that the phase attributes of the near, center, far conductors is BCA. If the lines were horizontal, the lineman would expect the phase shift reported by phase identification instrument **235** to increase towards −45 degrees as the lineman moved closer to the lines and decrease towards −15 degrees as the lineman moved further from the lines. If the lines were vertical, the phase shift with movement would be in the opposite direction.

In a typical utility, the voltage magnitude of three-phase conductors are not always precisely equal and their phases are not always precisely separated by 120 degrees. The horizontal or vertical separation between three-phase conductors are also not always equal. Additionally, static phase offsets between the reference base station phase and the utility phase is not always adjusted precisely to zero degrees in phase identification instrument **235**. All these effects can cause small resultant vector phase shifts that can place the resultant phase in an adjacent 60 degree segment of FIG. **22** and FIG. **23** thus causing a phase attribute error. Two techniques can be used to minimize making these attribute errors.

Suppose the lineman was standing at position **240** in FIG. **3** and obtained near, center, far conductor phase attributes ABC from FIG. **22**. By moving to position **260**, the lineman would expect to obtain near, center, far attributes CBA. This second measurement at position **260** confirms that the first measurement at position **240** was correct. If instead, the second measurement at position **260** was BCA, the two measurements don't match.

The near conductor signal is strongest and most dominate and its phase attribute is indicated by the first letter of phase identification instrument **235** reported phase attribute. Therefore, the ABC attribute measured at position **240** indicates near conductor **215** in FIG. **3** is attribute A. The BCA attribute measured at position **260** indicates near conductor **225** is attribute B. Center conductor **220** must therefore be attribute C which indicates the BCA attribute measured at position **260** is the correct one.

If these same results are obtained for vertical lines, it is not possible to stand on the other side (stand above) the vertical lines. Instead, a measurement directly under the vertical lines can be compared with a measurement away from the vertical lines.

Suppose the lineman was standing at position **570** in FIG. **21** and obtained near, center, far conductor phase attributes ABC at −10 degrees lagging from FIG. **23**. By moving to position **575**, the lineman would expect to obtain the same near, center, far attributes at a more negative lagging angle. Obtaining a more negative lagging angle at position **575** confirms that the first measurement at position **570** was correct. If instead, the second measurement at position **575** was a less negative lagging angle or perhaps phase attribute ACB with a small leading angle, the two measurements don't match.

Since the near conductor signal is strongest and most dominate, the near (bottom) vertical conductor is phase A. Since the resultant vector phase shift was in the counterclockwise direction with movement away from the vertical conductors, the correct near, center, far attributes should be ACB. That is, the center and far (top) vertical conductors should be C and B respectively.

Phase identification instrument **235** can be designed to report all three phase attributes for each measurement or to report only the phase attribute of the nearest conductor. If only two of the three-phase conductors are present, the reported far attribute can simply be ignored. For example, if ABC was reported for two conductor construction, the near conductor attribute would be A and the far conductor attribute would be B. The third attribute C would be ignored.

Phase attribute errors can be minimized by accurately calibrating phase identification instrument **235** to the substation tagging reference phase. The best method of performing this calibration is to obtain a phase attribute measurement on an isolated single phase conductor. Examples are single phase conductors that branch off of three-phase overhead lines or an unshielded single phase conductor in a three-phase switching cabinet. The latter can be obtained by removing a shielding cap from one of the conductor bushings in the cabinet.

As illustrated in FIG. **14**, FIG. **15**, and FIG. **16**, there is no resultant vector phase shift when measuring single phase conductors. Phase identification instrument **235** can be precisely calibrated by measuring the phase attribute of an isolated single phase conductor with known phase attribute and adjusting the resultant vector phase to match the reference phase for that phase attribute. This adjustment is typically performed in the phase attribute computing software.

Many phase attribute measurements are taken in substations, cabinets, ground level transformers, and from bucket trucks. In these situations, the safe handheld instrument separation distance is on the order of a few feet at most distribution voltages. This allows phase identification instrument **235** to be held close enough to the conductor under test to minimize the influence of other nearby conductors on the phase attribute measurement. In those situations, the phase attribute is determined using the resultant vector phase illustrated in FIGS. **14** through **16**. Since phase identification instrument **235** does not have to be held within a few inches of the conductor, or actually touching the conductor, no hot stick is required.

The handheld phase identification instrument **235** described in this invention can be safely used by non-linemen to obtain phase attribute measurements on overhead lines, building power meters, and 120 volt wall sockets. This allows lower cost personnel to be used to gather phase attributes. By holding the handheld instrument close to residential meters, the primary phase attribute of the circuit or three-phase conductor feeding power to the residence can be determined. This allows low cost meter reader personnel to quickly gather phase attributes of buildings as they make their meter reading rounds.

Since the signal level into phase identification instrument **235** will vary from very low levels when at a large distance from overhead conductors to very large levels when used on ground level conductors, amplifier **295** must have a very high dynamic range. Also, its phase shift with input signal level must be as constant as possible to minimize any static phase shift variation with signal level which could led to phase attribute errors or mask the resultant vector phase variation with lineman position.

The most appropriate choice for amplifier **295** is to implement it as a hard limiter. A hard limiter essentially operates as a one bit analog to digital converter where any voltage above threshold has a "one" value and any voltage below threshold has a "zero" value. A hard limiter can be easily implemented using the open loop gain of an operational amplifier with no feedback resistor. A high gain, high speed (with respect to the 60 Hz powerline voltage frequency), high impedance, and low noise operational amplifier has exceptional sensitivity and dynamic range with very low phase shift variation. Its use in the present invention is key to implementing a high performance low cost solution for amplifier **295**.

A hard limiter, followed by a bandpass filter, has the desirable characteristic of suppressing the relative signal level, of all low level signals, by 6 dB at the output of the hard limiter with respect to the strongest input signal. This characteristic helps eliminate all out-of-band interference signals since the strongest narrowband input signal will be the fundamental powerline frequency signal of 60 Hz in the USA and 50 Hz in many foreign countries. Bandpass filters in phase identification instrument **235** filters out non-powerline frequencies.

FIG. **26** illustrates a handheld version of phase identification instrument **235**. Input terminal **290** consists of a thin metal disk which is connected to amplifier **295** inside plastic tube **289**. Insulated cover **296** protects input terminal **290**. Amplifier **295** is connected to circuit block **298**. Movable grounded metal sleeve **297** is optional and can be used to make phase identification instrument **235** more directional.

For example, suppose the lineman stands at position **250** directly under center conductor **220** in FIG. **3** and points the handheld phase identification instrument **235** directly at conductor **220**. Then irrespective of the distance differences between input terminal **290** and conductors **215**, **220**, and **225**, the capacitance coupling between input terminal **290** and conductor **220** is greater than the coupling to conductors **215** and **225** because input terminal **290** faces conductor **220**. Due to the thin disk profile of input terminal **290**, the other two conductors have a more edge-on view and thus lower coupling capacitance. This lower capacitance provides some conductor signal directivity to phase identification instrument **235**.

Optionally, this directivity can be increased by moving (**299**) grounded metal shield **297** over input terminal **290**. This action further reduces the coupling to conductors **215** and **225**. This movable shield feature can be beneficial in crowded cabinets, to reduce the interfering influence of adjacent conductors, when measuring the phase attribute of a particular conductor.

In most cases, precise lineman phase attribute measurement position is not required. All that is required is to follow the general position guidelines and use the resultant vector phase principals disclosed in this patent application. However, charts and diagrams can be prepared and supplied with phase identification instrument **235** to assist linemen in correctly gathering phase attributes. This is possible because the electric utility industry uses fairly standardized overhead, substation, and cabinet construction techniques throughout the industry. For each typical measurement situation, a diagram of optimum lineman position and the expected resultant vector results for each conductor phase situation can be produced and supplied to the lineman. This information could also take the form of programs or pictures on a personal computer.

Ideally, the magnitudes of each three-phase voltage vectors are identical and their phases are separated by exactly 120 degrees. In general, offsets from these ideal values are small in most situations. However, distribution circuits and loads can cause deviations which will slightly modify the resultant phase vectors illustrated in this disclosure. These variations change quite slowly in most situations since powerline circuitry seldom changes and loads vary slowly over the course of a day or days. To account for these variations, a lineman could first measure phase at a convenient accurate location (such as an isolated overhead single phase conductor or an unshielded conductor in a ground level cabinet) to determine the static phase and voltage magnitude variations involved. This information could then be entered into phase identification instrument **235** or a personal computer and used to compensate or modify the resultant vectors expected in each measurement situation.

The vectors and phase attribute in all figures except FIG. **24** and FIG. **25** are for ABC phase rotation. In some utilities, phase rotation is ACB. For those utilities, B and C need to be reversed in all the figures. That is, wherever B appears, change it to C. Wherever C appears, change it to B. The phase shift of the resultant vector as the lineman moves away from horizontal and vertical three-phase lines with ACB phase rotation are summarized in FIG. **24** and FIG. **25** respectively.

Note that FIG. **22** and FIG. **23** illustrate for ABC phase rotation that ABC conductor attributes result in a lagging resultant vector phase while ACB conductor attributes result in a leading resultant vector phase. FIG. **24** and FIG. **25** illustrate for ACB phase rotation that ABC with a lagging phase becomes ACB with a lagging phase and ACB with a leading phase becomes ABC with a leading phase. The phase rotation with distance remains the same.

This characteristic can be used to determine the phase rotation of a utility if it is not already known. If the near, center, far attributes of three-phase equally spaced horizontal lines are known to be ABC and a lagging resultant vector phase (−30 degrees for example) is obtained, then the phase

rotation is ABC. If a leading resultant vector phase (+30 degrees for example) is obtained, then the phase rotation is ACB. Typically, however, most utilities already know their phase rotation.

Phase attribute measurements are always taken by measuring conductor voltage with respect to ground. Currently, when phase attribute measurements are taken by mounting phase identification instrument **235** on an extendo stick and holding it close to an overhead conductor, the instrument reference to ground is through its capacitance to ground. However, since phase identification instrument **235** is high above the ground and in close proximity to other conductors, it capacitively couples to both ground and other conductor phases. This coupling, along with the resistance of the hot stick to ground forms a complex impedance circuit between the point of measurement and ground which introduces random phase shifts into the phase attribute measurement. Although these phase shifts are seldom large enough to cause an attribute error, they do cause errors in the resultant vector phase.

In the present invention, these phase shifts will be minimal because phase identification instrument **235** is close to the ground and far from the phase conductors. Being close to ground increases its capacitance to ground thus lowering its impedance to ground. Therefore, the inherent phase accuracy of phase identification instrument **235** is increased and any phase error is identical for all three conductor signals because all three signals arrive simultaneously on the same input terminal **290**. This increases the precision of the resultant vector phase. Additionally, if ever required for increased precision, phase identification instrument **235** can easily be grounded whereas grounding is not normally possible when attached to an extendo stick.

Although the preferred embodiments of the invention have been illustrated and described in detail, it will be readily apparent to those skilled in the art that various modifications may be made therein without departing from the spirit of the invention. For example, phase identification instrument **235** illustrated in FIG. **26** need not be handheld. In some cases, it may be desirable to mount phase identification instrument **235** on an short hot stick to place it in closer proximity to a particular conductor, or set of conductors, in special construction situations. Some utilities combine three-phase 12.5 KV lines under 69 KV lines (called under build). Placing phase identification instrument **235** closer to the lower 12.5 KV lines would reduce the influence of the higher 69 KV lines, when measuring 12.5 KV phase attributes.

What is claimed is:

1. A method of identifying three-phase conductor phase attributes in a three-phase power distribution network, said method comprising:

providing a powerline voltage reference phase at a reference location;

providing a non-contact phase identification instrument at a field location, said instrument configured to capacitive couple to said powerline voltage on each said three-phase conductor;

positioning said instrument so that distances between said instrument and each said three-phase conductor are in a near, center, far relationship;

summing said powerline voltage signal from each said three-phase conductor in said instrument to produce a said powerline voltage signal resultant vector;

measuring said resultant vector phase; and

identifying said three-phase conductor phase attributes by comparing said resultant vector phase with said reference phase.

2. A method as claimed in claim **1** wherein said comparing for three-phase conductors with ABC phase rotation comprises:

identifying near, center, far said three-phase conductor phase attributes as ABC if said resultant vector phase lags said reference phase A by less than 60 degrees;

identifying near, center, far said three-phase conductor phase attributes as ACB if said resultant vector phase leads said reference phase A by less than 60 degrees;

identifying near, center, far said three-phase conductor phase attributes as CAB if said resultant vector phase lags said reference phase C by less than 60 degrees;

identifying near, center, far said three-phase conductor phase attributes as CBA if said resultant vector phase leads said reference phase C by less than 60 degrees;

identifying near, center, far said three-phase conductor phase attributes as BCA if said resultant vector phase lags said reference phase B by less than 60 degrees; and

identifying near, center, far said three-phase conductor phase attributes as BAC if said resultant vector phase leads said reference phase B by less than 60 degrees.

3. A method as claimed in claim **1** wherein said comparing for three-phase conductors with ACB phase rotation comprises:

identifying near, center, far said three-phase conductor phase attributes as ACB if said resultant vector phase lags said reference phase A by less than 60 degrees;

identifying near, center, far said three-phase conductor phase attributes as ABC if said resultant vector phase leads said reference phase A by less than 60 degrees;

identifying near, center, far said three-phase conductor phase attributes as BAC if said resultant vector phase lags said reference phase B by less than 60 degrees;

identifying near, center, far said three-phase conductor phase attributes as BCA if said resultant vector phase leads said reference phase B by less than 60 degrees;

identifying near, center, far said three-phase conductor phase attributes as CBA if said resultant vector phase lags said reference phase C by less than 60 degrees; and

identifying near, center, far said three-phase conductor phase attributes as CAB if said resultant vector phase leads said reference phase C by less than 60 degrees.

4. A method as claimed in claim **1** wherein said comparing for three-phase conductors with ABC phase rotation when two conductors are present comprises:

identifying near, far said three-phase conductor phase attributes as AB if said resultant vector phase lags said reference phase A by less than 60 degrees;

identifying near, far said three-phase conductor phase attributes as AC if said resultant vector phase leads said reference phase A by less than 60 degrees;

identifying near, far said three-phase conductor phase attributes as CA if said resultant vector phase lags said reference phase C by less than 60 degrees;

identifying near, far said three-phase conductor phase attributes as CB if said resultant vector phase leads said reference phase C by less than 60 degrees;

identifying near, far said three-phase conductor phase attributes as BC if said resultant vector phase lags said reference phase B by less than 60 degrees; and

identifying near, far said three-phase conductor phase attributes as BA if said resultant vector phase leads said reference phase B by less than 60 degrees.

5. A method as claimed in claim **1** wherein said comparing for three-phase conductors with ACB phase rotation when two conductors are present comprises:

identifying near, far said three-phase conductor phase attributes as AC if said resultant vector phase lags said reference phase A by less than 60 degrees;

identifying near, far said three-phase conductor phase attributes as AB if said resultant vector phase leads said reference phase A by less than 60 degrees;

identifying near, far said three-phase conductor phase attributes as BA if said resultant vector phase lags said reference phase C by less than 60 degrees;

identifying near, far said three-phase conductor phase attributes as BC if said resultant vector phase leads said reference phase C by less than 60 degrees;

identifying near, far said three-phase conductor phase attributes as CB if said resultant vector phase lags said reference phase B by less than 60 degrees; and

identifying near, far said three-phase conductor phase attributes as CA if said resultant vector phase leads said reference phase B by less than 60 degrees.

6. A method as claimed in claim **1** additionally comprising:

measuring said three-phase conductor phase attributes by positioning said instrument at a first location left of horizontal three-phase conductors;

measuring said three-phase conductor phase attributes by positioning said instrument at a second location right of said horizontal three-phase conductors;

identifying said three-phase conductor near attribute at said first location as near attribute obtained at said first location;

identifying said three-phase conductor far attribute at said first location as near attribute obtained at said second location; and

identifying said three-phase conductor center attribute as that attribute not identified for outer said horizontal three-phase conductors.

7. A method as claimed in claim **2** additionally comprising:

measuring said three-phase conductor phase attributes by positioning said instrument at a first location, said first location close to vertical three-phase conductors;

measuring said three-phase conductor phase attributes by positioning said instrument at a second location, said second location further from said vertical three-phase conductors than said first location;

identifying near, center, far said three-phase conductor phase attributes as ACB if said first location attributes obtained were ABC and said second location resultant vector phase leads said first location resultant vector phase;

identifying near, center, far said three-phase conductor phase attributes as ABC if said first location attributes obtained were ACB and said second location resultant vector phase lags said first location resultant vector phase;

identifying near, center, far said three-phase conductor phase attributes as CBA if said first location attributes obtained were CAB and said second location resultant vector phase leads said first location resultant vector phase;

identifying near, center, far said three-phase conductor phase attributes as CAB if said first location attributes obtained were CBA and said second location resultant vector phase lags said first location resultant vector phase;

identifying near, center, far said three-phase conductor phase attributes as BAC if said first location attributes obtained were BCA and said second location resultant vector phase leads said first location resultant vector phase; and

identifying near, center, far said three-phase conductor phase attributes as BCA if said first location attributes obtained were BAC and said second location resultant vector phase lags said first location resultant vector phase.

8. A method as claimed in claim **3** additionally comprising:

measuring said three-phase conductor phase attributes by positioning said instrument at a first location, said first location close to vertical three-phase conductors;

measuring said three-phase conductor phase attributes by positioning said instrument at a second location, said second location further from said vertical three-phase conductors than said first location;

identifying near, center, far said three-phase conductor phase attributes as ABC if said first location attributes obtained were ACB and said second location resultant vector phase leads said first location resultant vector phase;

identifying near, center, far said three-phase conductor phase attributes as ACB if said first location attributes obtained were ABC and said second location resultant vector phase lags said first location resultant vector phase;

identifying near, center, far said three-phase conductor phase attributes as BCA if said first location attributes obtained were BAC and said second location resultant vector phase leads said first location resultant vector phase;

identifying near, center, far said three-phase conductor phase attributes as BAC if said first location attributes obtained were BCA and said second location resultant vector phase lags said first location resultant vector phase;

identifying near, center, far said three-phase conductor phase attributes as CAB if said first location attributes obtained were CBA and said second location resultant vector phase leads said first location resultant vector phase; and

identifying near, center, far said three-phase conductor phase attributes as CBA if said first location attributes obtained were CAB and said second location resultant vector phase lags said first location resultant vector phase.

9. A method as claimed in claim **1** additionally comprising:

positioning said non-contact phase identification instrument near an isolated single phase conductor with known phase attribute;

measuring said resultant vector phase; and

calibrating said non-contact phase identification instrument by adjusting said resultant vector phase to said powerline voltage reference phase.

10. A method as claimed in claim **1** additionally comprising:

positioning said non-contact phase identification instrument near a building power meter or wall socket;

measuring said resultant vector phase; and

identifying phase attribute of said three-phase conductor phase attributes supplying power to said meter or to said wall socket.

11. A method as claimed in claim **1** additionally comprising:

finding occurrences of isolated single phase conductors with attributes A, B, and C;

positioning said non-contact phase identification instrument near each said isolated single phase conductors;

measuring said powerline voltage magnitudes for each said isolated single phase conductors;

measuring said resultant vector phase for each said isolated single phase conductors; and

calibrating said non-contact phase identification instrument to account for any unequal said powerline voltage magnitudes or for any said resultant vector phase differences not equal to 120 degrees between phase attribute A, B, or C conductors.

12. An apparatus for identifying three-phase conductor phases in a three-phase power distribution network, said apparatus comprises:

a base station at a reference location, said base station configured to provide a powerline voltage reference phase;

a non-contact field probe at a field location, said field probe configured to capacitive couple to said powerline voltage signal on each said three-phase conductor to form a said powerline voltage signal resultant vector;

a circuit within said field probe, said circuit configured to measure said resultant vector phase; and

computing means to determine said three-phase conductor phases by comparing said resultant vector phase with said reference phase.

13. An apparatus as in claim **12** wherein said non-contact field probe further comprises a movable shield, said movable shield configured to partially shield said non-contact field probe from one or more said three-phase conductor.

14. An apparatus as in claim **12** wherein said field probe comprises:

an input terminal configured to capacitive couple to said three-phase conductor phases;

an amplifier configured to amplify said resultant vector formed on said input terminal; and

a circuit block configured to measure said resultant vector phase and communicate said resultant vector phase to a user or other computing equipment.

15. An apparatus as in claim **14** wherein said amplifier provides high dynamic range gain with low phase shift.

16. An apparatus as in claim **14** wherein said amplifier is configured as a hard limiter.

17. An apparatus as in claim **12** wherein said non-contact field probe is handheld.

18. A method of identifying a three-phase conductor phase in a three-phase power distribution network, said method comprising:

providing a powerline voltage reference phase at a reference location;

providing a non-contact phase identification instrument at a field location, said instrument configured to capacitive couple to said powerline voltage signal on said three-phase conductor;

positioning said instrument close to a particular said three-phase conductor, said particular three-phase conductor nearer to said instrument than any other said three-phase conductor;

measuring said powerline voltage signal phase using said instrument; and

identifying said particular three-phase conductor phase by comparing said powerline voltage signal phase with said reference phase.

19. A method as claimed in claim **18** additionally comprising:

positioning said instrument at a first location, said first location on one side of horizontal three-phase conductors;

identifying said first location nearest horizontal conductor phase;

positioning said instrument at a second location, said second location on opposite side of said horizontal three-phase conductors;

identifying said second location nearest horizontal conductor phase; and

identifying center conductor phase as phase not identified at said first location or said second location.

20. A method as claimed in claim **18** additionally comprising:

positioning said instrument at a first location, said first location under offset vertical three-phase conductors;

identifying bottom conductor phase of said offset vertical three-phase conductors;

positioning said instrument at a second location, said second location a sufficient distance from said offset vertical three-phase conductors so that center conductor is nearest conductor to said instrument;

identifying said center conductor phase of said offset vertical three-phase conductors; and

identifying top conductor phase of said offset vertical three-phase conductors as that phase not measured for said bottom conductor or for said center conductor.

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