PROTECTION OF THE EAST GARDEN CITY 345KV PHASE ANGLE REGULATING TRANSFORMERS

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SPOKANE WASHINGTON

OCTOBER 20 - 22, 1992

1.0 Introduction

The New York Power Authority (NYPA) operates 11 power plants with a combined output of more than 6800 MW and 1,400 miles of transmission lines in New York State. NYPA recently completed the Sound Cable Project, a 26.3 mile underground/submarine 345KV transmission line which provides an additional connection between the Consolidated Edison (Con Ed) and Long Island Lighting Company (LILCO) systems to reinforce and improve Long Island's electricity supply. In order to control the flow between the Con Ed and LILCO systems two 345KV, 450 MVA Phase Angle Regulating (PAR) transformers were installed at the new East Garden City 345KV substation. This paper will describe the protection and operation of the East Garden City phase angle regulating transformers.

2.0 System Description

The Sound Cable Project is a 345KV interconnection (Y49) between the Con Ed Sprain Brook 345KV substation and the LILCO East Garden City 138KV substation. Power flows on the Y49 345KV interconnection are controlled by two 450MVA phase angle regulating transformers (PAR's) which are installed in the new East Garden City 345KV substation (figure 1). Each PAR is connected in series with a 450MVA 345KV/138KV autotransformer and the two PAR and autotransformer configurations are connected in parallel.

The LILCO system includes four additional interconnections to other utilities (figure 2). The Lake Success - Jamaica 138KV, Valley Stream - Jamaica 138KV and Shore Road - Dunwoodie 345KV (Y50) circuits provide additional interconnections to the Con Ed system. The Northport - Norwalk Harbor 138KV circuit provides an interconnection to the Northeast utilities system. Phase angle regulating transformers are included on all of the LILCO interconnections with the exception of the Shore Road - Dunwoodie Y50 345KV circuit which is maintained as a "free-flowing" tie.

Phase angle regulating transformers on the LILCO interconnections allow the scheduled interchange of power between the utilities to be maintained.

3.0 PAR Description

The East Garden City phase angle regulating transformers (also referred to as "phase shifting" transformers) are Trafo Union Siemens type TLSN8255 + TLAN8255 and are rated 270/360/450 MVA, OA/FA/FA, 65°C rise, 345KV, 3 phase. Load tap changers, Reinhausen type TI2000 permit phase angle variations of 25° advance to 25° retard in a total of 32 steps (16 advance, 16 retard). As shown in figure 3, the series unit and the exciting unit of the PAR are mounted in separate tanks, with four throat connections between the tanks (three-single phase primary connections and one-three phase secondary connection). The total assembled weight of each PAR is approximately 560 tons. The series units are rated 86270V/66122V with the secondary windings connected in delta and the exciting units are rated 345000V/67728V grounded wye - grounded wye. The exciting units have a three legged core type construction.

3.1 PAR Theory of Operation

The flow of real power between two systems (defined source and load) is proportional to the angular difference between the source and load voltages and is defined by the relationship

$$P_{SL} = \frac{V_S V_L \sin \sigma}{X}$$

Where P_{SL} = real power flow from source to load

V_S = source voltage

V_L = load voltage

X = reactance between V_S and V_L

σ = angle by which V_S leads V_L

A phase angle regulating transformer can control the flow of real power by varying the phase angle (σ) between the two systems. The phase angle regulating transformer accomplishes this by adding a regulated quadrature voltage to the source line to neutral voltage. This quadrature voltage is derived from the phase-to-phase voltages of the other two phases (figure 4). Phase angle shifts of the A phase voltage would be developed by adding a quadrature voltage derived from B&C phase voltages. Angular shifts of B phase utilize A&C phase quadrature voltages and C phase angular shifts utilize A&B phase quadrature voltages. The phase angle shift can be varied by changing the magnitude of the quadrature voltage.

3.1 (continued)

In the East Garden City phase angle regulating transformers, the quadrature voltage is introduced between the source and load side voltages by means of the series transformer. The secondary of the series transformer is connected across the exciting unit secondary phase to phase voltages. The exciting unit secondary phase to phase voltages will be reflected to the primary of the series transformer and will add or subtract from the source side primary voltage to obtain the desired angular shift (σ) of the load side primary voltage. The magnitude of the required quadrature voltage (V_Q) to produce the desired phase shift is approximately:

$$V_Q = (V_{L-N})\ (2 \sin \frac{\sigma}{2})$$

As shown in figure 5, for a 25° phase shift:

$$V_Q = (345KV/\sqrt{3})\ (2 \sin \frac{25^\circ}{2})$$

$$V_Q = 86210 \text{ volts}$$

The East Garden City PAR series transformers have a voltage ratio of 86270 V\66122 V = 1.305. A quadrature voltage of 66076 volts (86210V ÷ 1.305) must be applied to the secondary of the series transformer to produce a 25° phase shift.

The PAR primary exciting unit has a current rating of 326 amps as derived from the primary series unit rating of 753 amps as shown in figure 6.

The East Garden City PAR exciting transformers have load tap changing capability which allows the exciting transformer secondary phase to phase voltages to be varied from 67728 volts to zero volts in 16 stages. This allows the phase shift to be varied from 0° to 25° in approximately 1.6° increments. A phase reversal switch is included in the exciting unit secondary to allow the quadrature voltage which is developed by the exciting transformer to be either added or subtracted from the source voltage to allow the advance or retard of the load voltage.

4.0 Protection Systems

The East Garden City PAR's are protected by dual, redundant protection systems in accordance with the Northeast Power Coordinating Council (NPCC) Bulk Power System Protection Criteria. This requires dual protection systems, including dual DC battery systems, individual current transformer secondary windings for each system, dual trip coils, and physical separation of wiring and devices.

The PAR primary protection systems include three single phase, percentage-differential relays with harmonic restraint and sudden pressure relaying. The primary differential and sudden pressure relays operate the primary lockout relay to energize trip coil #1 of the associated 345KV and 138KV circuit breakers.

The PAR secondary protection systems include three single phase, percentage-differential relays with harmonic restraint, neutral time-overcurrent relays with harmonic restraint supervision in both the exciting unit primary and secondary neutrals, and sudden pressure relays. The secondary differential, neutral overcurrent and sudden pressure relays operate the secondary lockout relay to energize trip coil #2 of the associated 345KV and 138KV circuit breakers.

Additional systems which were included for protection of the East Garden City phase angle regulating transformers included overexcitation and "out of step" protection systems.

4.1 Primary Protection System

Three single phase, percentage-differential relays with harmonic restraint are used to provide overall differential protection for each phase angle regulating transformer. The primary differential zone will extend from the line side of the 345KV breaker to the high voltage bushings of the 345/138KV autotransformers. As shown in Figure 7, CT's for the source and load sides of the series unit as well as the neutral side of the exciting unit primary winding are all connected in Y. A delta CT connection could also have been used. We elected to utilize wye connected CT's because of advantages in phase identification and current transformer secondary circuit neutral grounding. In addition, the wye connection will allow the third harmonic to restrain the differential relay for overexcitation conditions. Since the primary differential relay system CT connections are all on the series unit primary winding side, the primary differential relay will be unaffected by series unit saturation that could occur during external faults.

4.1 (continued)

The primary differential relay system will provide coverage for all PAR primary winding faults. Series and exciting unit secondary lead and winding faults are covered by the secondary differential protection system and backup ground overcurrent relaying.

The primary differential relays are connected to satisfy Kirchoff's Law at the mid point junction of the series unit primary winding where:

$$I_{source} = I_{load} + I_{exciting}$$

This relationship will be satisfied when identical CT ratios and connections (wye or delta), and relay taps are selected for the source and load sides of the series unit primary windings and neutral side of the exciting unit primary winding.

For the East Garden City PAR's, the maximum load current is 753 Amps. CT ratios were chosen to limit CT secondary load currents to less than 5 amps. A CT ratio of 1200/5 was thus chosen for all CT's. The three line AC connection for the primary differential relay system is shown in figure 8.

4.2 Secondary Differential Protection System

Three single phase, percentage-differential relays with harmonic restraint are used to provide differential protection for the series transformer and some backup protection for the exciting unit. The PAR secondary differential zone will extend from the line side of the 345KV breaker to the high voltage bushings of the 345/138KV auto transformers. As shown in figure 9, CT's for the source and load sides of the primary series winding are connected in delta, while CT's on the neutral side of the secondary exciting unit are Y connected.

The secondary differential relay system CT connections were chosen to provide additional coverage for series and exciting transformer secondary faults. Since one restraint circuit of the secondary differential relay system is on the secondary side of the series transformer, saturation of the series transformer must be considered. The saturation of the series transformer would upset the ampere-turns-coupling between the primary and secondary windings of the series unit and could result in the misoperation of the secondary differential system during an external fault. Series unit saturation during an external fault could occur due to the low voltage rating of the series unit (43% of the line-to-neutral voltage).

4.2 (continued)

Faults on both sides of the phase angle regulating transformer under both maximum short circuit and angular shift (maximum impedance) conditions should be analyzed to determine if series unit saturation is a possibility. For the East Garden City PAR's, EMTP studies verified that series unit saturation was not a concern. If series unit saturation were a problem, the desensitizing of the secondary differential relay system during the overvoltage condition would be required.

The secondary differential relay system CT connection and ratio requirements must be determined under full load conditions under both neutral and maximum angle shift tap positions. At the neutral tap position, the PAR series unit primary winding source and load currents are equal and in-phase. The current in the series unit secondary winding will be equal to the series unit primary current multiplied by the series unit turns ratio. Under a phase shift condition, the PAR source and load side currents are not equal, and the current in the series unit secondary winding is not as easy to determine.

4.2.1 <u>Ampere-Turns Coupling for the Series Unit</u>

Since the exciting unit primary winding connection is at the mid-point of the series unit primary winding, the PAR source side current is only flowing through one-half of the series unit primary winding. The PAR load side current is flowing through the other half of the series unit primary winding. The current in the series unit delta secondary winding as shown in figure 10, I_{delta}, is thus

$$I_{delta} = \frac{K}{2} I_{source} + \frac{K}{2} I_{load}$$

4.2.2 CT Connections

The series unit secondary delta connection results in the following exciting unit secondary lead currents:

$$I'_{EA} = \frac{K}{2}(I_{SC\ source} + I_{SC\ load}) - \frac{K}{2}(I_{SB\ source} + I_{SB\ load})$$

$$I'_{EB} = \frac{K}{2}(I_{SA\ source} + I_{SA\ load}) - \frac{K}{2}(I_{SC\ source} + I_{SA\ load})$$

$$I'_{EC} = \frac{K}{2}(I_{SB\ source} + I_{SB\ load}) - \frac{K}{2}(I_{SA\ source} + I_{SA\ load})$$

Re-arranging these equations it can be shown that

$$I'_{EA} = \frac{K}{2}(I_{SC\ source} - I_{SB\ source}) + \frac{K}{2}(I_{SC\ load} - I_{SB\ load})$$

$$I'_{EB} = \frac{K}{2}(I_{SA\ source} - I_{SC\ source}) + \frac{K}{2}(I_{SA\ load} - I_{SC\ load})$$

$$I'_{EC} = \frac{K}{2}(I_{SB\ source} - I_{SA\ source}) + \frac{K}{2}(I_{SB\ load} - I_{SA\ load})$$

where

I'_{EA}, I'_{EB}, I'_{EC} = exciting unit secondary A, B, and C phase lead currents

$I_{SA\ source}$, $I_{SB\ source}$, $I_{SC\ source}$ = series unit primary source side A, B, and C phase currents

$I_{SA\ load}$, $I_{SB\ load}$, $I_{SC\ load}$ = series unit primary load side A, B, and C phase currents

K = series unit turns ratio.

As shown in figure 11, the connection of the secondary differential relay system will satisfy these equations if the PAR series unit primary source and load side CT's are connected in delta and the exciting unit secondary lead CT's are connected in wye. The secondary differential relays should be connected such that the series unit source and load currents flow into the restraint windings and the exciting unit secondary lead current flows out of the restraint winding.

This connection will provide balanced differential operation for external faults as well as all power flows for all PAR tap positions.

4.2.3 CT Ratio and Relay Tap Selection

In a conventional three winding power transformer, CT ratios and relay tap selections are based on balancing the differential relay system two windings at a time. This approach is not feasible for the PAR secondary differential relay system where the exciting unit secondary current is balanced against the sum of the series unit primary source and load currents.

CT ratios should be chosen to satisfy the relationship

$$\frac{I'_{EA}}{n_2} = \frac{(I_{SC\ source} - I_{SB\ source})}{n_1} + \frac{(I_{SC\ load} - I_{SB\ load})}{n_1}$$

substituting

$$I'_{EA} = \frac{K}{2}(I_{SC\ source} - I_{SB\ source}) + \frac{K}{2}(I_{SC\ load} - I_{SB\ load})$$

it can be shown that

$$n_2 = \frac{K}{2}\, n_1$$

where n_1 = series unit primary source and load side CT ratios

n_2 = exciting unit secondary lead CT ratio

K = series unit turns ratio

For the East Garden City PAR's the series unit primary source and load side CT ratios were chosen to be 1200/5 (240/1). The series unit turns ratio K = 1.305. Therefore the ideal secondary lead CT ratio was determined to be

$$n_2 = \frac{1.305}{2}\,(240/1)$$

$$n_2 = 156.6/1$$

This CT ratio would result in the following current ratio

$$\text{Current ratio} = \frac{\frac{753\sqrt{3}}{240} + \frac{753\sqrt{3}}{240}}{\frac{1702}{156.6}}$$

Current ratio = 1.0

4.2.3 (continued)

A current ratio of 1.0 allows all relay tap settings to be set at the same value. The non-standard CT ratio of 156.6/1 would, however, result in greater than 10 amps in the CT secondary current and would thermally stress the CT and relay. We elected to utilize a standard CT ratio which would limit CT secondary currents to approximately 5 amps and to balance the differential system utilizing relay taps. As shown in figure 12, under full load, neutral tap position operation, 1702 amps is flowing in the exciting unit secondary and the series unit source and load side currents are 753 amps and in-phase. A CT ratio of 1500/5 (300/1) was thus chosen for the exciting unit secondary lead CT's. Since the sum of the series unit primary source and load currents must be balanced against the exciting unit secondary lead currents, relay taps should be chosen to match the current ratios

$$\text{Current ratio} = \frac{\frac{753\sqrt{3}}{240} + \frac{753\sqrt{3}}{240}}{\frac{1702}{300}}$$

Current ratio = 1.9157

If a relay tap of 8.7 amps were chosen for the series unit primary source and load restraint windings, an exciting unit secondary lead restraint winding tap of

$\frac{8.7}{1.9157}$ = 4.54 would result in zero mismatch. A relay tap of 4.6 amps was chosen for the exciting unit secondary lead restraint winding relay tap.

4.2.4 Mismatch Calculations

The percent mismatch (M) with these taps equals

$$M = \frac{1.9157 - 8.7/4.6}{8.7/4.6} \times 100 = 1.3\%$$

4.2.3 (continued)

At the maximum 25° retard shift position

$I_{SA\ source} = 753\angle 0°$ Amps

$I_{SA\ load} = 753\angle 25°$ Amps

since $I_{SA\ source} = I_{EA} + I_{SA\ load}$

where I_{EA} = exciting unit primary A phase current

$I_{EA} = 753\angle 0° - 753\angle 25°$

$I_{EA} = 326\angle -77.5°$

$I'_{EA} = I_{EA}$ x exciting unit turns ratio

at 25° shift the exciting unit turns ratio =

$\frac{345000v}{67728v} = 5.094$

therefore $I'_{EA} = 326\angle -77.5° \times 5.094$

$I'_{EA} = 1660.6\angle -77.5°$

The exciting unit secondary current can also be derived from the series unit secondary currents.

<u>For the C phase relay</u>

$I_{SC\ source} = 753\angle 120°$

$I_{SB\ source} = 753\angle 240°$

$I_{SC\ load} = 753\angle 145°$

$I_{SB\ load} = 753\angle 265°$

source side CT current =

$$\frac{(I_{SC\ source} - I_{SB\ source})}{240/1} = \frac{753\angle 120° - 753\angle 240°}{240}$$

source side CT current = $5.434\angle 90°$ Amps

4.2.3 (continued)

load side CT current =

$$\frac{(I_{SC\ load} - I_{SB\ load})}{240/1} = \frac{753\angle 145^\circ - 753\angle 265^\circ}{240}$$

= 5.434 115 Amps

$$\text{exciting unit secondary load CT current} = -\frac{1660.6\angle -77.5^\circ}{300/1}$$

$$= 5.5333\ 102.5^\circ \text{ Amps}$$

$$\text{current ratio} = \frac{5.434\angle 90^\circ + 5.434\angle 115^\circ}{5.5333\ \angle 102.5^\circ}$$

$$= 1.91755$$

tap ratio = 8.7/4.6 = 1.891

$$\text{mismatch} = \frac{1.91755 - 1.891}{1.891} \times 100 = 1.4\%$$

The secondary differential relay system is balanced under both neutral (1.3% mismatch) and maximum angle shift (1.4% mismatch) tap position. A 25% slope characteristic was chosen for additional security.

4.3 Back-Up Ground Fault Protection

Inverse short time-overcurrent relays with harmonic restraint supervision were applied in both the exciting unit primary and secondary neutrals to provide back-up ground fault protection for the PAR's. When applying phase angle regulating transformer ground overcurrent protection, two significant items must be addressed. The first item is whether the ground overcurrent relay which is applied to the neutral of the exciting unit primary windings must be coordinated with line side ground relays. The second item is restraint requirements during energization due to unbalanced magnetizing inrush currents.

The requirement to coordinate the exciting unit primary ground overcurrent relay (51N2) with line side ground relays depends on whether the exciting transformer is a source of zero sequence current.

4.3 (continued)

The East Garden City PAR exciting units are wye-grounded, wye-grounded, three phase, three-legged core construction. In a Y-Y three phase, three legged core construction, the direction of flux induced by zero sequence current is the same in all three legs. This results in a flux return path through air, resulting in a relatively low exciting impedance to zero sequence current. The three-legged, three phase core construction thus has an effect of providing a fictitious delta tertiary winding of relatively high impedance, and allows the flow of zero sequence current.

The zero sequence equivalent circuit of the East Garden City PAR's is thus similar to a wye grounded-delta-wye grounded three winding transformer. Figure 13 shows the zero sequence equivalent circuit of the EGC PAR's. Although the positive sequence impedance of the PAR's varies from 7.34% at 0° phase shift to 12.42% at -25° phase shift, the zero sequence impedance of the PAR remains fairly constant across the tap range.

Since the East Garden City PAR's are sources of zero sequence current, the exciting unit primary winding ground overcurrent relay (51N2) must coordinate with line side ground overcurrent relays.

The PAR exciting unit secondary winding ground overcurrent relay (51N1) does not require coordination with line side ground overcurrent relays. The 51N1 relay setting was arbitrarily chosen to be the same as the 51N2 relays. This setting allows high speed operation for all exciting unit secondary ground faults.

To prevent the misoperation of the PAR ground overcurrent relays 51N1 and 51N2 during energization, instantaneous overcurrent relays with harmonic restraint (50N1 & 50N2) were added to supervise the ground overcurrent relays 51N1 and 51N2. (Harmonic restraint supervision of the exciting unit secondary winding ground overcurrent relay 51N1 was probably not required but was applied anyway). The harmonic restraint relays 50N1 and 50N2 were set to operate at 80% of the pick-up of the ground overcurrent relays 51N1 and 51N2. The harmonic restraint instantaneous overcurrent unit will be restrained from operation when the second harmonic component of current is twenty percent or more of the fundamental component of current.

4.4 Sudden Pressure Relaying

Sudden pressure relays (sometimes referred to as rapid pressure rise relays) are applied to both the series units and exciting units. The sudden pressure relays are wired to trip both the primary and secondary lockout relays. The sudden pressure relays are required for the detection of turn-to-turn faults which might not be detected by differential relaying. The sudden pressure relay operates when the rate of pressure increase inside the transformer tank exceeds the safe limits established by the transformer manufacturer.

4.5 Parallel Operation - "Out of Step" Protection

The parallel operation of phase angle regulating transformers introduces an additional protection concern if the PAR's were to be operated "out of step". The operation of parallel phase angle regulating transformers with different phase angle shifts could result in the circulation of large currents between the PAR's. If the PAR's were directly connected in parallel, the circulating current due to "out of step" operation of the PAR's would be limited only by the impedances of the PAR's. At East Garden City, the additional impedance of the autotransformers limits the magnitude of circulating current significantly, such that operation of the PAR's one step apart could be tolerated continuously under maximum load conditions.

Figure 14 illustrates the "Out of Step" protection scheme which was installed at the East Garden City 345KV substation. The scheme includes both tap position and circulating current sensing of a PAR out of step condition. The scheme will trip the associated breaker if the PAR's are out of step for greater than 10 minutes and a PAR winding hot spot indication exceeds 140°C. An alarm is provided if the PAR's are out of step for 30 seconds. The scheme can be disabled via supervisory control if one PAR is out of service.

The tap position sensing circuit includes the hardwiring of the tap position indications to pick up relay 78 when the PAR's are any even multiple of two steps apart. This is accomplished by paralleling every fourth tap position indication for each PAR (four combinations for each PAR) and connecting each combination in series with the other PAR tap position combinations which would result in the PAR's being two steps apart. Once the PAR's are two steps apart the 78 relay will pick up and be sealed-in. The tap position out of step sensing circuit would be reset by relay 3 when the PAR's are returned to the same tap position.

The circulating current sensing circuit includes an overcurrent relay (50) connected to operate on the differential current between the two phase angle regulating transformers. The overcurrent relay has been set to detect a one step "out of step" condition. Since the differential current which is fed to the overcurrent relay is twice the circulating current, the overcurrent relay which was utilized required a significant overcurrent capability (11 amps for 10 minutes).

4.6 Overexcitation Protection

A three phase, solid state voltz/hertz relay system with adjustable inverse time characteristics was applied on the phase angle regulator side of both 345KV circuit breakers. These systems will provide overexcitation protection for both the phase angle regulating transformers and autotransformers by tripping the associated 345KV and 138KV circuit breakers at East Garden City.

5.0 Conclusions

The complete protection of a phase angle regulating transformer requires a combination of schemes, including differential, ground overcurrent and sudden pressure relaying.

The location and turns ratio of current transformers must be determined prior to PAR manufacture to ensure adequate differential protection system coverage.

Differential relaying schemes must be examined closely to determine CT connection and ratio requirements. The magnitude and direction of currents in all windings should be determined under both neutral and full angular shift conditions to ensure proper differential relay operation under all load and fault conditions.

The use of ampere-turn-balance concept for the series windings coupled with the analysis of the PAR at its neutral tap position provides a clear method for the correct design of the differential relay systems. Relay connections, CT ratios, and relay tap selection and mismatch calculations are easy to establish and understand utilizing this concept.

The application of back-up ground fault protection must be examined carefully to determine restraint requirements during energization magnetizing inrush conditions. The ground overcurrent relay coordination requirements for external faults must also be examined.

Series unit saturation during external fault conditions should be analyzed to determine if additional restraint is required for the differential protection schemes.

6.0 References

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BIOGRAPHIES:

MOHAMED IBRAHIM was born in Talka, Egypt on February 13, 1943. He received the B.S. degree in Electrical Engineering from Egypt in 1964 and the M.S. in Electrical Engineering from Newark College of Engineering, Newark, New Jersey in 1973. He attended and completed the Advanced Power System Engineering Course at General Electric, Schenectady, 1973-1974. He completed 33 credits of post graduate work at New Jersey Institute of Technology. He is a registered Professional Engineer in New York State.

From 1964 to 1969, he worked as a teaching assistant at Cairo Higher Institute of Technology, Egypt. From 1970 to 1980 he worked with the American Electric Power Service Corporation in New York where he was a Senior Engineer and his work was related to Protective relaying and Control design, analysis of high voltage transmission outages and performance and computer relaying. At the beginning of 1980 he joined Ebasco Service Incorporated as a Senior Engineer. His work was related to nuclear power plants. In October, 1980 he joined New York Power Authority as a Supervisory Electrical Engineer. He is presently the Director of the System Protection and Control Engineering Section. He participated as a visiting lecturer at the Auburn University and the Rensselaer Polytechnic Institute. He is a member of the adjunct teaching staff at Polytechnic University in New York teaching graduate protective relaying courses. He is the co-author of eight technical papers in the computer relaying and protection areas.

FRANK STACOM was born in New York City, New York on May 2, 1957. He received the B.E.E. and M.E.E. degrees from Manhattan College, Bronx, New York in 1979 and 1987 respectively. He attended and completed the Power Systems Engineering Course at General Electric, Schenectady, NY in 1987-1988. He is a registered Professional Engineer in New York State.

Mr. Stacom was employed at the Long Island Lighting Company as an engineer in the System Control and Protection Engineering Division from 1979 to 1982. In 1982 he joined the New York Power Authority as an engineer and worked on SCADA and computer applications. He joined the System Protection and Control group in 1983 and is presently a Senior Engineer working on the design and analysis of NYPA protective relay systems.

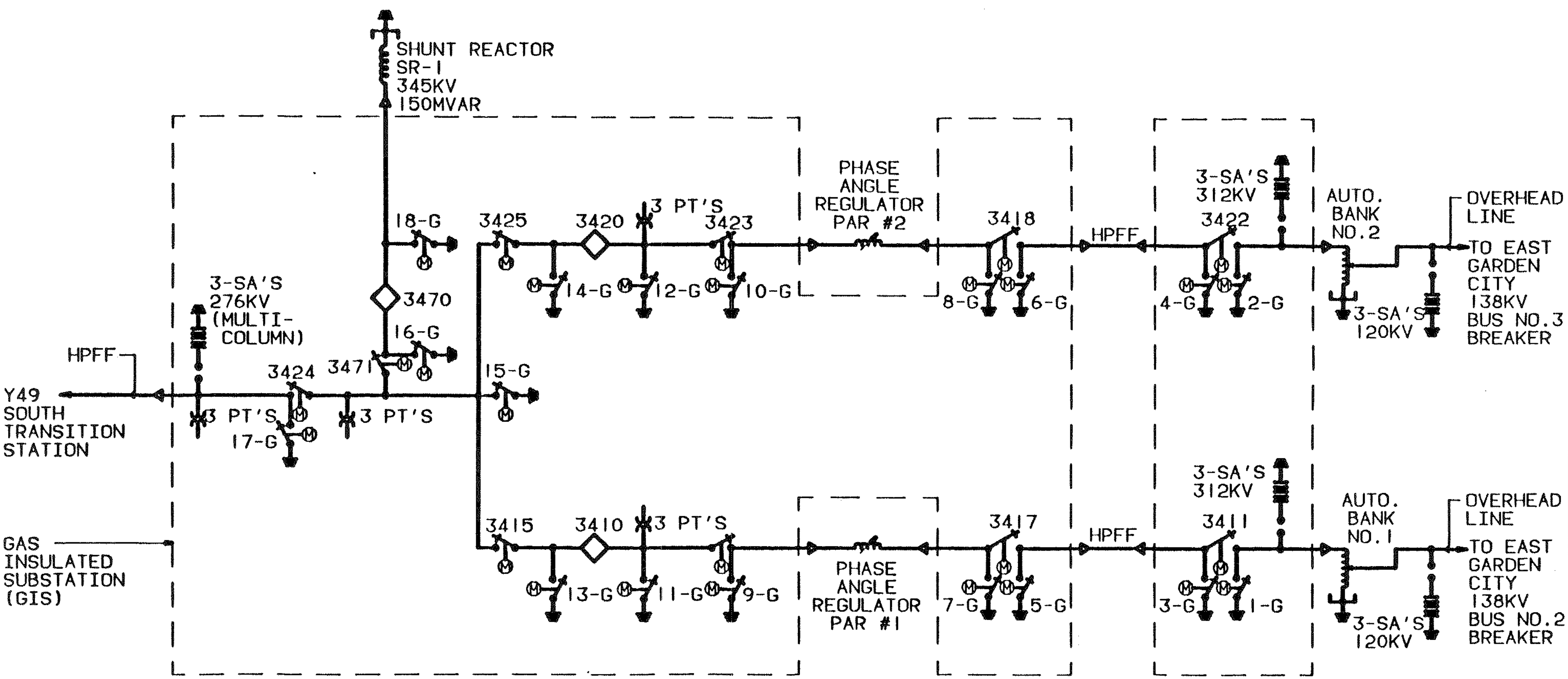


FIGURE 1
EAST GARDEN CITY

3/12/92 SOPS/ELECT

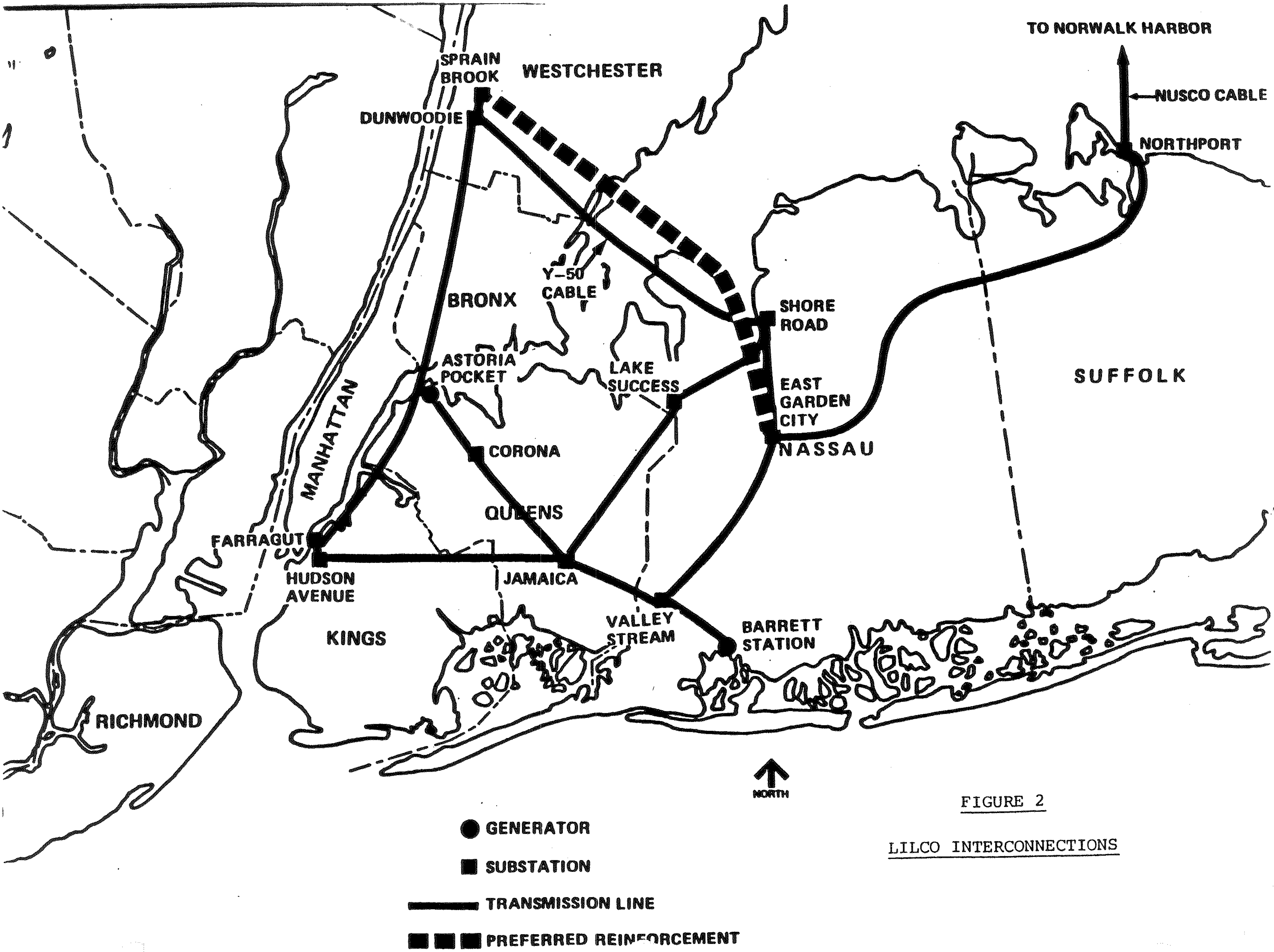


FIGURE 2

LILCO INTERCONNECTIONS

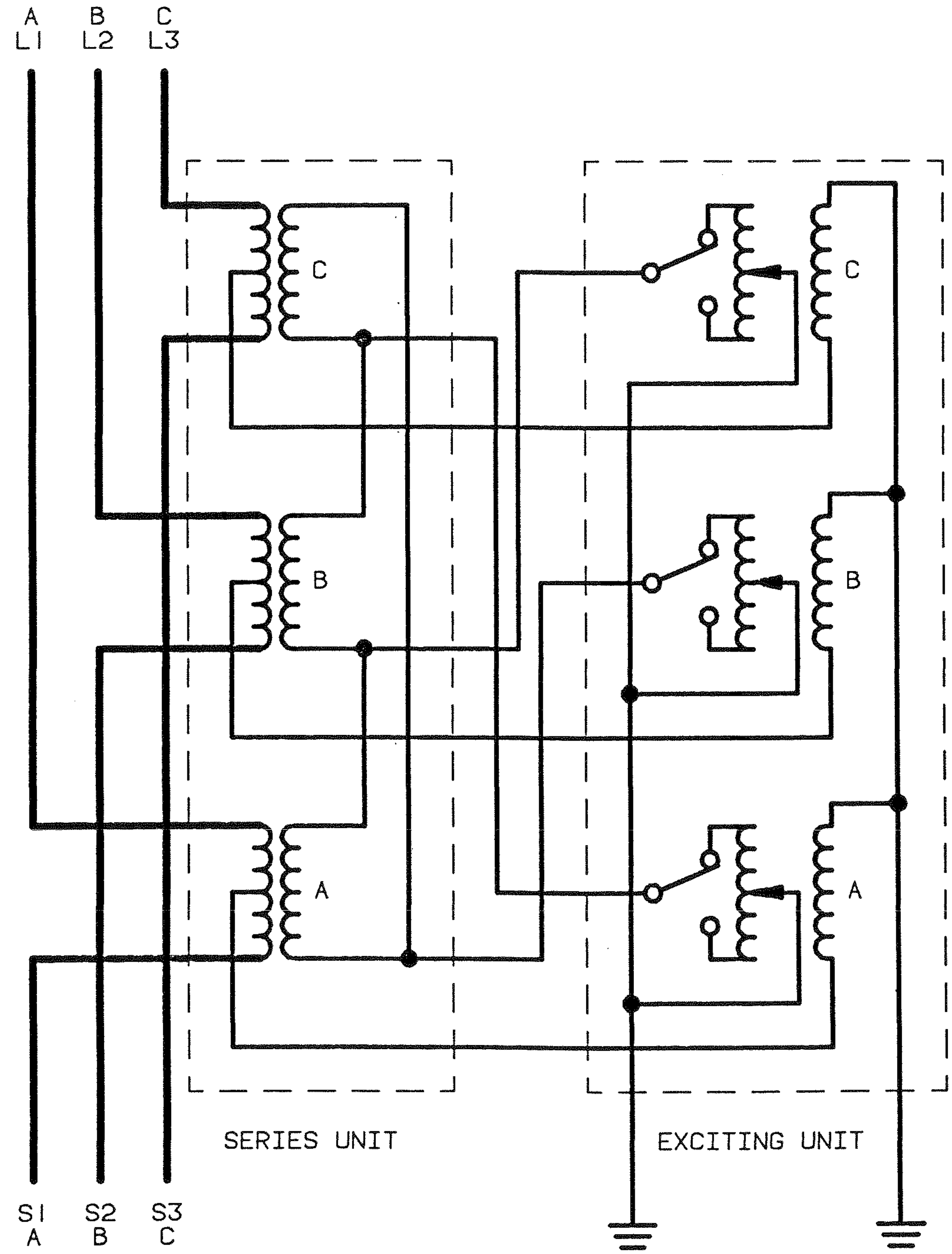
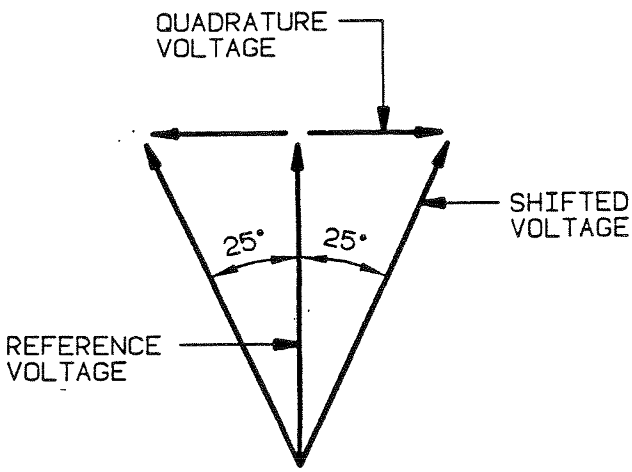
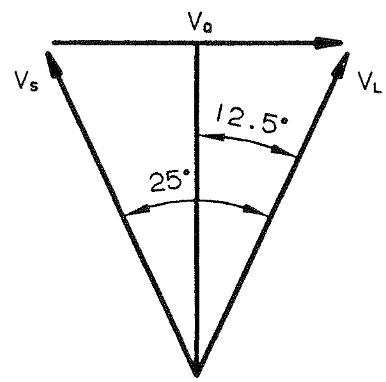


FIG. 3 PHASE ANGLE REGULATING TRANSFORMER



REFERENCE VOLTAGE	QUADRATURE VOLTAGE
V_A	V_{CB} OR V_{BC}
V_B	V_{AC} OR V_{CA}
V_C	V_{AB} OR V_{BA}

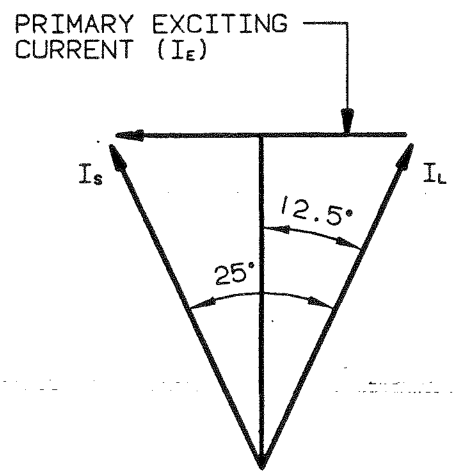
FIG. 4 QUADRATURE VOLTAGE ADDITION TO REFERENCE VOLTAGE



$$V_a = 2 \times \frac{345}{\sqrt{3}} \times \sin 12.5^\circ$$

$$V_a = 86.21\,\text{KV}$$

FIG. 5 SERIES UNIT PRIMARY VOLTAGE RATING (V)



$I_S(MAX) = 753A$

$I_E = 2 \times 753 \times \sin 12.5° = 326A$

FIG. 6 EXCITING UNIT PRIMARY CURRENT RATING (I_E)

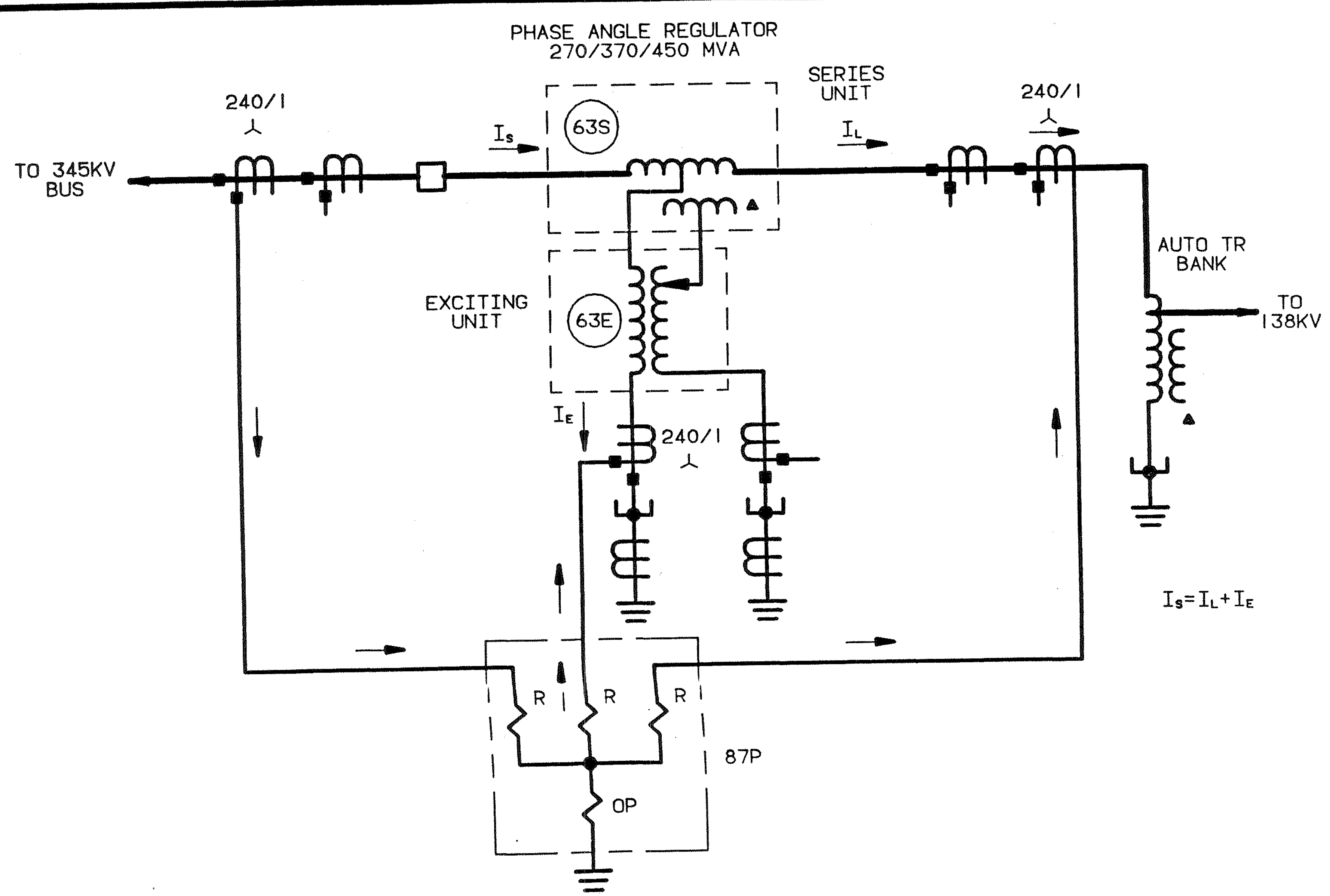


FIG. 7 A.C. ONE LINE FOR PRIMARY DIFFERENTIAL RELAYING SYSTEM

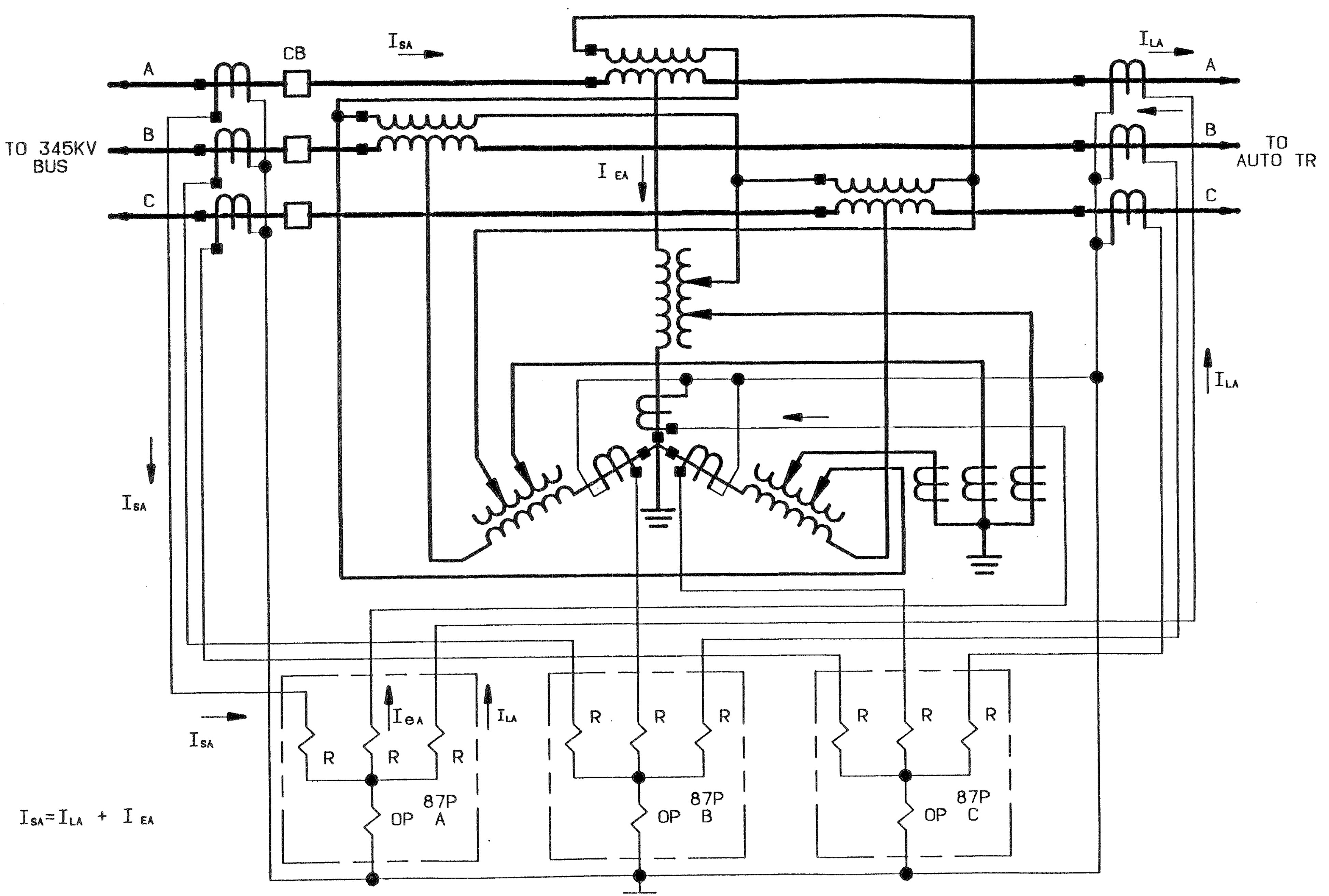


FIG. 8 3-LINE AC CONNECTION FOR PAR PRIMARY DIFFERENTIAL RELAY

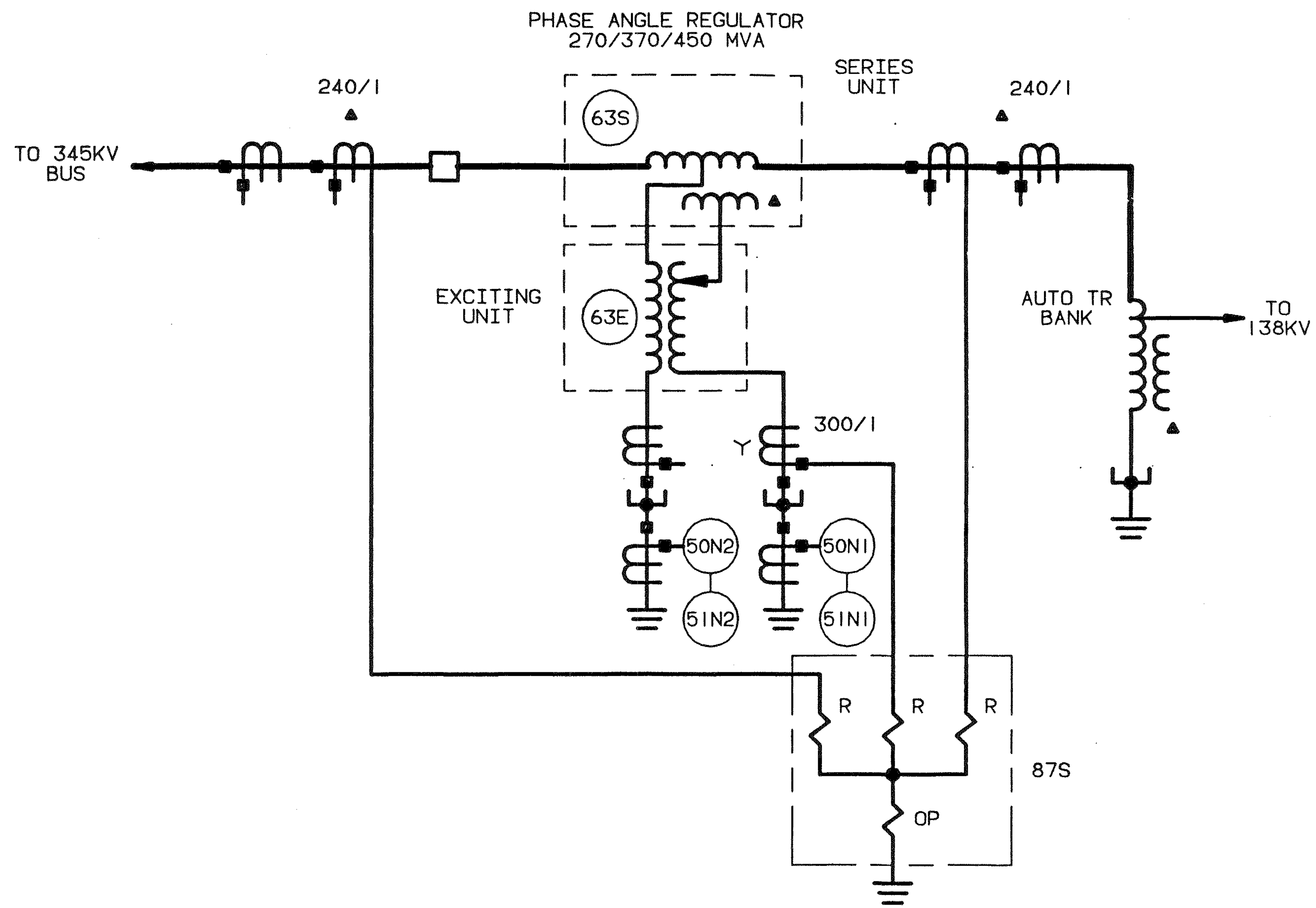
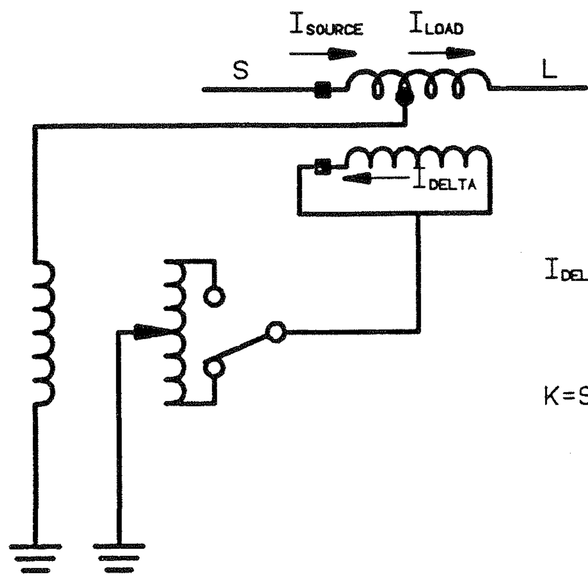


FIG.9 A.C. ONE LINE FOR SECONDARY DIFFERENTIAL RELAYING SYSTEM



$$I_{DELTA} = \frac{K}{2} I_{SOURCE} + \frac{K}{2} I_{LOAD}$$
$$= \frac{K}{2} [I_{SOURCE} + I_{LOAD}]$$

K=SERIES UNIT TURNS RATIO

FIG. 10 AMPERE-TURNS COUPLING FOR SERIES UNIT

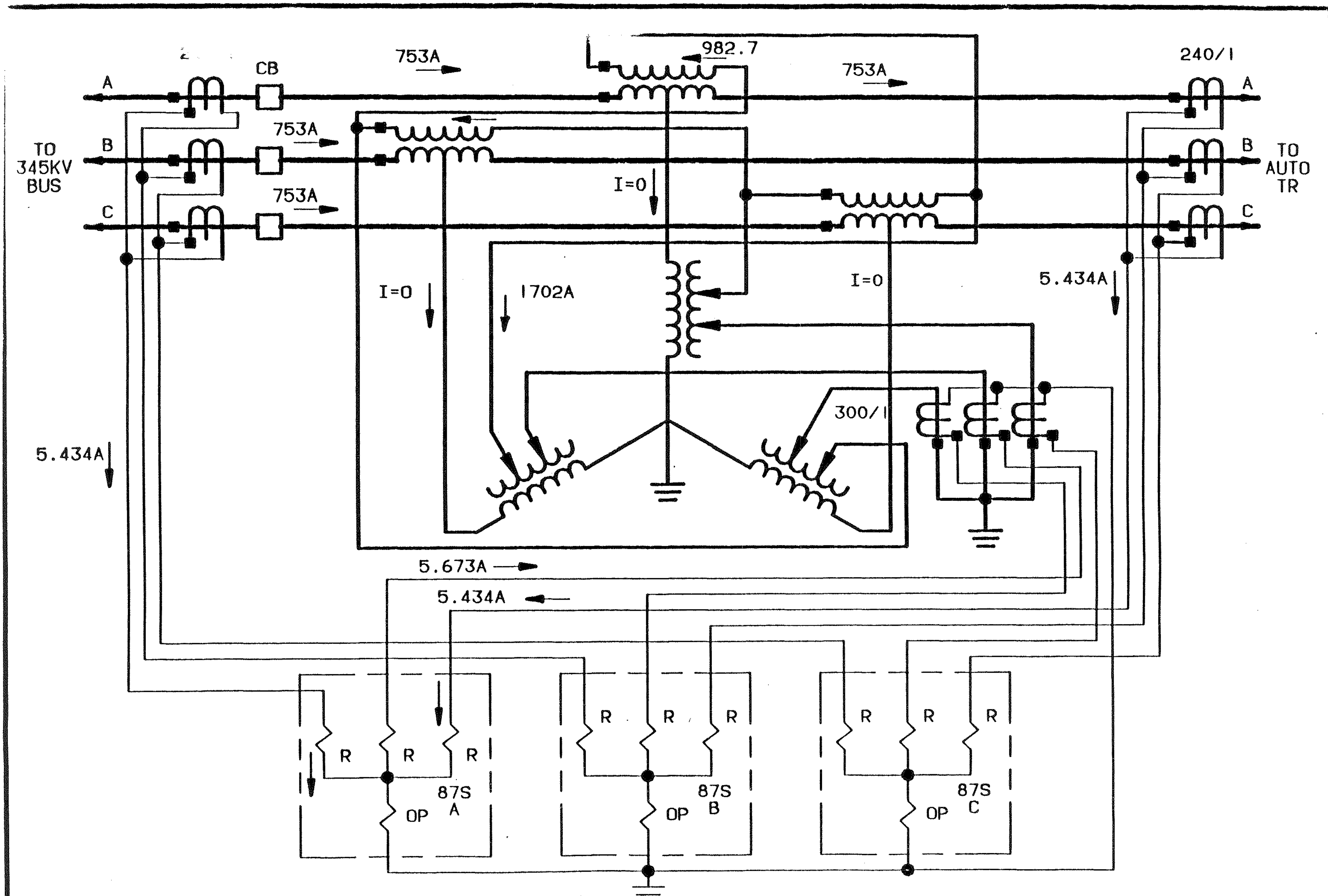


FIG.12 PRIMARY CURRENT FOR PAR NEUTRAL TAP POSITION

3/12/92 SOPS/ELECT

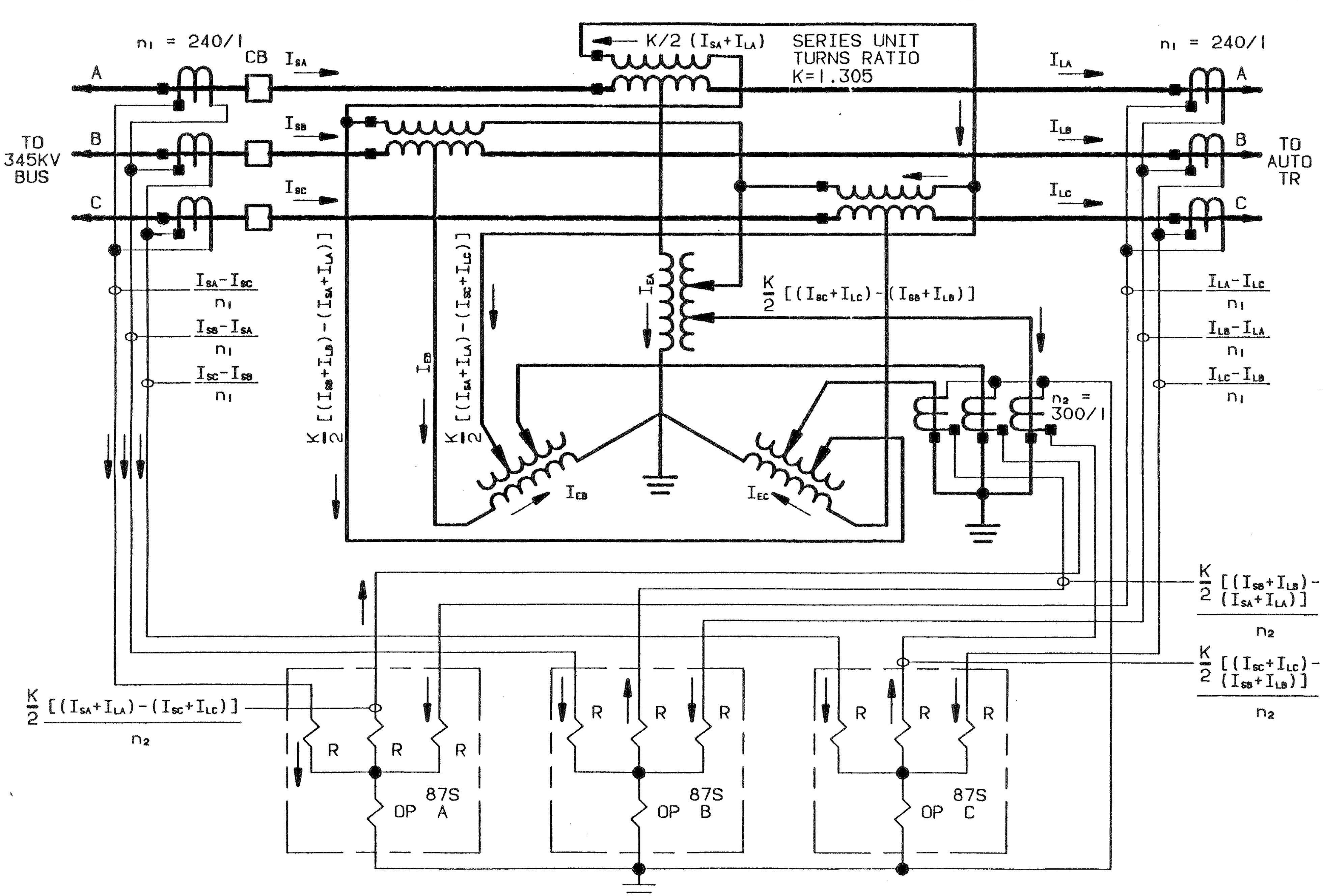


FIG.11 3-LINE AC CONNECTION FOR SECONDARY DIFFERENTIAL RELAY SYSTEM

3/12/92 SOPS/FLECT

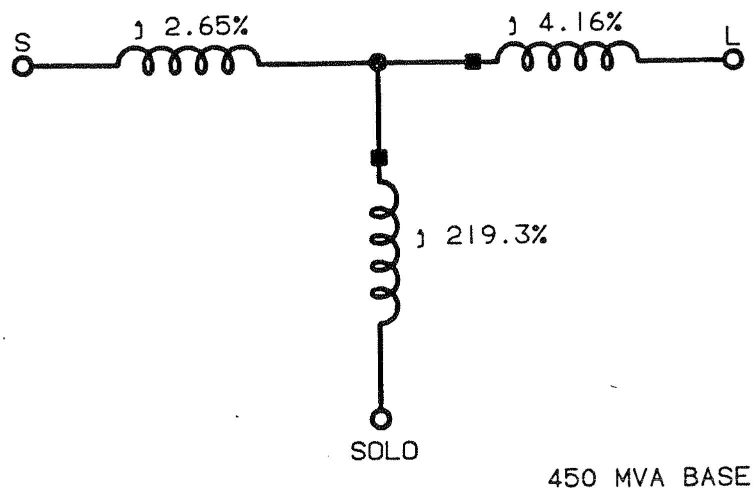


FIG. 13 ZERO SEQUENCE EQUIVALENT CIRCUIT

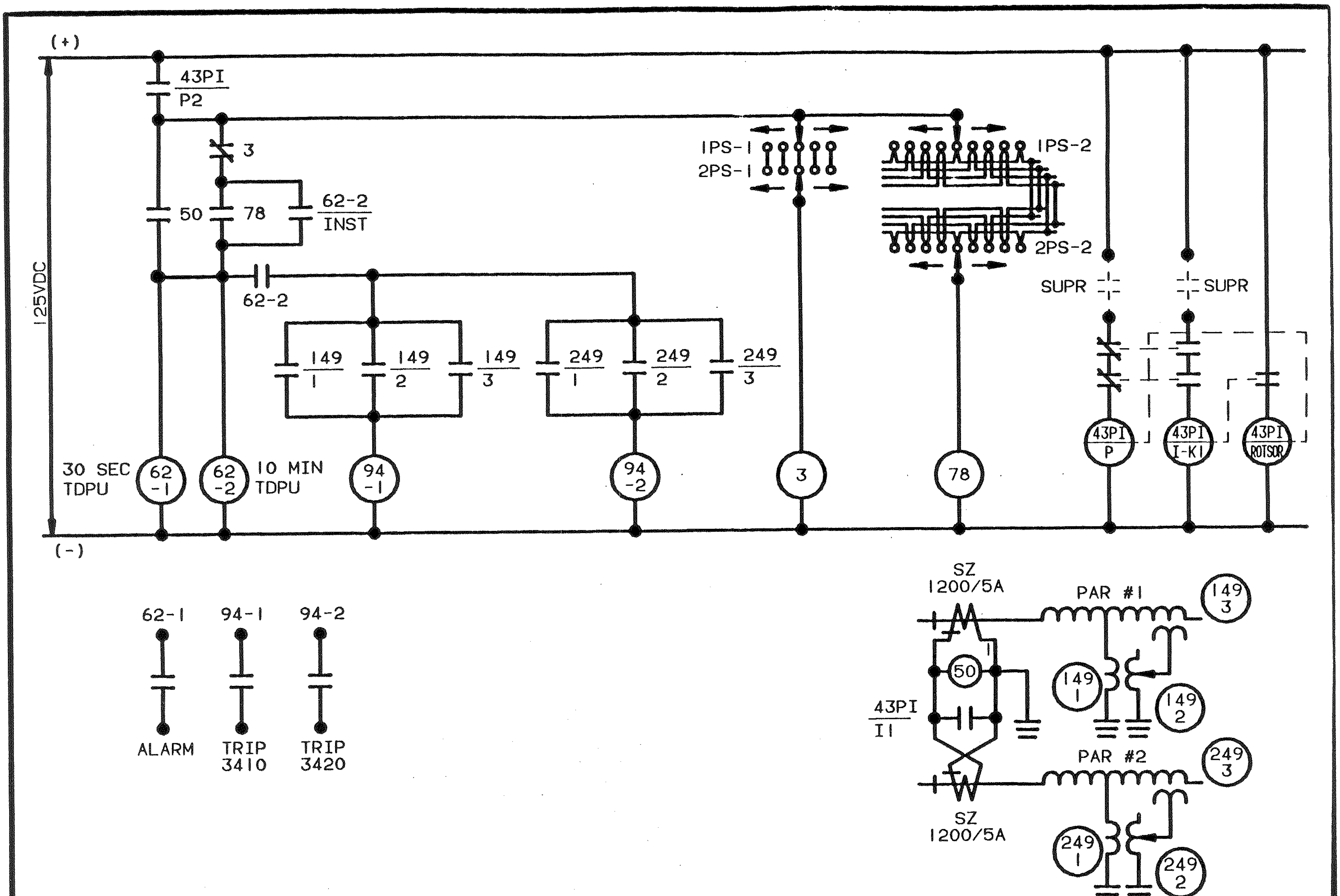


FIG.14 PAR "OUT OF STEP" PROTECTION