# Instructions for Parallel Operation of Load Tap Changers by Circulating Current Method





When two or more load tap changing transformers are connected in parallel any difference in their voltage ratios will cause a current to circulate between them. Paralleling equipment incorporated into the control circuits operates the tap changers in such a manner as to minimize this circulating current.

The necessity for paralleling equipment is illustrated in Figure 1. Two transformers, Units 1 and 2, are shown paralleled to carry the total load current $I_L$ which divides into two components, $I_{L1}$ through Unit 1 and $I_{L2}$ through Unit 2. Each transformer is equipped with load tap changing equipment indicated schematically by the arrow at the secondary connection. The control of the load tap changers is operated from current and potential transformers connected to the secondary lines of the respective transformers. These transformers feed a voltage regulating relay indicated by 90 and a line drop compensator indicated by LDC in each unit.

The line drop compensator illustrated is that used with the Type CVR-1 voltage regulating relay, but the paralleling principles are applicable to other types of voltage regulating relays and line drop compensators. For simplicity, the same letters are used for identification of the given current throughout the diagrams, it being understood that numerical values are proportional to transformer ratios. In Figure 1 the two load tap changers are placed out-of-step so that Unit 1 provides a higher secondary voltage than Unit 2 and causes the circulating current $I_C$ to flow as indicated in the loop formed by the two units and their primary and secondary bus bar connections.

When Unit 1 provides a higher secondary voltage, the circulating current $I_C$ is added to the load current of Unit 1 and subtracted from the load current of Unit 2. The characteristics of the line drop compensator are such that an increase in load current causes the tap changer's voltage regulating relay to initiate operation in the raise direction. This operation increases $I_C$. Similarly the reduction in load current in Unit 2 because $I_C$ subtracts from load current causes that voltage regulating relay to operate that tap changer in the lower direction, further increasing the difference in voltage between Unit 1 and Unit 2, and therefore further increasing $I_C$. Thus the effect becomes cumulative and the two tap changers will continue operating in opposite directions until Unit 1 reaches its maximum raise position and Unit 2 reaches its maximum lower position. The paralleling equipment reverses this cumulative effect so that the circulating current will cause the tap changers to operate toward each other rather than away from each other.

The circulating current method of paralleling uses a network of auxiliary current transformers with appropriate interconnections to separate the circulating current from the load current in the line drop compensator circuits, direct the load current through the line drop compensators, and direct the circulating current through an auxiliary compensating device. This device, shown as an idle winding in the LDC of Figure 1, is functionally an extra reactance element for the line drop compensator. When current is circulated in it, it will produce a voltage in the voltage regulating relay circuit to unbalance the voltage regulating relay and cause it to operate the tap changer.

The circuits for circulating current paralleling are shown in Figure 2. Two auxiliary current transformer networks utilizing auxiliary transformers K2 and K3 are placed ahead of the line drop compensator. In each network, the winding of a current transformer is connected in series with the line drop compensator in each unit. The secondary windings are connected in series with all other secondaries in the same net-

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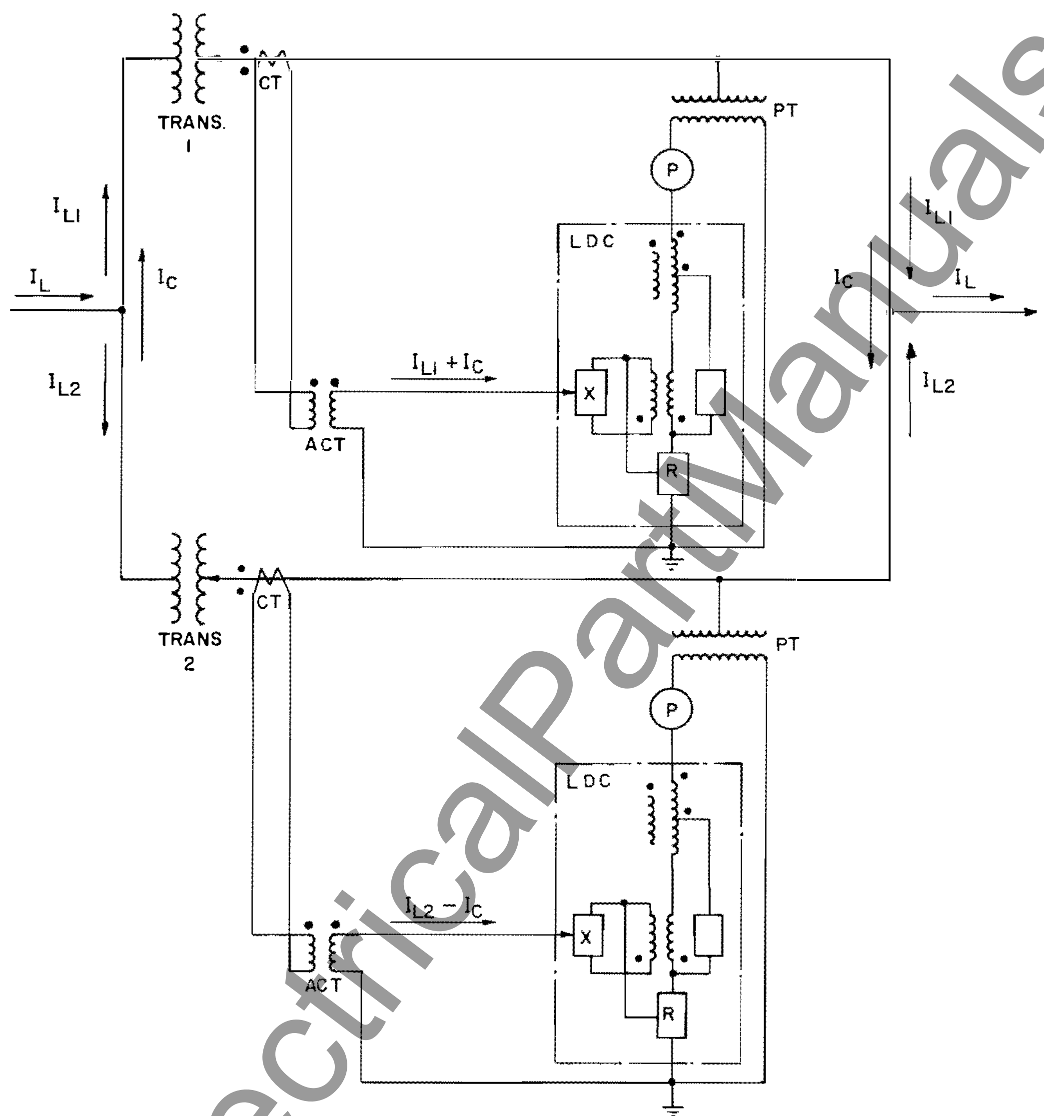



LEGEND

| | | | |
|---|---|---|---|
| $I_L$ | = TOTAL LOAD CURRENT | ACT | = AUXILIARY CURRENT TRANSFORMER |
| $I_{L1}$, $I_{L2}$ | = PORTION OF LOAD CURRENT IN TRANSFORMERS 1 & 2, RESPECTIVELY | LDC | = LINE DROP COMPENSATOR |
| | | P | = VOLTAGE REGULATING RELAY |
| $I_C$ | = CIRCULATING CURRENT DUE TO DIFFERENCE IN TAP CHANGER POSITIONS | CT | = LINE CURRENT TRANSFORMER |
| | | PT | = LINE POTENTIAL TRANSFORMER |

**Fig. 1** *Typical Circuit where Circulating Current Paralleling is applicable*

work. The secondary currents of all K2's must therefore be equal and the secondary currents of all K3's must also be equal, although K2 and K3 currents are not necessarily equal to each other. The K2 transformers are chosen so that their secondary currents will be equal when their primary currents are proportional to $I_{L1}$ and $I_{L2}$ respectively. All the K3 transformers have the same ratio so that their secondary currents are equal when the primary currents are equal. The polarity of connection in each case is such that currents must be flowing in the same direction. The auxiliary paralleling compensator device of the line drop compensators is connected ahead of the K2 and K3 networks.

The K2 transformers, as previously stated, are chosen so that their secondary currents are equal when the primary currents are in the proportion $I_{L1}$ and $I_{L2}$ and flowing in the same direction, permitting $I_{L1}$ and $I_{L2}$ to flow through the K2 network with very little burden added to the circuit, as indicated in Figure 2. The circulating current component, $I_C$, however, is positive in one unit and negative in the other unit and the K2 network presents a high impedance to this current forcing $I_C$ to flow through the auxiliary reactor of the line drop compensator. Thus, the K2 network separates load current from circulating current and directs these components into separate paths through the line drop compensator.

The K3 transformers, as previously stated, have equal primary ratings as well as equal secondary ratings. This makes it necessary that the primary currents be equal in both units. The common connection between K2 and K3 transformers provides a point at which the current is the sum of $I_{L1}$ plus $I_{L2}$. The current flowing through the K3 transformers is therefore one-half of $(I_{L1} + I_{L2})$, or $I_L/2$. The K3 network thus makes the current in the line drop compensators directly proportional to the total load current and independent of the division of this load current through the paralleled unit. This feature becomes particularly important when one unit is removed from service, leaving the other unit to carry the complete load current. Because the current through the compensators remains unchanged and still proportional to one-half the total load current, there is no change in the voltage regulation at the load center.

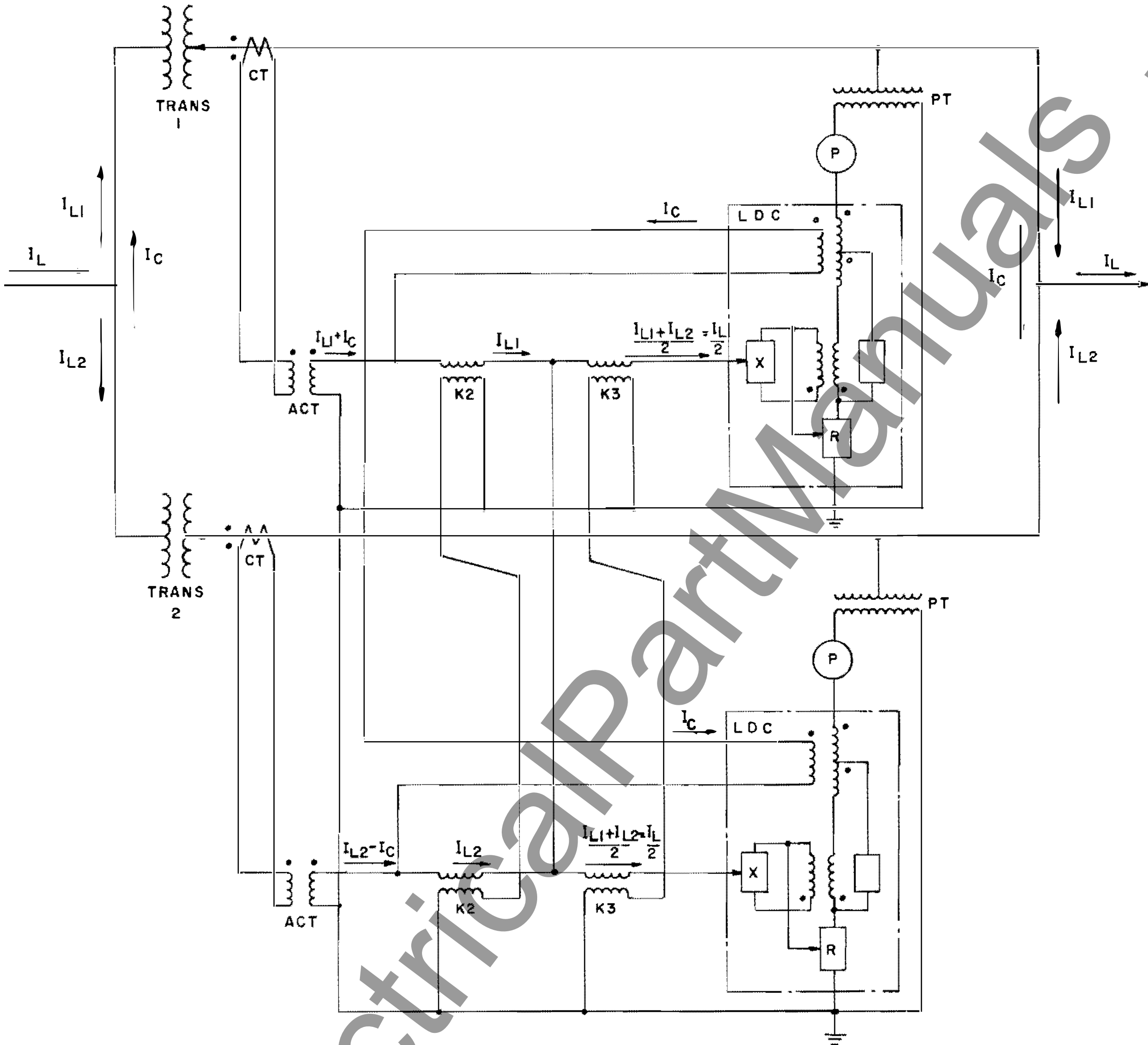
The network of Figure 2, as has been described, has separated load current and circulating current and directed the circulating current through the auxiliary reactor. This current is of one polarity in the compensator of Unit 1 and of opposite polarity in the compensator of Unit 2. Further study of Figure 2 shows that the circulating current circuit in each unit is connected to LDC in reverse polarity with respect to the load current so that an increase in circulating current in Unit 1 will now cause the voltage regulating relay to operate that tap changer in the lower direction instead of the raise direction; similarly an increase in circulating current in Unit 2 will now cause that unit to operate in the raise direction instead of the lower direction. Operating Unit 1 in the lower direction or Unit 2 in the raise direction will tend to reduce the value of circulating current. The units will now operate to such positions as to minimize the circulating current, or in other words operate to keep the tap changers in step with each other.

The circulating current paralleling system accomplishes these functions:

1. The tap changers operate to stay in step with each other and to keep circulating current to a minimum.
2. Removes the effect of circulating current from the line drop compensation.
3. Makes line drop compensation proportional to the total load on the bank of paralleled units and independent of the division of that load among the units.

## ADDITIONAL FEATURES

The circuits are shown in Figure 2 as permanent connections for two units. In actual usage, the wiring is always arranged




LEGEND

$I_L$ = TOTAL LOAD CURRENT

$I_{L1}$, $I_{L2}$ = PORTION OF LOAD CURRENT IN TRANSFORMERS 1 & 2, RESPECTIVELY

$I_C$ = CIRCULATING CURRENT DUE TO DIFFERENCE IN TAP CHANGER POSITIONS

K2 = AUXILIARY CURRENT TRANSFORMER FOR SEPARATING LOAD AND CIRCULATING CURRENTS

K3 = AUXILIARY CURRENT TRANSFORMER FOR EQUALIZING LOAD CURRENTS

ACT = AUXILIARY CURRENT TRANSFORMER

LDC = LINE DROP COMPENSATOR

P = VOLTAGE REGULATING RELAY

CT = LINE CURRENT TRANSFORMER

PT = LINE POTENTIAL TRANSFORMER

**Fig. 2** *Typical Circuit incorporating Elementary principles of Circulating Current Paralleling* so that it is possible to add additional units in parallel with the original bank. This is accomplished by simply adding additional auxiliary current transformers in the K2 and K3 networks in each additional unit which is paralleled. This arrangement for three units is shown in Figure 3.

The standard wiring of circulating current paralleling controls is arranged to permit connecting auxiliary contacts of the transformer and/or bus circuit breakers into the paralleling circuit. This permits the paralleling circuits to adjust automatically to changes in the method of system operation and to adjust automatically if one unit is removed from service. The breaker auxiliary switches must be wired in at the time of installation as part of the installation of the equipment in the substation. Terminal block points are provided in the tap changer control cabinet for these connections. The contacts designated by numeral 152 are on the transformer breakers while contacts designated by numeral 24 are auxiliary contacts for the bus tie breakers. Figure 3 shows the auxiliary contacts open or closed as they would be when all breakers are closed.

A third feature included in the standard controls for parallel operation is a manually operated two position switch for selecting parallel or independent operation. Whenever this switch is placed on the independent position, the tap changer control will operate exactly as though no paralleling equipment were supplied. This permits using the unit on a radial type feeder. When this switch is placed on the parallel position, it places that unit in parallel operation with all the others connected into this same paralleling network whose paralleling switches are also on the parallel position.

The breaker auxiliary contacts and the paralleling switch both function to separate the paralleling network into sections according to the way in which the transformers are paralleled. Referring to the K2 network in Figure 3, it will be observed that either the paralleling switch contact 43P1, the transformer breaker contact 52b, or the tie breaker contacts 24b will short circuit the K2 network and divide it into two sections. The portions can then operate independently. In a similar manner the contacts 52a, 43P2, or 24a open the circulating current circuit between units so that circulating current from one portion of the network cannot be fed into another portion of the network.

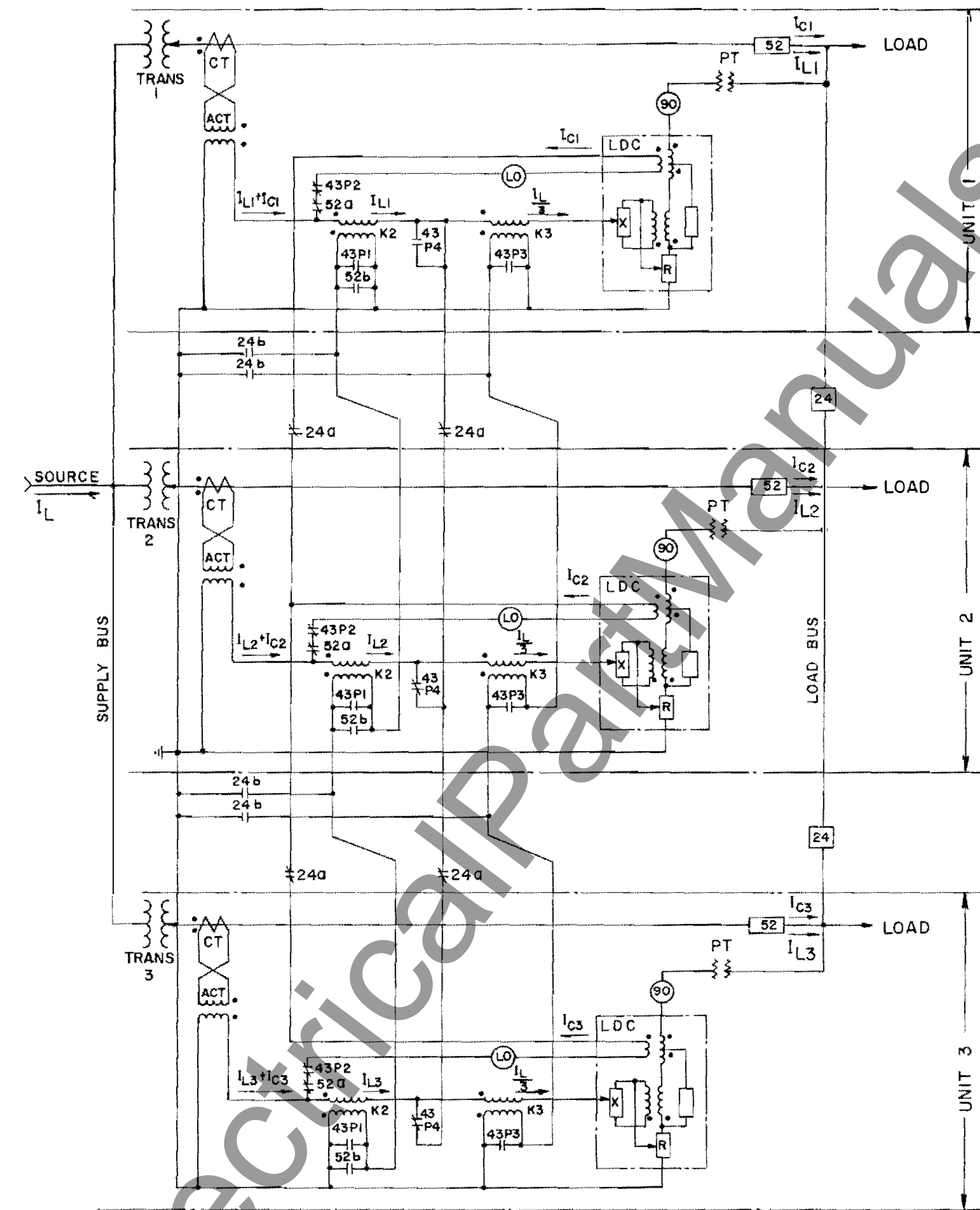
The connections for the K3 network are similar to those for the K2 network except that no contacts are used from the transformer breaker. This is because opening a transformer breaker does not affect the total load on the transformer bank and therefore no change is necessary in the line drop compensation in the control circuit.

Typical connections of the bus tie and transformer breaker auxiliary switches are shown in Figure 3. This instruction leaflet cannot possibly cover the numerous bus connections used in substations, but by applying the principles described, suitable bus tie and transformer breaker auxiliary switch connections can be derived for almost any substation bus arrangement.

## OPTIONAL FEATURES

Lockout relaying is an optional feature available with circulating current paralleling and is illustrated in Figure 3 by the circle marked LO. This relay is an overcurrent device and is adjusted for such sensitivity that the tap changers may get a few steps apart and be allowed to continue operating to bring themselves back together, but if they become far enough apart that the circulating current reaches a predetermined limit, the LO relay will operate. The LO relay may be used for either or both of two functions:

1. The contacts may be connected into the tap changer control circuit to stop the tap changers from operating.
2. The contacts may be connected to an alarm which alerts the station operator when the limit value of circulating current has been reached.




LEGEND

$I_L$ = TOTAL LOAD CURRENT

$I_{L1}, I_{L2}, I_{L3}$ = PORTION OF LOAD CURRENT IN TRANSFORMERS 1,2,3 ,RESPECTIVELY

$I_{C1}, I_{C2}, I_{C3}$ = CIRCULATING CURRENTS DUE TO DIFFERENCES IN TAP CHANGER POSITIONS

52 = TRANSFORMER CIRCUIT BREAKER

43P = MANUALLY OPERATED PARALLEL-INDEPENDENT SELECTOR SWITCH

$I_{L1} + I_{L2} + I_{L3} = I_L$

$I_{C1} + I_{C2} + I_{C3} = 0$

ACT = AUXILIARY CURRENT TRANSFORMER

LDC = LINE DROP COMPENSATOR

90 = VOLTAGE REGULATING RELAY

CT = LINE CURRENT TRANSFORMER

PT = LINE POTENTIAL TRANSFORMER

24 = BUS TIE CIRCUIT BREAKER

LO = LOCK-OUT RELAY

K2 = AUXILIARY CURRENT TRANSFORMER FOR SEPARATING LOAD AND CIRCULATING CURRENTS

K3 = AUXILIARY CURRENT TRANSFORMER FOR EQUALIZING LOAD CURRENTS

**Fig. 3** *Typical Circuit showing complete Circulating Current Paralleling including Auxiliary Devices*

The LO relay may be a directional relay instead of an overcurrent relay. When the directional relay is used, the relay is sensitive to the direction in which the units have separated and the contacts can therefore be used to prevent operation in the direction which would further increase circulating current but permit tap changer operation in the direction to decrease circulating current. When the LO relay is directional, polarizing voltage for directional sensitivity must be obtained from suitable potential transformers.

## ADJUSTMENT, MAINTENANCE AND INSPECTION

Since the transformer and network components used in the circulating current method of paralleling are all static devices, there will normally be no adjustment or maintenance required. The switch contacts of the paralleling switch and circuit breaker auxiliary switches should be inspected occasionally and cleaned if necessary, but because of the infrequent operation of these devices they are more apt to become dirty from environmental influences than from burning due to their operation.

The auxiliary element of the line drop compensator which is used for the circulating current paralleling is designed to cover the requirements of most paralleling conditions. There may occasionally be cases where the impedance of the circuit is such that the circulating currents resulting from tap changers being out-of-step with each other will be either too great or too small to be used in the standard manner as shown in Figures 2 and 3. In such cases an auxiliary tapped current transformer may be used in this circuit to step up or step down the circulating current to usable values. In such cases the initial factory adjustment of the taps on the auxiliary current transformer will be based upon the calculations involving volts per step of the tap changer and circuit impedance of the transformer and buses. In case it should become necessary to change the taps on such transformers it should be remembered that increasing the current introduced into the compensator element will increase the sensitivity of the control to out-of-step conditions. If this is made excessive, the units may hunt because, due to inherent variations from design values, there will almost always be some small residual circulating current even at the minimum positions. On the other hand if the taps are adjusted so that the current entering the compensator is too small, the control will be insensitive and will let the tap changers remain several steps apart. Sensitivity of the paralleling control will also depend upon the bandwidth setting. It is almost always possible to find settings which will keep the paralleled units within two steps of each other, in many cases they can be kept within one step of each other, and in some cases it may be possible to keep them exactly in step without causing hunting. In the usual case shown in Figures 2 and 3 where there is no auxiliary tapped current transformer, the circuit sensitivity is calculated to limit the difference in tap changer positions to one step when the voltage regulating relays are set for a two volt bandwidth.

It is normally recommended that the tap changers of units to be paralleled be placed on the same tap position before the bus tie breakers and/or transformer breakers are closed. Operation in this manner will prevent initial large circulating currents. If, however, the units are not on the same position, the paralleling circuits will operate to bring the tap changers together as soon as the units are put into service, following of course the normal time delay of the tap changer control circuits. Note that if the units are equipped with lockout relays, and the breakers are closed when the units are a number of steps apart, the lockout relays may operate and prevent the tap changers from bringing themselves into step. This would not happen with directional lockout relays.

## TROUBLE SHOOTING

In case units connected for parallel operation do not perform properly, it is recommended that the following points be investigated.

1. Recheck all wiring between units to make doubly sure that installation is made in accordance with the wiring diagram and that bus tie and transformer breaker auxiliary contacts are properly connected into the circuit.

2. Check the voltage regulating relay settings to make sure that all paralleled units are set for the same voltage level and bandwidth.

3. Check the line drop compensator settings to make sure that both the R and X compensator dials are set the same on all units.

4. Check connections to current transformers particularly if multiratio CT's are used, to make sure that all units have the proper CT ratios.

5. Check potential transformer connections to make sure that potential and current supplies are in phase with each other when the transformers are carrying unity power factor load.

6. Check both potential and current transformer primary connections to make sure that all units have their current transformers in the same phase and that all units have their potential transformers in the same phase.

7. Check the K2 and K3 networks to make sure that the secondaries of the current transformers are actually connected in series and not in opposition. One of the easiest ways to check this is by placing a voltmeter across the PS1 contacts or the PS3 contacts of the paralleling switch when the switch is in the parallel position and with the units carrying some load. If the connections are proper, the voltage at this point should be only a few volts. If the connections are reversed the voltage at this point may be several hundred volts. If high voltage is measured, the CT secondaries are connected in opposition and should be reversed on one unit.

8. If the paralleling circuits are operating but the units operate away from each other instead of toward each other, the circulating current connections into the auxiliary element of the line drop compensator are reversed and should be corrected.

WARNING: All of the circulating current paralleling circuit is connected in the current transformer circuits of the LTC transformer. Therefore whenever any connections are to be changed or any circuits opened in the trouble shooting procedure, the main current transformers of all paralleled units should be carefully and adequately short circuited.

RENEWAL PARTS

Order Renewal Parts from the nearest Westinghouse Office giving Serial Number, Type, and S.O. or Style Numbers stamped on the transformer nameplate and a complete description of the Parts required.

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