

Advanced Paralleling of LTC Transformers by Δ VARTM Method

1.0 ABSTRACT

Beckwith Electric Company **Application Note #11**, *Introduction of Paralleling of LTC Transformers by the Circulating Current Method*, builds a system and describes the operation for the basic case of two identical transformers operating in parallel. **Application Note #13**, *Advanced Paralleling of LTC Transformers by the Circulating Current Method*, expands that definition to the many installations that have more than two transformers or have mismatched transformers with different electrical characteristics (ratings or impedances).

This Application Note will build on those Application Notes to include those applications where:

- 1) a system condition could exist where the primary windings of the paralleled transformers might be fed from different source transmission lines or
- 2) there is a large variation in relative impedances of the paralleled transformers as tap changes occur.

These conditions can result in undesirable operations for paralleled transformers controlled using normal circulating current, master/follower, or power factor type controls.

2.0 ISSUES

To reiterate, the basic premise for LTC transformers operating in parallel is simple:

- 1) The transformers must continue their basic function of controlling the load bus voltage as prescribed by the setting on the control.
- 2) The transformer must act so as to minimize the current which circulates between them, as would be due to the tapchangers operating on appropriate (not necessarily equal) tap positions.
- 3) 1) and 2) above must continue correctly in multiple transformer applications regardless of station breaker operations and resultant station configuration changes.

This application note will focus on the unique, but frequently encountered, operating conditions described above where paralleling equipment other than the **Δ VARTM Method** could result in undesirable tapchanger operations.

3.0 CONSIDERATIONS

3.1 Defining the Problem

- 1) Master/follower paralleling methods assume that, under all system operating configurations, the desired objectives of the operation are met by maintaining the same physical tap position on all paralleled transformers. The operation consists of one active control commanding additional transformers' tapchangers to follow.
- 2) Circulating current paralleling methods assume that a continuous circulating current path is maintained for all system operating configurations and that any changes in the circulating current magnitude is, in fact, a result of an undesirable change in the relative tap positions of the paralleled transformers. Circulating current methods bias all paralleled controls to operate next in the direction to minimize the circulating current.
- 3) Power factor paralleling methods assume that the most desirable combination of tap positions on paralleled transformers is one that maintains equal power factors in the transformers. This method usually does not bias the controls to operate but blocks the control from operating in the wrong direction based on the power factor. Further, it is difficult to apply power factor methods in substations with more than two transformers in parallel.

Figure 1 illustrates a substation arrangement which can result in the system condition where one of the paralleled transformers can be fed from one transmission line while the other is fed from a separate line. Another arrangement which can result in the same phenomena is that of ring bus arrangements with both line positions and transformer positions. Operation under these configurations can violate the assumptions of each of the three methods described above.

3.2 Understanding the Conditions

- 1) A power transformer has a very high (25 to 50) X/R ratio. That is, power systems in general are reactive and the resistive effects of transformer impedances are negligible.
- 2) An in-phase voltage change (as in a tapchanger operation) applied to a reactive circuit (as in paralleled transformer configuration) only changes the circuit VAR flow and NOT the Watt flow.
- 3) Since tap changes do not create changes in circulating KW flow, KW flow must not be a factor in controlling the paralleled tapchangers. If system or equipment characteristics (other than tap mismatch) can substantially effect the KW flow through the transformers, VAR flow must be the only determining control quantity.
- 4) Transformers with directly-connected secondaries supplying load are in parallel regardless of the high-side connection configuration.

4.0 THE Δ VARTM METHOD

The theoretical basis for the Δ VARTM Method of paralleling is that paralleled transformers are meant to SHARE the VAR load (as well as the KW load) of the load bus. Since the KW sharing of the parallel transformers is determined by the relative transformer impedances and NOT the tap position, KW flow should not be able to affect tap position choice. Further, the best choice of loading parallel transformers is to maintain the VAR sharing, regardless of KW loading.

The Δ VARTM Method will result in the VAR flow to the substation load to be shared in the appropriate ratio by the paralleled transformers. It should be noted that matching auxiliary CT's are required in circulating current

schemes when equally-sized transformers with different impedances are paralleled. Those auxiliary CT's are not necessary when the **Δ VAR™ Method** is used.

The **Δ VAR™ Method** is implemented in the M-2001B Digital Tapchanger Control in two ways: designated as **Δ VAR 1 or Δ VAR 2**. The difference is in the additional equipment required for implementation.

The **Δ VAR 1** implementation uses all the same auxiliary equipment as the circulating current method. Namely, a parallel balancing module (which separates the load current from the circulating current) and an overcurrent relay (which gives independent backup protection to the paralleling operation). This fact makes it directly replaceable to other controls using circulating current methods.

The **Δ VAR 2** implementation is limited to use with no more than two transformers and when both transformer currents are input to both controls. This eliminates the need for the parallel balancing module and removes the path for the installation of the overcurrent relay. For this implementation, the sensitivity setting is added to the M-2001B Tapchanger Control along with a circulating current overcurrent inhibit function. The **Δ VAR 2** implementation also contains a CT ratio matching setting, making it unnecessary to match CT ratios for proper operation.

The **Δ VAR™ Method** is incorporated in the Beckwith Electric M-2001B Tapchanger Control, as an option, which internally calculates and compares the individual transformer VAr flows to make decisions for parallel biasing and operation.

5.0 OPERATIONAL COMPARISONS

5.1 Common High & Low Side Busses

Referring to Figure 1, all breakers (A through D) are closed. All analysis in previous application notes apply. Changes in circulating current are a function of mismatching tap position operations. Problems can occur if impedance changes in one transformer are substantially different from the impedance changes in the other as tap changes occur. The problem is that the KW loading is changing, as reflected in the circulating current, and therefore could be a factor in tap positioning--except with the **Δ VAR™ Method**.

5.2 Paralleling Interrupted

Referring to figure 1, breakers B ,C or D operate singly or in combination to isolate one transformer from the other. Any paralleling method uses "a" or "b" contacts from the breakers to determine this condition and operate appropriately.

5.3 Source Side Separation

Referring to figure 1, breaker A opens which separates the sources to the paralleled transformers. Although contacts could also indicate this condition, there is no operating procedure for the standard methods of paralleling for these circumstances.

Before the breaker operation, either KW or VARs or both could have been flowing from one portion of the transmission system to the other through these lines (or, more load was being supplied by one line than the other). When the breaker opens, the voltages on both lines will reflect the preceding condition by either being at different voltage levels (VAr flow) or different phase angles (KW flow). That is, that flow will attempt to continue through the transformers, albeit more limited by the additional transformer impedance inserted into the circuit.

Remembering that tap changes (in-line voltage change) will not materially effect KW flow in a reactive circuit and that a solution which best equalizes the loading of the paralleled transformers would be desirable, following are the responses of the different methods to this condition.

1) Master/Follower method of paralleling – No response for correctional action. After the response to a changed load bus voltage, the intersystem flow would be added to one transformer load and subtracted from the other. Since this difference could be substantial, it is unacceptable for most systems.

2) Circulating Current method of paralleling –

a) If the intersystem flow was VArS, the circulating current method would bias the operation of the tapchangers to attempt to offset the flow. This would result in operation at different tap positions for the two transformers and proper sharing of the load from the two sources. That is, the tap difference would equal the voltage level difference, thus stopping the flow-thru VArS. This is satisfactory operation.

b) If the intersystem flow was KW, the circulating current method would again bias the operation of the tapchangers to attempt to offset the flow. However, the KW flow cannot be corrected with tapchanger operations. The result is fairly unpredictable but certainly not satisfactory.

c) If the intersystem flow was a combination of VArS and KW, the circulating current method would bias the operation of the tapchangers to attempt to offset the flow resulting in the same result as b), above.

3) Power Factor method of paralleling –

a) If the intersystem flow was VArS, the power factor method would block the operation of the appropriate tapchanger to attempt to minimize the difference in power factor. This would result in operation at different tap positions for the transformers which would cause equal VAr flow in the transformers. This is satisfactory operation even though the final positions might take longer to get to because of the blocking action described earlier.

b) If the intersystem flow was KW, the power factor method would block the operation of the appropriate tapchanger to attempt to minimize the difference in power factor. This would result in operation at different tap positions for the transformers which would cause unequal VAr flow in the transformers. The result is that the transformer with the highest KW load will now be forced to also have the highest VAr loading.

c) If the intersystem flow was a combination of VArS and KW, the power factor method would operate as described in b) above.

4) **Δ VARTM Method** of paralleling – Since the **Δ VARTM Method** ignores all KW flows, it has only one purpose under all system conditions. That purpose will result in the VAr flow to the substation load to be shared in the appropriate ratio by the paralleled transformers. This “appropriate ratio” is determined by the choice of the current transformer ratios used to correctly parallel different-sized transformers.

- A tap difference causes a circulating current (I_c)
- I_c is calculable from the tap step voltage and transformer impedance
- If C open = Independent operation — LDC OK
 B or D open = Independent operation — correction needed
 A open = Parallel operation — separate sources ($\Delta\text{VAR}^{\text{TM}}$ required)
- I_c is mostly VARs since transformer impedances are mostly reactance

NOTE: kW flows are NOT effectively controlled by tap position but by relative impedance or phase-shifting transformers

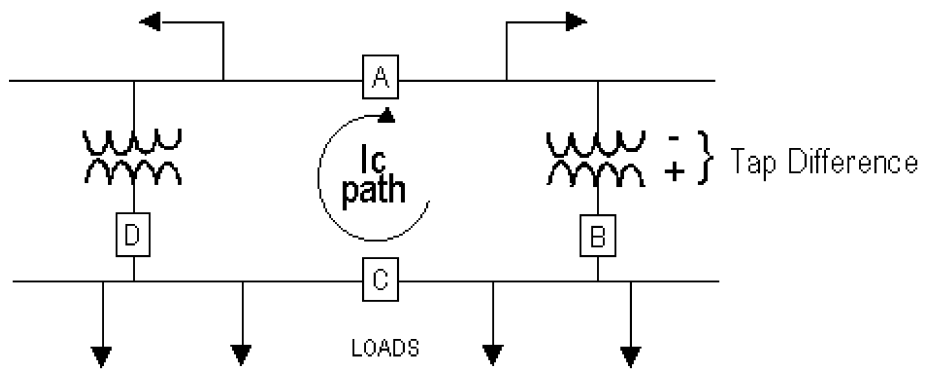


Figure 1. Substation Breaker Arrangement