HOW TAPCHANGER CONTROLS CONTRIBUTE TO PREMATURE TRANSFORMER FAILURES

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ABSTRACT-- This paper focuses on LTC (Load Tap Changer) transformer control practices, which may cause tapchanger hunting and therefore excessive tapchange operations. Applications of paralleling methods and the determination and confirmation of optimum settings, which may contribute to excessive or untimely tap change operations, are discussed. The transformer applications considered in this paper will include transmission tie transformers as well as transmission–distribution interface transformers.

Attention will be drawn to common paralleling commissioning practices in the field that can create conditions for tapchanger "hunting." In many applications, a control function will result in different actions depending on the system configuration and parameters. These changing system conditions are continuously affected by automatic operations on the transmission and distribution systems, such as protective relay operations or load management techniques. Some of these system conditions will also be discussed.

I. INTRODUCTION

Analysis of premature failure of load tap changer (LTC) transformers on utility systems often identifies the tap changers as a major contributing factor. LTC factors responsible for transformer failures include: oil quality (particulate contamination), LTC contact temperature rise, contact coking, carbon film build-up, short circuit mechanical forces and contact wear and arcing. Some of these are a result of the contact film or tarnish that builds up on all contacts operating in oil. These factors create increasing contact resistance thereby increasing voltage drop, localized heating, contact pitting, oil contamination and general deterioration.

Any cumulative damage, which will affect the transformer life, can be a function of the number of operations as well as the loading conditions when those tapchanges occur. Numerous operations in a few tap positions may accelerate the deteriorization of other tap contacts due to the dispersion of damaging products in the oil. Unacceptably frequent, unnecessary or poorly timed tapping operations of LTC transformers can substantially contribute to the acceleration of these damaging conditions.

II. PARALLELING METHODS – MISUSE/INCORRECT SETTINGS

Of the several paralleling methods, including circulating current, circulating reactive current or var sharing, master/follower, and negative reactance; the most widely used is the circulating current method. Unfortunately, this method may easily be misapplied resulting in tapchanger "hunting" for some conditions. This mis-application is sometimes initiated in the field commissioning of the paralleling system.

A. Circulating Current Paralleling Method

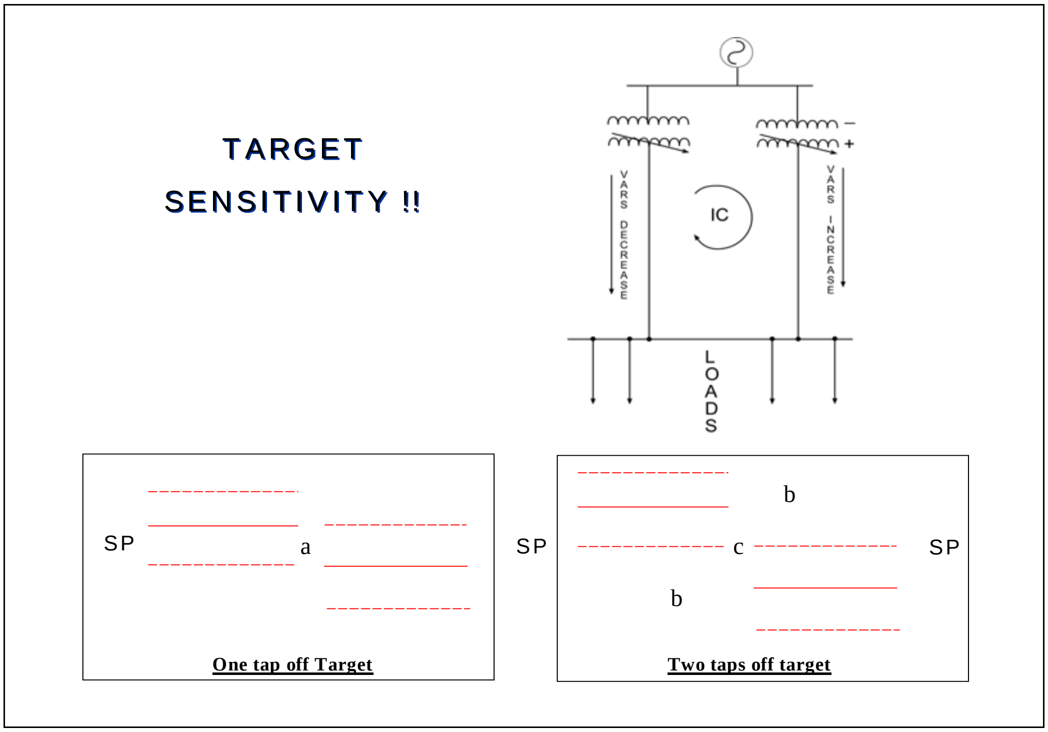
This method depends on the biasing of each control setpoint when the taps are not in the "best" relationship. There are three premises for the "best" relationship for transformers operating in parallel [1]:

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

These biases are a function of the magnitude and direction of the circulating current (1/2 the difference current) in each transformer. Each bias tends to cause the next tapchange of either tapchanger to approach the other. Although the circulating current method can be used for multiple paralleled transformers, the description is simplified by considering a two-transformer application.

Figure 1 illustrates the amount of circulating current bias that might be considered optimum. As shown, the maximum "off-tap" continuous operation before an action is assured is only one. With two off-tap operations, at least one tapchanger is assured of returning towards the other since the bus voltage would be in one of the (b) areas.

This bias or shift amount is controlled by a "sensitivity" setting which must be equal for all paralleled transformer controls. If the sensitivity of each control is different, the setpoint biases, or shifts—will be different. This would cause a loss of the integrity of the original setpoint level, which is the average of the two biased setpoints. This point illustrates that all paralleled transformer sensitivities **must** be set equally.



Paralleling Bias Example
FIGURE 1

Condition #1-Sensitivity

If the sensitivity setting is too high and exceeds that shown in Figure 1 for the two-taps-off-target bias, the voltage may not be stable. In other words, there are bus voltage levels where neither control is satisfied (voltage is in band). This condition can be pictured in Figure 1 where the bias would be increased from that illustrated which spreads the bandwidths apart. This “oversensitivity” creates an open voltage range between the bandwidths and the bus voltage is in area (c) between the control bands. This creates a continuous “hunting” operation with unlimited tapchanger operations. The ominous feature of this action is that, since the tapchangers are continuously taking the taps in opposite directions, the action is not indicated by the bus voltage.

For determining the proper sensitivity setting, the following is proposed:

1. The transformers be set on the same tap in a position which maintains bus voltage as close to the setpoint as possible.
2. With the sensitivities set at neutral, raise one transformer up one tap and lower the other one tap.
3. If both controls operate to return the taps to the original position, the sensitivity is set too high and both sensitivities need to be reduced one setting.
4. If no control calls for an operation, the sensitivity may be set too low and both should be increased one setting.

The proper action is for one control to return the tapchanger to the original position.

Proper operation will be maintained only if the controls are not oversensitive to the circulating current. Only err in the less sensitive direction.

Many utility practices used for field commissioning assume the paralleling equipment will always keep the transformers on the same tap position. This assumption can be shown to be erroneous by referring to Figure 1 and the “one tap off target.” With the taps one position apart and the bus voltage in the area of (a), neither control would call for a tapchange. This is a normal operating position for the circulating current method. As the bus voltage would move out of the area of (a), one transformer would operate towards the position of the other.

To accomplish this erroneous assumption, either of two errors is commonly made. Each error will create the possibility of “hunting.” The first error is to increase both of the paralleling sensitivities until both transformers return to the same position. The second error is to increase the paralleling sensitivity of only the transformer that did not return to the original position. This error also causes the centerband of the resultant voltage control to deviate from the original setpoint.

Condition #2-Nonsimilar Transformer Applications

If paralleled transformers are dissimilar in ratings or impedances, it is imperative that the paralleling equipment circulating current be negligible when the transformers are on the appropriate tap positions. If equally rated transformers have different impedances, the unequal load currents create an apparent circulating current between the transformers. Auxiliary CTs must be installed to equalize these currents in the paralleling equipment when the transformers are on the appropriate tap positions. This is also true for differently rated transformers or applications with CT ratios that are not in the same ratio as the ratings. Many applications are found, in the field, which have not corrected for these differences and where the paralleling operation is incorrect.

Without this correction of difference current in circulating current schemes, as the load changes, the kvar and the kW components of the circulating current changes. The circulating current method interprets this difference current as a mismatch in taps and responds. The kvar portion can be offset by tap operation but the responding change in kW loading between the transformers can be aggravated.

Condition #3-Dynamic Relative Impedances

As the taps change, if the change in impedance between two transformers is not equal, a change in differential kW and kvar flow will occur at different "best" tap levels. Otherwise stated, an application where both transformers have the same impedance at the neutral tap positions but change differently as they tap in the same direction. This may occur when the transformers are not wound with the coils in the same relative position to the core.

When transformers of different impedances are paralleled, fixed auxiliary CTs are used to balance the currents, as described above. This solution cannot be implemented if the difference in impedance is dynamic during normal operation.

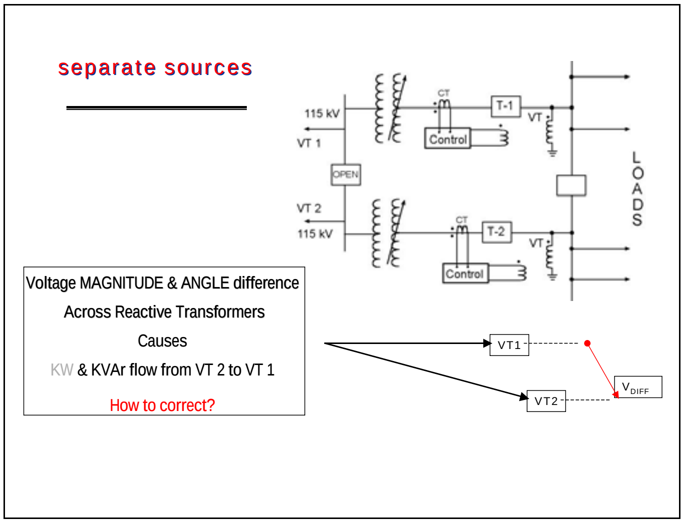
In this application, the circulating current method is not applicable and the circulating reactive current or var sharing method must be used. This method is described in a subsequent section of the paper.

Condition #4-High Side Bus separation

The circulating current method assumes the circulating current is reactive since the transformers have a high R/X ratio. This is a good assumption as long as both the high and the low voltage sides are bussed together. However, if any switching condition can cause the high side buses to be fed from separate sources or transmission lines (as shown in Figure 2), this assumption can cause unrelenting tapchanges in a "hunting" mode.

This "hunting" mode is established when the circulating current includes kW current resulting from a difference in the source voltage angles. The circulating current method attempts to correct for this kW flow by biasing the setpoints to change taps. These operations, in turn, cause a kvar flow in the opposite direction. When a threshold current level is reached, the circulating current method reverses its actions and retraces the taps, which were not able to correct the kW flow. This condition may exist for some time before detection since the bus voltage is not changing significantly during this process.

In this application, the circulating current method is not applicable and the circulating reactive current (var sharing) method must be used. This method is described in a subsequent section of the paper.



Separated High-Side Condition
FIGURE 2

B. Circulating reactive current (CRC) or var sharing Paralleling Method

As described under the circulating current method, *<u>Condition #4-High Side Bus separation</u>*, the inclusion of any kW load current in the circulating current can cause serious misoperations.

Although a complete description is beyond the scope of this paper, it should be recognized that different types of controls might react differently with circulating current paralleling. Older analog controls use the equivalent of a reactance setting of the line drop compensation to determine the setpoint bias. Newer digital control models use algorithms that could vary in their setpoint bias calculations.

The CRC method, by definition, uses the magnitude of the reactive portion of the circulating current to determine setpoint bias. A practical understanding of the operation may be better obtained by the term “var sharing” method. Since the voltages are equal on the paralleled transformer load bus, any attempt to minimize the circulating reactive current is actually equalizing the var loading of both transformers. This method may also be referred to as “circulating var” method, which is actually possible if the control algorithm includes the voltage.

The CRC paralleling method essentially ignores all kW load current to determine the setpoint biases. In a highly reactive system, relative transformer and system impedances, and not the tap position, determine the kW sharing of the paralleled transformers. Therefore, kW flow should not be used to affect tap position choice. Further, in most applications, the best choice of loading parallel transformers is to maintain the var sharing regardless of kW loading.

Source side separation, illustrated by Figure 2 with the high side breaker open and all others closed, introduces the probable unequal flow of vars and/or kWs in the two transformers. An equivalent configuration can occur at stations with ring bus or multiple bus breaker arrangements on the source side. This operation violates the assumptions of all methods except the CRC method for maintaining the most appropriate tap positions on the paralleled transformers.

The stated purpose of the CRC method, under all system conditions with the transformers paralleled, is to minimize the reactive circulating current. This, in turn, tends to equalize the transformer var flows by the <u>appropriate ratio</u> of the size of the paralleled transformers. This “appropriate ratio” is determined by the choice of the current transformer ratios used to correctly parallel differently sized transformers. Although auxiliary CTs are not required for equally sized transformers with different impedances, the total ratios do need to reflect the different sizes of the transformers.

For example, if a 100 MVA transformer is paralleled with a 50 MVA transformer, the desired var loading ratio is 2. This is accomplished automatically if the CT ratios are different by a factor of 2, which could be normal. [3]

Implementation of the CRC method is accomplished one of three ways. The first, which is most appropriate for retrofitting from the typical circulating current method, is merely to exchange only the control while continuing to use all the parallel balancing equipment. This is the only method that allows for the typical backup equipment for runaway protection.

An overcurrent relay in the circulating current path is generally used, with the circulating current method, to block further operations if the variation in the transformers’ tap positions becomes too great. [2]

A second method is to use the communication channels between individual transformer LTC controls. This method allows for each control to use information from the others to make tapchange decisions. Since no external path for circulating or difference current is available, any backup protection must be programmed into each control.

The third method is for each control to share the current (with common voltage) connection with other units. With this shared inputs information, each control is able to calculate the flows in the other transformers. Again, backup protection must be included in the individual control programming.

Condition #1-Sensitivity

The importance of the sensitivity setting for the var sharing method is as important as it is in the circulating current method. Oversensitive settings can cause tap position “hunting” and must be avoided.

Condition #2-Nonsimilar Transformer Applications

With the CRC method and different transformer impedances, auxiliary CTs are not required to match the actual loading conditions of the transformers. The system effect in such applications is to reduce the overall load on the lower impedance unit and shift some var load to the higher impedance unit. This helps balance the transformer loadings. This also properly operates in the application of dynamically changing transformer impedances stated above.

In the application with parallel balancing equipment, the balancing auxiliary CT is still required to balance load due to differently rated transformers or ones with CT ratios that are not in the same ratio as the ratings. In these applications, without the balancing CT, unnecessary tapchanges are likely to occur. In applications involving communications between the controls, the CT ratio difference can be corrected by internal control settings.

Condition #3-High Side Bus Separation

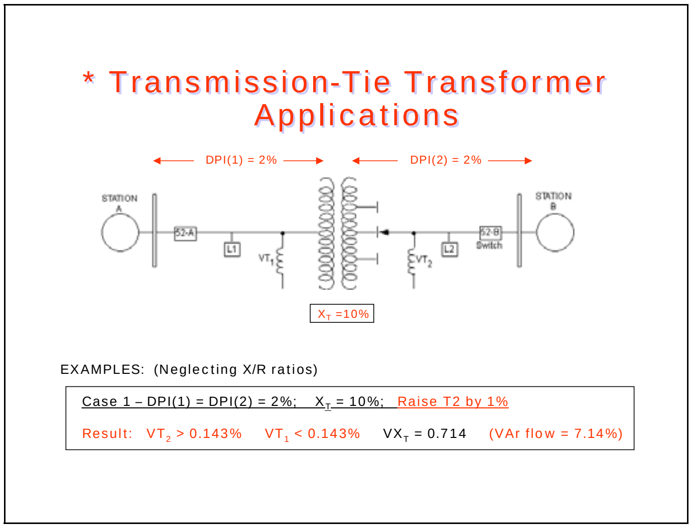
Since the CRC method does not assume the circulating current is reactive, the condition shown in Figure 2 does not cause the “hunting” possibility described for the circulating current method. This method is the only one properly reacting to balancing the var loads under these conditions.

The actual kW load current will distribute according to the source impedances while the var loading can be affected by the tapchanger.

III. NETWORK/INTER-TIE APPLICATIONS

In some applications, tapchanges on system intertie transformers have a greater effect on system var flows than on bus voltages. In some of these applications, several tapchanges are required for any significant voltage effect.

Figure 3 illustrates one of these possible applications. The system driving point impedances from the transformer terminals to the sources is shown as 2%. The transformer impedance is shown as 10%. The tap step is indicated as 1% to raise VT_2, the voltage on the right side of the transformer.



Tie Transformer Application
FIGURE 3

The calculations illustrate that (with one 1% tapchange) the induced var flow equals 7.14% and VT_2 only increases 0.143%, while VT_1 actually drops 0.143%. The remaining 0.714% of the tap voltage is actually lost in the transformer impedance voltage drop.

To raise VT_2 by 1%, in this example, would require 7 tap steps and VT_1 would actually decrease by 1% in the process.

Depending on the overall transmission system with several intertie locations, the LTC transformer tapchange operations may need to be coordinated to reduce unnecessary tapchanges. Some controls are capable of supervising the voltage setpoint level with var flows, which may be helpful in some applications.

IV. CONCLUSIONS

With some estimates of LTC involvement in LTC transformer failures reaching as high as 50%, using and setting the correct, reliable control features is extremely important. Any misapplications, which can cause unnecessary operations, must be kept to a minimum. This is especially true in cases where tap position "hunting" can occur. This "hunting" not only increases the total number of operations but many times forces them to occur in rapid succession.

Although an LTC transformer control has a basically simple operation, it is important to assure proper operation during the myriad of special system operating conditions. Not only must the control do the basic job, but also it must respond correctly to every possible system operating event that might occur.

Examples discussed in this paper include the proper use and commissioning of one frequently used paralleling method – circulating current. The CRC or var sharing paralleling method is also discussed, since it is applicable where the circulating current is not. Improper use of a paralleling method or improper setting and commissioning, in these applications and others, may cause "hunting" for appropriate tap positions and dramatically increase the number of tap changes. These unnecessary operations tend to cause wear and degradation of the tap changer contacts.

In today's world of computer technology and sophisticated digital controls, sometimes the value of separate physical backup protection is lost. One example is when such items as paralleled transformer circulating overcurrent protection for runaway conditions exist in the "virtual" world rather than the "real" world. If failure of the control with the "virtual" protection is the initiating event, the protection is obviously lost at the very time it is needed.

REFERENCES

[1] "Introduction to Paralleling of LTC Transformers by the Circulating Current Method", Tapchanger Control Application Note #11, Beckwith Electric Co., Inc., February 1998.

[2] "Advanced Paralleling of LTC Transformers by the Circulating Current Method", Tapchanger Control Application Note #13, Beckwith Electric Co., Inc., 1999.

[3] "Advanced Paralleling of LTC Transformers by ∆VAR™ Method", Preliminary Tapchanger Control Application Note, Beckwith Electric Co., Inc., July 2000.

BIOGRAPHY

E. Tom Jauch is a Utility Power System Consultant for Beckwith Electric Company, Inc. His consulting practice involves projects relating to T&D power system studies and equipment applications and training. Jauch has more than 47 years of experience including 20 years as a senior application engineer and manager of business development for General Electric's Electric Utility System's Engineering Department located in Schenectady, New York. Jauch is a former instructor in the Graduate School of Electrical Engineering at Rensselaer Polytechnic Institute and Union College in New York as well as Auburn University. He was a senior engineer with Central Illinois Light Company (CILCO) for five years. Prior to becoming a consultant, Jauch was Manager of Application Engineering for Control Products and Systems with Beckwith Electric Company. Prior to that, he was an engineering consultant to Beckwith Electric on protection and control product lines. Jauch has a Bachelor of Science in Electrical Engineering from Bradley University in Illinois and has authored numerous technical papers and magazine articles on power transformers, controls, and protective relaying. He is a life senior member of the IEEE, a member of the Power Engineering Society, and is active in the Power Transformer Committee and the Substations Committee.